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World Road Association

ROAD Safety MANUAL

2003 - PIARC TECHNICAL COMMITTEE ON ROAD SAFETY (C13) Version 1.00

Road Safety Manual

Recommendations from the World Road Association (PIARC)

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PREFACE

MESSAGE FROM THE PRESIDENT OF PIARC

People around the world are becoming increasingly concerned about the scope of the road safety problem. However, the situation varies widely from country to country, and progress is extremely uneven. We see improvements in some countries and setbacks in others - primarily countries in the developing world and those that are undergoing economic transition; and we see the accident toll rising as traffic volume grows.

This manual, an initiative of the World Road Association's Road Safety Committee, is designed to give highway engineers a better understanding of the impact that infrastructure has on road safety at all phases of design and operations. The result of fruitful exchanges among experts from various countries, this manual is a valuable reference tool for every engineer with an interest in road safety problems. We hope that transposing the information contained in the manual to the local context will help to improve road safety, and reduce the terrible toll of deaths and injuries in road accidents around the world. This remarkable project will certainly play a key role in spreading the word about best practices - the primary mission of the World Road Association.

I would like to thank Kare Rumar of Sweden, along with Peter Elsenaar of the Netherlands, who succeeded Mr. Rumar as Chairman of the Road Safety Technical Committee while the manual was being put together, as well as the Committee members who wrote sections of the manual, and the many expert reviewers who provided feedback. The production of this manual would not have been possible without the substantial work done since 1998 by Carl Bélanger of Canada-Quebec, who coordinated the writing of the manual within the Committee.

We wish to thank the governments of Switzerland, Greece, and France for their financial support, without which this manual could not have come to fruition - and most of all, the Canada-Quebec government for its invaluable contributions in terms of human, financial, and material resources. Sincere thanks for your generosity.

In closing, I hope that everyone who reads this manual will help by circulating it as widely as possible, and will apply the principles it describes in order to help improve road safety around the world.

Happy reading and safe driving!

OLIVIER MICHAUD

President, World Road Association (PIARC)

MESSAGE FROM THE SECRETARY GENERAL OF PIARC

The World Health Organization has chosen road safety as the theme for World Health Day 2004. The World Road Association is proud to present this manual, our contribution to the collective effort to make the roads of the world a safer place.

The quantity and quality of information in this manual makes it an unparalleled reference on various infrastructure-related aspects that have an impact on road safety. The authors designed this manual to be used as an educational tool for training students and professionals alike. The print and CD-ROM versions of the manual are complementary in nature; the CD-ROM includes a set of software tools that facilitate the use of technical procedures.

This first edition has required substantial investment from PIARC and we want to build on this foundation by ensuring that topics will be regularly revised and updated, and by developing additional sections describing other safety-related problems, such as the behaviour of road users. The next Technical Committee will also be asked to consider adaptations that should be made in an edition designed for use in developing countries.

We invite readers to send us their comments and suggestions, so that future editions of the manual will fully meet the expectations of users. You can also help us by making sure that the manual is widely used, particularly as a training tool.

JEAN-FRANÇOIS CORTÉ

Secretary General, PIARC

INTRODUCTION

With more than one million people dieing worldwide on roads every year and with the number of fatalities and injuries rapidly increasing, there is an urgent need for strong remedial action to be taken by all responsible bodies involved in road safety.

However, one of the main problems faced by road safety practitioners is the lack of a comprehensive reference manual that summarizes the knowledge acquired over the years. It is scattered among countless articles in journals, conference proceedings, research reports, and a variety of other sources. Furthermore, the information contained therein is sometimes contradictory and difficult to reconcile for analysts who are not experts. Experience clearly demonstrates that these analysts have neither the time nor the expertise required to synthesize this information, which all too often leads to less than optimal decisions. The situation is made all the more problematic by the fact that the countries with the worst accident records and the most pressing need for intervention are generally the most wanting in terms of specialized personnel and work tools.

The members of the Road Safety Committee of the World Road Association (PIARC) developed this manual with a view to improving the current situation by providing easier access to state of the art knowledge.

Obviously the creation of a comprehensive reference manual is a considerable undertaking, and in order to produce results within a reasonable timeframe, the decision was made to initially focus on the road infrastructure. As a result, the intended readers of this first edition of the manual are road engineers and technicians, regardless of the country in which they practice.

OUTLINE OF THE MANUAL

The manual is organized into four parts.

The first part is an introduction to road safety. It describes the scope of the problem, lays out general strategies for managing road safety, and discusses the key factors that contribute to accidents. The purpose is to provide readers with an overview of the problem so that they can better understand the potential, as well as the limitations of the actions they may be taken.

The second part of the manual focuses more directly on road engineering, and describes a complete road safety improvement process, from data collection and problem identification to the evaluation of the impacts of implemented actions. This process, as described, is suited for the analysis of high accident locations (blackspots) which is generally the first safety action taken by road authorities. However, it is clear that the safety efforts made by road authorities must extend far beyond blackspot correction. Therefore, the proposed tools and methods should be used to analyse sites of a larger dimension (road segments, complete roads or network area), as well as abnormal accident patterns.

Safety analysts rely heavily on the information contained in accident reports which provide essential data for identifying and understanding the problems faced by drivers. However, the analysis of this data must be complemented by examination of the physical and operational characteristics of the infrastructure, a fundamental element to making informed decisions. Accordingly, a distinction is made in the manual between the "reactive" approach, which relies on accident analyses and the "proactive" approach, which is based on observation of road and traffic characteristics. It describes how to combine these two approaches in order to optimize the quality of identification (Chapter 5), safety diagnoses (Chapter 6), and evaluation (Chapter 8).

The third and fourth parts of the manual are quite technical and provide practical assistance. Part III details the relationship between safety and a variety of road components (horizontal and vertical alignment, road surface, etc.). It also discusses the principle human capabilities and limitations that analysts must consider in order to gain a clear understanding of the origin of the problems they are facing and to facilitate the choice of appropriate solutions. Finally, Part IV explains how to conduct various technical studies that are often required during safety analyses (spot speed studies, traffic counts, etc.). Simple procedures are described and their implementation is illustrated by means of practical examples. There is a close relationship between Chapter 6 of the manual, which deals with safety diagnoses, and Parts III and IV, which contain practical tools for undertaking those diagnoses.

In keeping with the purpose of this manual, and considering the target reader, substantial effort was made to simplify and summarize the available information, provide a user-friendly interface, and develop various software applications that greatly facilitate the use of the techniques described herein. Accordingly, an interactive CD-ROM version of the manual has been developed that includes a number of hyperlinks and automatic-calculation programs (called "calculators"). The programming language chosen for these enhancements frees the reader from software constraints. The electronic edition of the manual requires only a Microsoft Windows® operating system and Adobe Acrobat® Reader (this latter software can be downloaded free from the Internet).

- every term that appears in ***bold green italics*** in the manual is a hyperlink that readers can use to jump to the corresponding section of the work;
- each reference to a calculation utility [**NAME OF CALCULATION UTILITY**] provides access to a "calculators".

In either case, the reader needs only to left click on the appropriate item.

FUTURE DEVELOPMENT

This premiere edition of the PIARC Road Safety Manual represents the first step towards developing a standard reference in the field of road safety. However, further work is required before the manual will fully deserve this title.

Firstly, the scope of its road engineering contents must be enlarged with the addition of technical information describing the impact that other road components have on safety. Since almost every element of the road infrastructure influences safety, development will once again need to be prioritized, but problems encountered in developing countries should guide these choices. Secondly, the current contents of the manual must be expanded to deal more directly with the other components of the "road safety system" and with the interactions within this system (human, road environment, vehicle).

The manual will also need to be updated on a regular basis in order to keep pace with new methodological and technical advances and to ensure that the information it contains remains pertinent. And finally, any errors or omissions that slipped by the authors will have to be corrected. In this respect, we hope that constructive feedback from readers will contribute to the improvement of the manual.

The establishment of mechanisms for ensuring the continuity, pertinence, and ongoing existence of the manual presents a major challenge for both the Association's secretariat and for future members of the Road Safety Committee.

STANDARDS

In order to enhance the practical aspects of the manual, various equations and numerical examples of calculations have been included along with examples of recommended values in certain countries. Of course national standards take precedence over these values but any significant difference between the values recommended in a country's standards and those specified in this manual should provide food for thought.

ACKNOWLEDGEMENTS

This manual was written entirely by a group of motivated experts from the PIARC Road Safety Committee who believed in the necessity to develop this type of reference work and who agreed to participate in the project on an entirely voluntary basis. They were assisted by Patrick Barber of the Ministère des Transports du Quebec, a methodical collaborator whose participation was vital. Each author's contribution is clearly identified within the manual.

The early drafts of the manual were subjected to various stages of review. In addition to PIARC Road Safety Committee members, a number of outside experts helped to improve the initial versions of the manual by providing useful comments. Their contribution was most appreciated: Marie Beauchemin, Leanna Belluz, Martin Bretherton, Thomas E. Bryer, Stéphane Campeau, Annie Canel, Philip J. Caruso, Paul de Leur, Gerry Forbes, Nathalie Gosselin, Eric Hildebrand, Geoffrey Ho, Paul Hunt, Mavis Johnson, Hari Kalla, Jean-François Leclerc, Martin E. Lipinski, José M. Pardillo Mayora, John Milton, Kim Nystrom, Richard F. Pain, Ronald Pfefer, Stanley F. Polanis, Bruce W. Robinson, Mike Skene, Rudolph M. Umbs, and Steffen Wenk.

We also owe thanks to the organizations and individuals who were kind enough to allow us to include excerpts of the results of their work in this manual. We hope that we have obtained all required permissions and we apologize in advance for any unintentional oversight in this regard.

The contribution of the Ministère des Transports du Québec, which made a considerable investment in this project, must also not pass unnoticed. Particular thanks to longstanding collaborators Sylvain Rhéaume and Benoît Tessier, who developed all of the software involved in this project with their customary efficiency, to the skilled team of graphic designers, consisting mainly of Barbara Jacques, Sylvie Lemaire, Bernard Payeur, and Stéphane Rioux and to the support of a coordinating and steering group that guided this project at its most critical moments, including Raymond Landry, Gilles Marquis, Gilles Sawyer, Guy Vaillancourt, and Anne-Marie Leclerc, the Canada-Québec first delegate.

On a more personal note, I would also like to extend my sincere thanks to my wife Jennifer and to our two daughters, for their incredible understanding and patience throughout this project. From now on, Myriam and Lauren, you will no longer have to ask me: "How much longer until the manual is finished?"

Carl Bélanger
Project Coordinator
April 23, 2004

Training

This manual may be used for training purposes in university highway-engineering programs or continuing education programs designed for professionals in the field.

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PIARC is offering special rates for bulk purchases of the manual in order to promote training activities. Interested individuals or groups are asked to contact PIARC. Please include the following information in your request:

- Type of training activity planned (undergraduate or graduate university course, continuing education, other);
- Target audience (engineers, technicians, others);
- Number of participants.

In order to ensure the broadest possible diffusion of knowledge, PIARC will not grant any exclusive licences for the organization of training activities based on this manual.

Note

While the authors of this manual have made every effort to present a fair picture of the state of knowledge at the time of publication, neither they nor PIARC can be held responsible in any way for any consequences that may result from the use of this manual. Readers are responsible for making sure that any actions that they may take are fair and appropriate.

PART 1

Introduction to road safety

CHAPTER 1

Scope of the road safety problem

Goff Jacobs

CHAPTER 1

Scope of the road safety problem

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1.1 BACKGROUND

The first death involving a motor vehicle is said to have taken place in London in 1896. Since then road accidents have claimed an estimated 30 million lives. Authorities in virtually all countries of the world are now concerned about the numbers of people killed and injured on their roads, and the social and economic damage that results.

As infectious diseases are brought increasingly under control, road deaths and injuries rise in relative importance. The World Health Organization and the World Bank have estimated that in 1990 road accidents lay in ninth place out of a total of over a hundred separately identifiable causes of death or disability (Murray and Lopez, 1996). By the year 2020, they are forecast to move up to second place in terms of "years of life lost", third place in terms of "disability-adjusted life-years (DALY's)"[1] and sixth place as a cause of death (Figure 1-1).

Figure 1-1 Changes - 10 leading causes of death and disability

1990			2020
Lower respiratory infections	1	1	Ischaemic heart
Diarrhoeal	2	2	Unipopular major depression
Perinatal	3	3	Road traffic accidents
Unipopular major depression	4	4	Cerebrovascular
Ischaemic heart	5	5	Pulmonary
Cerebrovascular	6	6	Lower respiratory infections
Tuberculosis	7	7	Tuberculosis
Measles	8	8	War
Road traffic accidents	9	9	Diarrhoeal
Congenital anomalies	10	10	HIV

Source: www.grsproadsafety.org

Although the situation is slowly improving in high-income countries (road deaths fell by an average of 10% in the OECD countries between 1986 and 1996), most developing countries face a worsening situation. This becomes apparent in the regional analyses that follow. International road safety experts, including members of PIARC Road Safety Committee, believe that this is not the inevitable price that has to be paid by these countries for the increased mobility of people and goods, but that there is much more scope for improving their road safety situation while developing into a more industrialized society. It is hoped that this Manual will assist in bringing that about.

It is also hoped that the Manual will be of value to road safety practitioners in the developed world where, despite continuous improvements, approximately 110,000 people die each year in road accidents.

1.2 GLOBAL ROAD FATALITIES AND INJURIES

Despite the acknowledged problems of data reliability and under-reporting, estimates of the global situation have to start with officially published statistics based on national police reports. In a recent study (Jacobs et al., 2000) undertaken for the Global Road Safety Partnership (GRSP), these statistics were built on by:

1. updating the fatality figures for the latest year available to 1999;
2. estimating for countries where fatality data were not available at all;
3. making an adjustment so that the "death within 30 days" definition was applied to all countries;
4. adjusting official figures to take into account the under-reporting of fatalities.

The rest of this chapter draws on the aforementioned report produced on behalf of GRSP and shares its caveats, strengths and weaknesses.

[1] 'DALYs' express years of life lost to premature death, as well as years lived with a disability, adjusted for the severity of the disability.

There is no standard approach to regional groupings used by the many different international organizations concerned with road safety. In order to facilitate the interpretation of data, a total of 192 countries were assigned to six major regional groups as follows:

- Sub-Saharan Africa;
- Asia-Pacific;
- Central and Eastern Europe (CEE);
- Latin/Central America and the Caribbean (LAC);
- Middle East and North Africa (MENA);
- Highly motorized countries (HMC), i.e., North America, Australia, New Zealand, Japan and Western Europe.

Less motorized countries (LMC) is the collective term used to describe the first five regions, where motorization is typically much lower than in the highly motorized countries (HMCs).

1.2.1 FATALITY ESTIMATES

Based on the factors described above, a realistic estimate of global road deaths is between 750,000 and 880,000 for the year 1999. The calculations and regional totals are presented in Table 1-1 and Figure 1-2. Updating these values, it is estimated that there may well have been between 800,000 and 950,000 road deaths worldwide in 2002.

Table 1-1 Estimated road fatalities with under-reporting (UR) adjustments (1999)

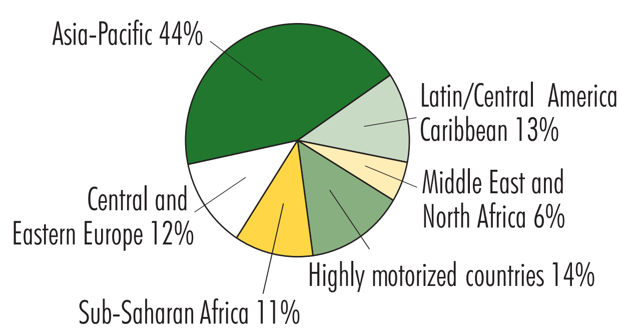
	1999 ESTIMATE	30-DAY FATALITY ADJUSTMENT FACTOR	ESTIMATE	LOWER UR ESTIMATES ADJUSTMENT FACTOR	ESTIMATE	UPPER UR ESTIMATES ADJUSTMENT FACTOR	ESTIMATE
HIGHLY MOTORIZED COUNTRIES (HMC)	98,834	ECMT[a]	105,654	1.02	107,767	1.05	110,937
ASIA-PACIFIC	228,405	1.15[b]	262,666	1.25	328,332	1.50	393,999
C/E EUROPE(CEE)	63,540	1.15[b]	73,071	1.25	91,339	1.50	109,607
LATIN/CENTRAL AMERICA AND THE CARIBBEAN (LAC)	64,699	1.15[b]	74,404	1.25	93,005	1.50	111,606
SUB-SAHARAN AFRICA	58,319	1.15[b]	67,067	1.25	83,834	1.50	100,600
MIDDLE EAST/ NORTH AFRICA (MENA)	28,864	1.15[b]	33,194	1.25	41,492	1.50	49,790
GLOBAL	542,661		616,056		745,769		876,539

[a] Adjustments recommended by the European Conference of Ministers of Transports for those countries not using the standard definition of a fatality as occurring within 30 days of the accident.

[b] An adjustment factor to take into account the fact that developing countries tend not to use the 30-day definition in practice.

A number of countries show wide variation between official (police) statistics and information from other sources. For example, in the Philippines, only one out of five medically reported road deaths is included in police statistics (World Health Organisation, 1999). In Indonesia, insurance companies report almost 40% more deaths than the police. In 1995, the Department of Health in Taiwan reported some 130% more deaths than the police (Lu et al., 1999).

Figure 1-2 Estimated road fatality - Regional distribution (1999)



In Karachi, Pakistan, a study comparing road casualties reported by the police with ambulance statistics showed only about half of road accident deaths were reported by the police (Razzak and Luby, 1998). Under-reporting also appears to be high in China, which already has the world's highest reported number of road deaths. Thus, the Beijing Research Institute of Traffic Engineering estimated that the actual number of people killed in road accidents in 1994 was about 111,000, more than 40% greater than the 78,000 reported officially by the police (Liren, 1996).

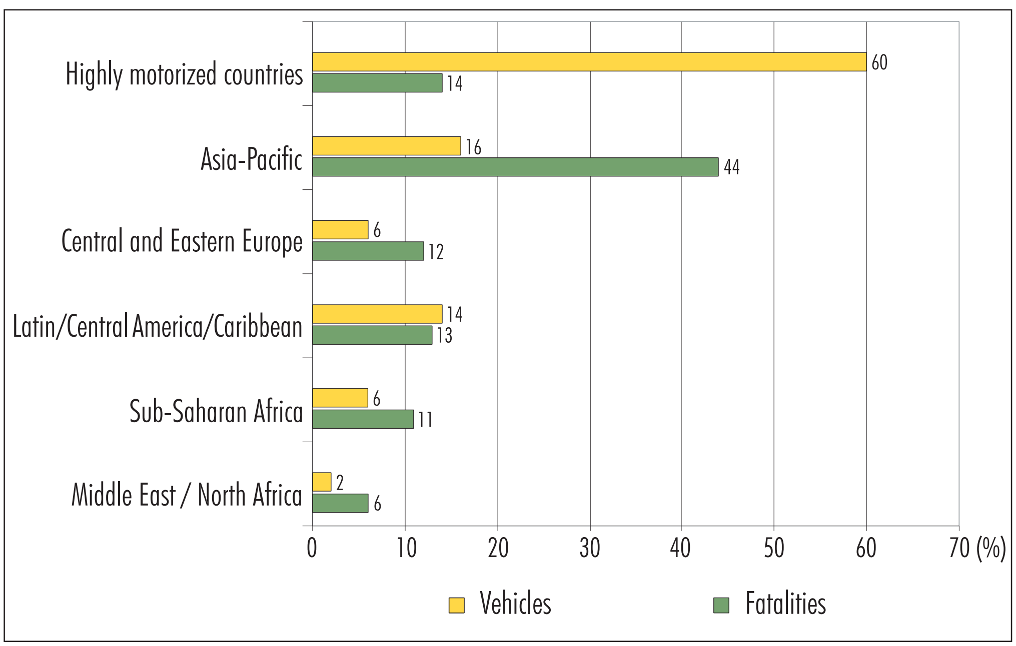
A number of studies indicate that under-reporting of fatalities is minimal in developed countries (between 2% and 5%) (James, 1991, and Simpson, 1997), while upper and lower adjustment factors of 25% and 50% are more realistic in developing countries.

It can be seen that the burden of global road fatalities is on the LMCs, where 86% of the world's road fatalities occur, with almost half of all fatalities occurring in Asia. Figure 1-2 shows the regional distribution of 750,000 fatalities, the low end of the range suggested for 1999.

Figure 1-3 shows an interesting comparison of the global distribution of road accident deaths and licensed vehicles by region. Highly motorized countries, with 60% of the world's vehicles, have only 14% of global deaths. Conversely Asia/Pacific, with only 16% of vehicles, has about 44% of global deaths. Central and Eastern Europe, Africa, and the Middle East show a similar pattern. Latin/Central America and the Caribbean is the only region of the developing world where road deaths and vehicles expressed as proportions of the global totals are almost equal.

While fatalities in the developed world have fallen over the last fifteen years or so, up to 110,000 road deaths still take place in these countries each year. For example, even in the UK and Japan, two countries with particularly low fatality rates, the percentage of people killed who are pedestrians is still worryingly high. Therefore, there can be no room for complacency, and continued efforts (and investment) are needed to ensure that road deaths continue to fall in the future.

Figure 1-3 Fatalities and vehicles (%)



1.2.2 INJURY ESTIMATES

The under-reporting of injuries is known to be even worse than the under-reporting of fatalities. However, based on the International Road Traffic and Accident Databases (1994) report and earlier studies, it was decided that a ratio of 100 injuries for every fatality would apply in the HMCs. For LMCs, a ratio of between 20 and 30 was taken to be a minimum estimate. These values produce annual road accident injury estimates for 1999 of at least:

- 11 million in HMCs;
- 12 to 23 million in LMCs.

The global estimate is thus between 23 and 34 million road accident injuries per annum. This is approximately twice the global road injury estimates made previously by the World Bank and GRSP, making the problem of even greater concern, particularly for the developing world.

1.2.3 FATALITY FORECASTS

Forecasting deaths worldwide is fraught with difficulties, as past trends may not give a reasonable picture of what may happen in the future. Some countries, such as Japan, experienced rapid deterioration in road safety in the 1960s, with an 80% growth in road fatalities but then, with massive investment, reduced deaths by almost 50% over the next decade. However, deaths started to climb once again in the early 1980s, due in part to a continued increase in vehicle ownership, but also due to decreased investment in lifesaving activities.

Trends in many parts of the world are not consistent, and there is evidence that rapid increases in deaths in Africa and Asia/Pacific show signs of slowing down. However, growth rates in these regions are still high and of concern ***(Section 1.4.1)***.

Social and political changes also play a part and ideally would be taken into account in any forecasting activity. However, these changes are also difficult to predict. For example, in the CEE region, changes in road accident reporting methodology took place with the transition to market economies. While the trend in this region over recent years has been one of fewer fatalities, it is quite possible that with economic development and rapid motorization there is the potential for growth in the number of accidents and fatalities.

Forecasting future trends should be approached cautiously for the reasons outlined above. With these caveats in mind, it is suggested that by 2010 the likely range of global road deaths will be 1.0 to 1.1 million, and 1.1 million to 1.3 million in 2020.

1.3 ECONOMIC COSTS OF ROAD ACCIDENTS

Apart from the humanitarian consideration in reducing road deaths and injuries in developing countries, a strong case can be made for reducing road accident deaths on economic grounds alone, as they consume massive financial resources that the countries can ill afford to lose. That said, it must of course be borne in mind that in developing and emerging nations, road safety is but one of the many problems demanding a share of funding and other resources. Even within the transport and highway sector, hard decisions have to be taken on the resources that a country can devote to road safety. In order to assist in this decision-making process it is essential that a method be devised to determine the cost of road accidents and the value of preventing them.

The first need for cost figures is at the level of national resource planning to ensure that a fair proportion of the available budget is allocated to road safety improvements. Fairly broad estimates are usually sufficient for this purpose, but they must be compatible with competing sectors.

A second need for road accident cost figures is to ensure that the best use is made of any investment and that the best (and most appropriate) safety improvements are introduced in terms of the benefits that they will generate in relation to the cost of their implementation. Failure to associate specific costs with road accidents will almost certainly result in the use of widely varying criteria in the choice of measures and the assessment of projects that affect road safety. In particular, if safety benefits are ignored in transport planning, then there will inevitably be under-investment in road safety.

A study conducted in 1977 by Fouracre and Jacobs estimated that road accidents cost on average 1% of a country's gross national product (GNP). This figure has been used by many countries and international aid agencies to estimate (albeit crudely) the scale of costs attributable to road accidents, but as countries have developed, a higher range, 1% to 3%, has been suggested by the World Bank and others (but it should be stressed, with limited supporting evidence).

Expressing accident costs as a percentage of GNP provides a useful, albeit crude approach to costing accidents, particularly on a global or regional basis. However, there is no real substitute in individual countries to carrying out a detailed appraisal of national accident costs.

1.3.1 RESULTS OF ACCIDENT COSTING PROCEDURES

As part of the global review undertaken for the GRSP (Jacobs et al., 2000), information was obtained from 21 studies worldwide that had attempted to cost road accidents. (one study in Latin/Central America and the Caribbean, seven in Asia, four in Africa, one in the Middle East and eight in highly motorized countries).

An analysis of these studies showed all developing countries using the "Human Capital" approach, while the majority of developed countries now use "The Willingness to Pay" approach[2].

Values derived of national accident costs (usually for the year 1995 or 1996) were expressed as a percentage of GNP for the different countries and results ranged from 0.3% in Vietnam and 0.5% in Nepal and Bangladesh to over 4% in New Zealand, Malawi and KwaZulu-Natal. However, relatively little is known about the accuracy of the costing procedures used in each country. For example, it is not known whether or not under-reporting of accidents has been taken into account, how damage-only accidents have been assessed, what sums (if any) have been added to reflect pain, grief and suffering if the Human Capital approach has been used, etc. Overall, it does appear that in most countries, costs exceed 1% of GNP. However, the figures also indicate that costs as a percentage of GNP may be lower in less developed countries and therefore caution should be exercised in moving from 1% of GNP to a much higher level for developing countries.

[2] These are the only two methods for costing road accidents now considered by specialists to be generally acceptable. Both include estimates of resource costs such as vehicle repair costs, medical costs, administration costs, etc., and both include an estimate of the cost of lost output of those killed or injured in accidents. The Human Capital approach also includes a notional value to reflect the ''Pain, Grief and Suffering'' of those killed or injured and of their loved ones. Conversely, the Willingness to Pay approach, by means of complex questionnaires, attempts to include a value which reflects what those affected (collectively) might be prepared to pay for a given reduction in perceived risk. For a review costing road accidents, the reader is referred to the Commission of the European Communities (1994) and to Elvik (1995).

Table 1-2 provides a crude estimate of global and regional costs assuming that the annual cost of road accidents is about 1% of GNP in developing countries, 1.5% in transitional countries, and 2% in highly motorized countries. It shows that road accident costs may be on the order of US$ 64 billion in developing and transitional countries, and US$ 453 billion in highly motorized countries, making a crude estimated total of US$517 billion worldwide.

Table 1-2 Road accident costs by region (1997)

REGION	REGIONAL GNP 1997 ($US)	ESTIMATED ANNUAL ACCIDENT COSTS	
		GNP %	COST (US $ BILLION)
HIGHLY MOTORIZED COUNTRIES (HMC)	22,665	2.0	453.0
ASIA/PACIFIC	2,454	1.0	24.5
CENTRAL/EASTERN EUROPE (CEE)	659	1.5	9.9
LATIN/CENTRAL AMERICA AND THE CARIBBEAN (LAC)	1,890	1.0	18.9
SUB-SAHARAN AFRICA	370	1.0	3.7
MIDDLE EAST/NORTH AFRICA (MENA)	495	1.5	7.4
TOTAL			517.4

The total sum received by recipient countries as official aid from all donor agencies combined (multilateral and bilateral[3]) has been estimated at $50 billion per annum (The Economist, June 12th 1999). This is actually less than the above estimate of the annual cost of road accidents in these countries. In other words, more is lost by developing and emerging nations solely as a result of road accidents than they actually receive as official aid from all agencies combined.

1.4 REGIONAL ANALYSES

This section presents a summary regional analysis of the above global figures:

- description of the current situation for the countries with the largest number of road fatalities in each region;
- review of the recent evolution in motorization, fatalities, and population by subregions follows, with information on the largest countries presented separately;
- information on the type of road accident casualties, including road user type, age and gender distribution.

Several indicators are included to define the "seriousness" of the road safety situation, as no single indicator accurately describes this situation.

The indicator most commonly used in motorized countries is the number of injury accidents per million vehicle-kilometers (which clearly relates accidents taking place to a measure of exposure to traffic), but few developing countries have vehicle usage data. Instead, the number of reported fatalities per 10,000 motor vehicles has been used by the World Bank and others to compare traffic safety records between countries.

However, fatality rates might be considered to be of less importance to a specific country than the actual number of deaths taking place. Fatality risk, the number of reported fatalities per 100,000 population, is the most common indicator used by the health sector to prioritize diseases and other causes of death.

In this section, therefore, both fatality rates and risks are presented.

[3] Bilateral aid is given in a partnership between governments of two countries. Multilateral aid is given by the governments of many countries and is commonly distributed through international organizations (e.g. United Nations, World Bank, Asian Development Bank).

1.4.1 RATES AND TRENDS

Fatality rates (deaths per 10,000 vehicles) are lowest in developed countries (in the range 1.1 to 5.0), while the highest (frequently in excess of 100) are found in African countries, particularly Ethiopia, Tanzania and Lesotho (Figure 1-4). Fatality risk (deaths per 100,000 population) is highest in a disparate group of countries, including Malaysia, Korea, Latvia, Saudi Arabia, and Colombia (Figure 1-5). As might be expected, values in Central and Eastern European countries lie closer to those of Western Europe than to the countries of Africa, Asia, or Latin America.

One of the most important differences between developed and developing regions is that, from the mid'80s, the number of road deaths actually fell by about 10% in Western Europe and North America, while they continued to rise in the Africa, Asia/Pacific, and Latin/Central America and the Caribbean regions.

Figure 1-6 shows trends in road deaths, population, and motor vehicles in different regions of the world. In comparing regional trends in a relatively small group of countries, the changes in the major country can dominate, and trends in the USA, China, South Africa, Poland, Brazil and Saudi Arabia are shown separately. Most noticeably, fatality trends in South Africa and Poland differ from other African and East European countries, respectively, whereas in the other regions trends in the major and other countries tend to show a reasonably similar pattern. Thus over the period 1987-95 deaths in the Asia Pacific region rose by 39%, in Africa (excluding South Africa) by 26%, in the MENA region by over 36%, and in the Latin America/Caribbean region (excluding Brazil) by over 100%. In Central and Eastern Europe there was a marked difference between Poland, where deaths increased by 31%, and other countries, where deaths fell.

In an earlier study (Ghee et al., 1997), it was found that between 1968 and 1990 road deaths increased on average by about 350% in African countries for which data were available and by over 200% in Asian countries. Conversely, road deaths in developed countries actually fell by about 20% over the same time period. There is therefore some evidence that the rapid increase in road deaths in Africa and Asia throughout the 1970s and early 1980s is now slowing down, but the problems in these regions still cause concern.

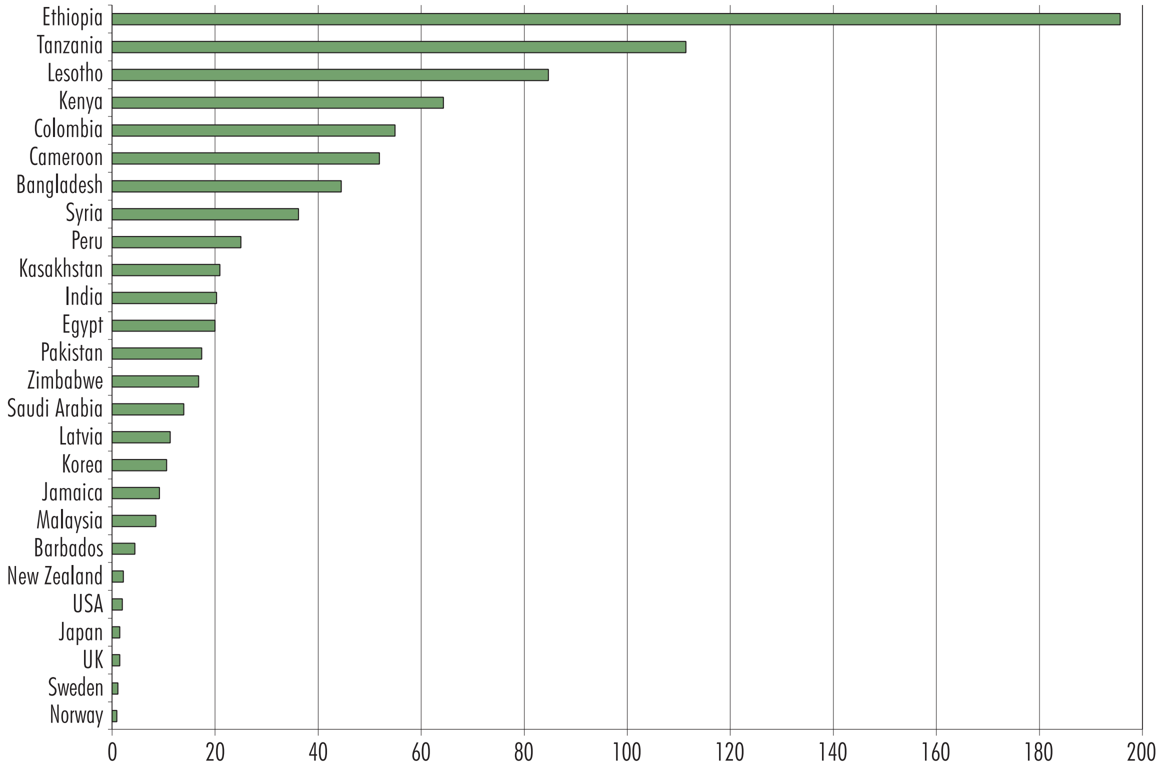
1.4.2 ACCIDENT PATTERNS

One of the factors leading to high death rates in developing countries is that proportionally more pedestrians are killed than in the developed world. Pedestrians are, of course, unprotected and are the most vulnerable of road users.

Figure 1-7 shows the proportion of all road fatalities where the victims are pedestrians for four regions of the world, namely Highly motorized countries, Eastern Europe, Africa (Sub-Saharan) and Asia/Pacific.

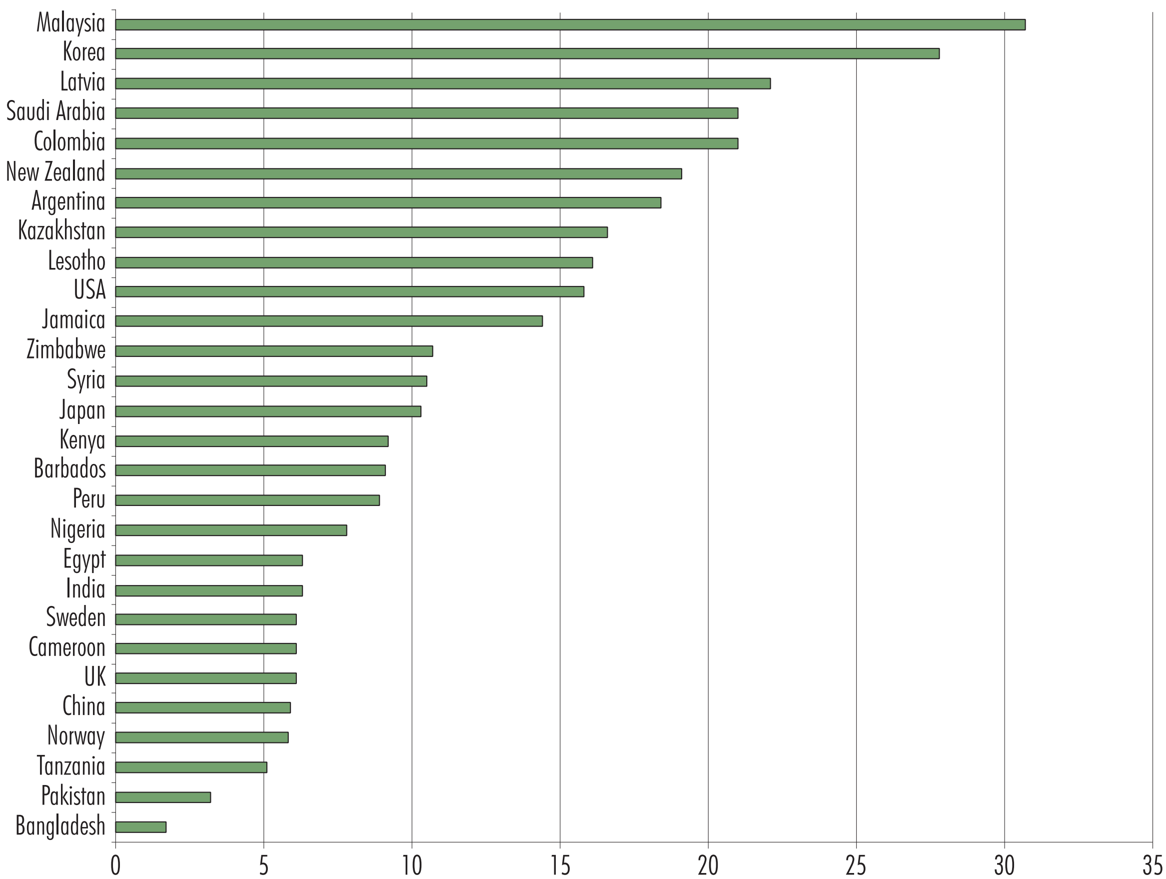
The percentage of pedestrian road deaths is lowest in the Highly motorized countries, with most being in the range of 12 % to 20%. Japan and the UK, which have among the world's lowest fatality rates overall, have surprisingly high percentages of pedestrian deaths. Pedestrian deaths in Eastern Europe are higher, and are fairly consistently in the 30 % to 42% range. Pedestrian rates are also high throughout Africa, with most in the range of 40 % to 50%.

Figure 1-4 Fatality rates (fatalities/10,000 licensed motor vehicles)[a]



[a] 1997 or last year available

Figure 1-5 Fatality risk (fatalities/100,000 population)[b]



[b] 1997 or last year available

Figure 1-6 Recent trends

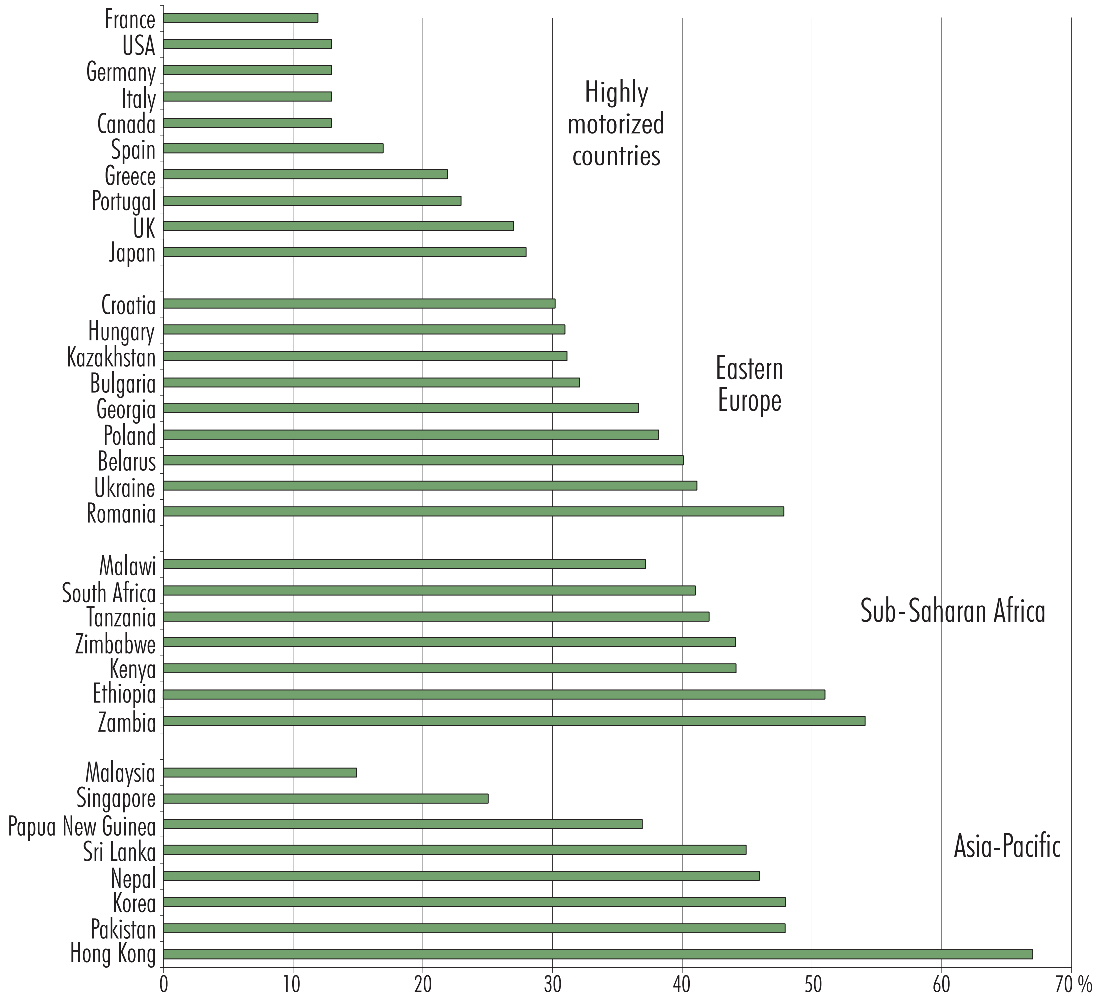
Rates of pedestrian deaths show greatest variation in Asia-Pacific countries. For example, it might be expected that rates would be similar in Hong Kong and Singapore, but this is not the case. Similarly, well-developed and fairly highly motorized countries of Malaysia and Korea show significant differences.

When deaths involving pedestrians, non-motorized vehicles and motorcyclists are combined to form the overall category of "Vulnerable Road Users" (VRUs), it represents, in Asian countries, a significant proportion of all people killed. For example, in Hong Kong, Singapore, Malaysia, and Taiwan, VRUs account for 80 to 90% of all fatalities, and in Fiji and Korea, about 50 to 60%.

An analysis of deaths by gender shows wide variation between countries (even within regions):

- the overall tendency, however, is for females to be more involved in nonfatal accidents than in fatal ones, possibly because females tend to be injured in urban accidents by vehicles traveling at lower speeds;
- the overall tendency is that proportionately more females are involved in both fatal and nonfatal accidents in the higher income countries;
- an English study shows that females in developing countries, when involved in a serious accident, suffer greater consequences than males (Ghee et al., 1997). Often, there is less investment in their medical treatment and recovery with proportionally far fewer receiving comprehensive hospital treatment. Furthermore, if their husband is killed, their legal status as a widow is often unfavorable and the loss of a husband can mean the breakup of a family.

Figure 1-7 Proportion of pedestrians among fatalities



An analysis of casualties and fatalities by age showed that young people are involved in proportionately more accidents in Africa, Asia and the Middle East than in the HMCs. Table 1-3 shows, from various studies, how the proportion of road deaths involving children aged under 15 has changed over time. It shows that in both groups of countries, there has been a slight fall in the proportion of road deaths involving children.

Table 1-3 Proportion of children under 15 in fatal accidents

YEAR	DEVELOPING COUNTRIES %	DEVELOPED COUNTRIES %
1982	20.0	10.0
1990	15.2	6.0
1998	15.0	5.2

In developing countries, children under 15 years of age consistently represent a greater proportion of the national population than in the developed world. However, the proportion of young people involved in road accidents in some countries is even greater than might be expected from the population age profile of these countries. Thus, in developing countries young pedestrians would appear to be particularly at risk.

In general, the data from all regions indicate that road accidents involving the economically active in the age group 25 to 40 dominate. This has particular significance from a social point of view in developing countries. When a household loses the main wage earner in a road death, the family is very likely to be plunged into poverty, with no insurance cover or pension system for the family to fall back on.

Bus accidents are particularly significant in developing countries. In HMCs, buses are involved in 3-5% of all injury accidents taking place, but in selected (predominantly urban) areas of Pakistan, Nigeria, and India, buses are involved in between 20 % and 40% of all accidents. At the national level in Sri Lanka, Kenya and Papua New Guinea, 14-20% of all accidents involve buses. In three African countries, bus involvement rates in accidents are up to four times greater than their fleet share might suggest. The high involvement of buses in accidents in developing countries is likely due to a number of factors, including poor driving standards, inadequate vehicle maintenance, and overloading of vehicles. This last consideration represents an important difference between developed and developing/emerging nations.

In HMCs, the prime concern is with the problem of young or inexperienced drivers and how to reduce their accident rates, while in the developing world the key issue should be improving the standards of “professional” (i.e. bus and truck) drivers.

1.5 SUMMARY

This chapter has described the magnitude and nature of the road safety problem worldwide and major differences between developed (highly motorized) and developing (less motorized) countries. In summary:

- it is estimated that in 2002 between 800,000 and 950,000 people may have died as a result of road accidents and that the majority of these deaths occurred in developing and emerging nations, with approximately half in the Asia-Pacific region alone;
- road fatalities are expected to continue to increase to 1.0 and 1.1 million by the year 2010 and between 1.1 and 1.3 million by 2020;

- the global cost in 1997 of road accidents has been on the order of US$520 billion, of which the cost in the developing regions would have been about US$65 billion;
- the total number of people killed in road accidents in regions of the developing world continues to increase, whereas in HMCs there has been a steady decrease since the late 1960s. However, the rate of increase of deaths in the developing world appears to be slowing down, particularly in Africa;
- the highest fatality rates (deaths per 10,000 motor vehicles) occur in African countries, particularly Ethiopia, Tanzania and Lesotho, while fatality risk (deaths per 100,000 population) is the highest in a disparate group of countries, including Malaysia, Korea and Saudi Arabia;
- pedestrians are a particularly high risk group throughout Africa and Asia as well as the Middle East. Car occupant casualties dominate in developed countries and are much more common in the Latin/Central America and the Caribbean region. In African and Asian countries, bus accidents present a particular problem;
- the proportion of road fatalities aged under 15 is up to three times greater in developing countries than in developed countries. However, males in the economically active age group make up the largest proportion of reported victims of road accidents in all regions.

1.6 CONCLUSION

Statistics indicate that over 80% of the global road deaths that currently take place each year occur in developing and emerging nations. Most highly motorized countries have had more than half a century to learn to cope with the problem of ever increasing motorization, while the less wealthy nations have had far less time, and for many the pace of change has been much greater. Many developing countries have a serious road accident problem and while in Europe and North America the situation is generally improving, many developing countries face a worsening situation.

Apart from the humanitarian aspects of the problem, road accidents cost the countries of Africa and Asia at least 1% of their Gross National Product each year, sums that these countries can ill afford to lose. Compared with causes of death more commonly associated with the developing world, deaths from road accidents are by no means insignificant. A lack of medical facilities in these countries has been shown to be an important factor leading to the high death rates.

The following chapters of this Manual deal with ways in which both developed and developing countries can improve their road safety systems through improved institutional frameworks, improved databases and road safety engineering actions.

With support from multinational and bilateral aid agencies, developing countries have accelerated their effort to improve road safety in recent years. Another important development has been the setting up by the World Bank, the International Federation of the Red Cross and the Red Crescent, and numerous other organizations of the Global Road Safety Partnership. This partnership aims to assist in the reduction of the global toll of death and injury by the mechanism of partnerships between the private and public sectors which promote collaboration and coordination of road safety activities worldwide.

It is hoped that these trends will continue and that all countries will, through joint programs of research and development and by sharing information (through PIARC for example), maintain an effective and scientific approach to reducing road deaths and injuries. It is hoped, this Manual will assist in that process.

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Chapter 2

Road safety management

Tomaz Pavcic

CHAPTER 2

Road safety management

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2.1 INTRODUCTION

The previous chapter has shown that traumas resulting from road accidents are one of the worst health problems and that the number of road fatalities is still rapidly growing in most developing countries. On a more positive side, it has also shown that a number of developed countries have succeeded during the last decades in reversing these trends by developing strategies and actions that proved to be effective.

It is important to recognize that various solutions may often be proposed to solve the same safety problem. Most accidents cannot be attributed to a single cause but are, rather, the end-result of complex sequences of actions and interactions between the various components of the so-called road safety system ***(Section 3.1.1)***. Experience has shown that targeting simultaneous actions on several of these components may be a very effective strategy to solve a specific problem. It creates synergy effects that increase the overall benefits of individual actions. For example, combinations of new laws, education and promotion activities and police enforcement have been very useful in increasing safety belt usage and reducing impaired driving.

Successful countries have also established, over the years, organizational structures to efficiently deal with road safety problems. Key elements of a sound management strategy include:

- clear definitions of the respective roles and responsibilities of each actor;
- creation of efficient coordination mechanisms that ensure a proper synchronization of actions.

This chapter relies upon these experiences and proposes general guidelines for the management of road safety actions.

2.2 ROAD SAFETY PROGRAM

A Road Safety Program (RSP) is defined here as the set of activities that needs to be initiated in order to reach a predetermined accident reduction target. It includes:

- measures that must be taken to better manage and coordinate road safety improvements efforts ***(Section 2.3)***;
- a choice of action priorities ***(Section 2.4)***.

Several components of a national road safety program (RSP) will generally be assembled in a single and official document called a Road Safety Action Plan that describes what a country will do to tackle road safety problems. Such a document is developed once it has been recognized that road traumas are an unacceptable mobility toll. The existence of an action plan, publicly endorsed by the nation's leader, is seen as a strong signal of a government's willingness to deal with safety issues.

The list of countries that have developed formal road safety action plans is growing rapidly. They have been implemented in most North American and European countries, in parts of Asia and in some African and South American countries. Substantial road safety improvements have been achieved in several of these countries.

Organizational restructurations are initially required to build up the coordination structures and technical skills necessary to tackle safety issues. An initial road safety program is then developed. This first-generation program will necessarily undergo regular modifications in order to adapt to the ever-changing road safety problems and societal readiness to accept new and often restrictive remedial measures. The Swedish "***Vision Zero***" and Dutch "***Sustainable Safety***" are good examples of evolved generations of road safety programs.

The following sections describe a general framework for road safety actions, based on the experience of several countries. It should be clear that the proposed structure does not present an exhaustive list of items to be included in a RSP and, inversely, that all the described elements do not necessarily need to be included in a program. Regional and national specificities create significant differences in the nature of the road safety problems encountered in each country and in the more appropriate solutions to these issues. Each country needs to develop strategies and solutions that are best suited to its features, including:

- historical, cultural and social background;
- political organization;
- socio-economic context;
- level of motorization and level of development of the transportation system;
- level of technical expertise.

It is important to recognize that there is no safety management model that can be universally applied in a blindfold manner. This chapter describes what has been found useful in several countries and should be helpful to policy makers who are responsible for organizing road safety actions in a specific country.

The Swedish "Vision Zero" and the Dutch "Sustainable Safety"

Vision Zero *(www.vv.se)*

Long-term goal:

No one will be killed or seriously injured within the Swedish road transport system.

Main principles:

The traffic system has to adapt to take better account of the needs, mistakes and vulnerabilities of road users. The level of violence that the human body can tolerate without the person being killed or seriously injured forms the basic parameter in the design of the road transport system. Vehicle speed is the most important regulating factor for safe road traffic. It should be determined by the technical standards of both roads and vehicle so as not to exceed the level of violence that the human body can tolerate.

Sustainable Safety *(www.swov.nl)*

The entire traffic and transport system is adjusted to the limitations and possibilities of road users. Prevention is better than a cure and everything is aimed at preventing accidents. If an accident does happen, the consequences are kept to the absolute minimum.

Infrastructure

At the design stage, 3 main principles need to be followed:

Functionality: the traffic will be distributed over the road network as was intended.

Homogeneity: there will be small speed and mass differences between transport modes that can collide.

Recognition: traffic situations are, to a great extent, predictable; at first glance you know what behaviour is expected from you and from other road users.

Vehicles

Constructed to simplify the driving task and offer adequate protection in an accident (vulnerable road users and others).

Road users

Educated and informed properly; their behaviour is tested regularly.

2.3 COMPONENTS OF A ROAD SAFETY PROGRAM

2.3.1 ORGANIZATIONAL STRUCTURE

Due to the wide range of organizations that can play a role in improving road safety, there is a need to establish formal administrative structures that can efficiently harmonize and maximize the effects of road safety efforts. In that respect, the implementation of a road safety council is seen as a useful measure, although some recent research has shown that relying on a strong lead agency may also be very effective ***(basic organizational structure)***.

Road safety councils

National road safety council

A National road safety council (NRSC) is a permanent body whose main tasks are to define a country's main orientations in terms of road safety needs and to provide coordination of actions between the main organizations that are involved at the national level. There is no ideal organizational model for this council, and again, it needs to be suited to the particularities of each individual country. However, it should have the following features:

- be chaired by a high-level politician (Prime Minister or equivalent);
- group senior managers from key organizations that should be involved in road safety:
    - governmental and para-governmental:
        - driver licensing;
        - transportation authorities;
        - police;
        - public health services;
        - education;
        - legislation;
        - vehicle registration and inspection.
    - private sector:
        - insurance companies;
        - transport-related industries;
        - research institutes;
        - etc.

    however, the membership of the NRSC must not be overly large (between 10 and 25 members); subcommittees should be appointed, as needed, to work on specific issues: education, speed management, etc. (Asian Development Bank, 1997).
- have its own budget and a permanent secretariat to provide technical and administrative support;
- meet on a regular basis to decide on the main road safety orientations.

Provincial, regional and local road safety committees

It is also essential that road safety actions be taken by provincial, regional and local authorities. At each of these levels, the number of agencies that need to be involved in the search for solutions is still very large and harmonization of efforts is most useful. Formal coordinating bodies should be established, with structures that may be similar to that of the National council but scaled down to the characteristics of the geographical area considered.

Integration of the efforts made at the national, regional, provincial and local levels is essential. The best results can be achieved by horizontal and vertical coordination of governmental and non-governmental road safety activities.

Basic organizational structure

In a review of practices in 13 countries, Aeron-Thomas et al. (2002) describe road safety as being managed by one of three basic organizational structures: a lead agency, a National road safety council or an independent Non-governmental organization (NGO). Each structure has advantages and disadvantages:

Table 2-1 Road safety organization structures

	LEAD AGENCY	NATIONAL ROAD SAFETY COUNCIL (NRSC)	INDEPENDENT/ NGO
Avantages	Faster-acting Clear funding stream	Broad-based input Local ownership	Campaigning and lobbying capability Able to receive various funds
Disadvan-tages	Limited focus Acceptance of non-governmental funds may be a problem	Mostly advisory role only Funding streams unclear	Little authority over public sector
Examples	Sweden, UK, Chile, South Africa, Ethiopia	Zambia, Bangladesh, Ghana, Fiji	Austria, Singapore

The authors indicate that both the lead agency and National road safety council (NRSC) structures can effectively improve road safety, as long as the following key issues are satisfied:

- *lead responsibility for road safety must be clearly defined, whatever organizational structure is adopted. Both the National road safety council (NRSC) and lead agency approaches can deliver improved road safety if adequately funded and professionally staffed;*
- *the specific responsibilities of the lead body must be clearly defined, in addition to its role of coordinating road safety interventions by other agencies;*
- *the lead responsibility often lies with the road authority, with its minister reporting on the road safety situation to government/parliament. This should not preclude other agencies from being involved if coordination is effective;*
- *good working relationships need to be established between all contributors. Effective liaison between the police and the engineering departments, which share responsibility for the safe operation of the roads, is a key relationship and an effective starting point;*
- *the most effective NRSCs are limited in size. This promotes close working relationships and accountability, but requires well supported working groups and a secretariat to deliver sound advice and to implement decisions. Working groups should include the business community and civil society in the development of road safety policy;*
- *members of coordinating bodies, or councils, however selected, need to be committed and able to deliver resources or political support.*

For more details on these reports, the reader is invited to consult either the full report (Aeron-Thomas et al., 2002), which is available on Internet, or four related summary notes that have been produced by GRSP *(http://www.grsproadsafety.org)*.

Roles and responsibilities

For road safety actions to be efficient, the roles and responsibilities of each organization need to be clearly defined. Worldwide, the following patterns are fairly consistent:

Road authorities

Central road authorities are often the lead agency in terms of road safety management. They are also responsible for road-related legislation and regulations and they provide project funding, consultation services and research assistance to provincial, regional and local road administrations.

They must ensure that roads under their jurisdictions have adequate safety levels. Initially, the emphasis is generally placed on the implementation of low-cost measures (i.e. blackspot improvement program), but after a few years, actions will gradually evolve towards other types of treatments and preventive actions ***(Chapter 5)***.

Police

Police authorities are responsible for law enforcement, a key element of an efficient road safety improvement strategy.

They are also responsible for the collection of accident data. This data must not only satisfy the requirements of police administrations but also provide reliable information to the various groups of analysts who conduct safety studies: road engineers, transportation planners, health and education authorities, road safety research organizations, etc.

Being the first level of road safety professionals called to an accident scene, police officers often have key information to define intervention needs and participate to the determination of realistic accident reduction targets. Cooperation between police and road authorities is therefore strongly recommended to improve the accuracy of safety diagnoses.

Private sector and interest groups

The success of many road safety initiatives depends on the active involvement of public organizations and private companies. Proper linkages must be established between governmental and non-governmental organizations to ensure their participation in road safety initiatives. In this regard, efforts of the Global road safety partnership (GRSP) is worth mentioning. The main objective of the group is to develop effective partnerships between business, civil society and government in order to deal more effectively with road safety problems.

The involvement of special-interest groups is also essential to accelerate the adoption of new safety initiatives, especially when the proposed measures are unpopular. If such measures are driven solely by transportation authorities, they are likely to be assigned low priorities on the political agenda and little progress will be made. Experience has shown that pressures exerted by recognized interest groups can effectively raise awareness of specific road safety problems and speed up the adoption of new safety initiatives.

2.3.2 INTEGRATED DATA SYSTEM

The existence of a reliable and integrated data system is fundamental to the efficient management of road safety activities. Without accurate accident data, it is impossible to determine the extent of road safety problems and to identify the most pressing needs. It is also impossible to develop a good understanding of the nature of the encountered problems, that will lead to the choice of appropriate solutions. Accident databases should provide information on:

- Where do accidents occur?
- When do they occur?
- Who is involved?
- What happened?

In order to conduct road safety engineering studies, information about accidents needs to be linked to road and traffic characteristics. ***Chapter 4*** describes in detail which data are needed and how to collect and maintain these data.

2.3.3 POLITICAL AND SOCIAL SUPPORT

The success of a road safety program is strongly tied to the social awareness of the importance of the problem and to the commitment of political leaders to improve the situation.

Countries exhibit different degrees of readiness to implement road safety measures, depending on the government's sensitivity to the problem and its importance on the political agenda. The World Bank Organization identifies three levels of road safety awareness (Ross et al., 1991):

Awareness level 1. In these countries, there is little safety awareness. Accident data may or may not be collected and any data system will be primitive. Little will be known about trends or road users at risk. General interest by government will be low, although there may be a few interested individuals (often doctors). There will be few traffic engineers and virtually no one working specifically on safety matters;

Awareness level 2. The government is aware of the road safety problem but has given it little priority. Accident data are sparse but available. Occasionally, there may be road safety pressure groups and there may even be an ineffective National road safety council. A few underfunded ministries with fragmented responsibilities may be interested in "doing something". The media may be beginning to press for action. Some university research may be underway;

Awareness level 3. Government will have recognized the need for assistance. An improved accident data system will have been established and staff will have been trained in safety operations. Analysis is undertaken to identify blackspots and road user groups most at risk. A National road safety council (NRSC) provides support to local safety committees, and coordinates a national road safety program. Road engineers and highway authorities are skilled in basic accident blackspot improvement work. Efforts are made to improve driving tests and vehicle examinations, to develop children's traffic education and improve legislation. There is a core of professionals specialized in safety who are keen to tackle the problem but lack resources. Road safety research is being undertaken and the media are actively pressing for action.

The lower the awareness level, the less likelihood there is of government interest and ability to integrate safety components into road projects.

Too often, awareness is raised only after the problem has reached disastrous dimensions. This clearly increases the level of investment that will be needed to bring the situation back to more acceptable levels.

According to Mulder and Wegman (1999), the formulation of road safety policies is a multi-phased process that begins with the *signalling of the problem*, and then continues with the *demand for recognition of the problem* and the *initial social recognition of the problem*. In those countries that have yet to reach these early phases, direct actions should be taken to increase problem recognition.

For this purpose, the *Road safety guidelines for Asia and Pacific region* (Asian Development Bank, 1997) recommend:

- conducting independent reviews to quantify the extent and nature of the problem and its evolution;
- organizing national road safety seminars involving all senior personnel from key government and non-government agencies who are responsible or otherwise interested in road safety.

Both activities should be supported by well-planned media coverage, which plays an important role in increasing the awareness of politicians and the general public.

As previously mentioned, lobby groups that put pressure on politicians have also been shown to be quite effective in increasing support for road safety activities.

Comprehensive *social marketing* approaches, which apply commercial marketing concepts and tools to solve health problems, have also been successfully used to increase support for and social acceptance of road safety initiatives (impaired driving, safety belts).

Why is it so difficult to attract attention to road safety problems?

Several factors explain why it is so difficult to attract attention to road safety problems. These include:

- general absence of accurate information on the scale, nature and characteristics of the problem;
- lack of information on the benefits of implemented countermeasures;
- absence of political will to deal with the problems (road construction projects give politicians more votes than road safety schemes);
- safety and mobility dilemma (road safety measures often limit mobility and as such, are therefore unpopular among politicians and road users; mobility is considered of primary importance);
- insufficient actions and inadequacy of resources (financial, organizational, technical, etc.);
- sharing of safety responsibilities among several organizations and inadequate coordination of these actions;
- limited consequences of each individual accident (compared to air, rail or sea catastrophes, a road accident does not seem so disastrous and is therefore less publicized);
- high rate of occurrence of road accidents (people accept risk as an inevitable toll of mobility).

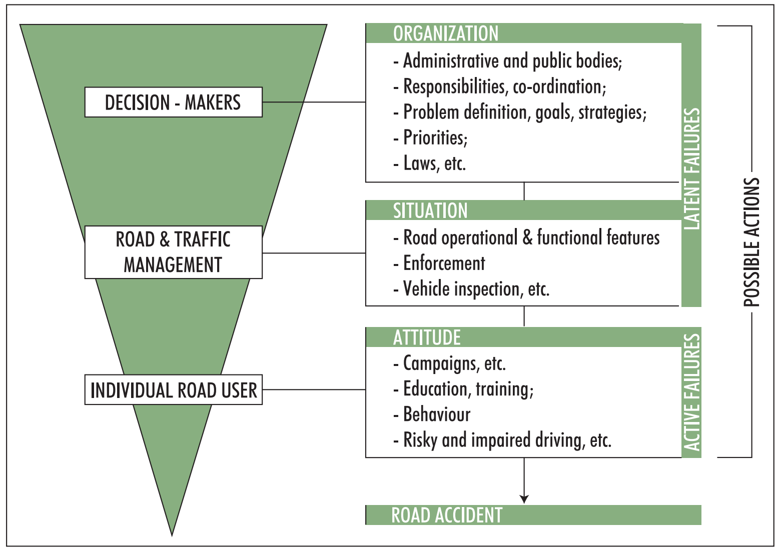
Recognizing these difficulties and developing ways to effectively deal with them should be part of a road safety management strategy.

Levels of road safety actions

Figure 2-1 shows that road accidents may originate from latent failures by decision-makers and road managers or active failures by road users.

It is crucial to understand that errors and inactions at the decision-makers' level, although they may be more difficult to identify, may have significant impacts on road safety.

Figure 2-1 Levels of road safety actions



Source: Rumar, 1994

2.3.4 FUNDING ROAD SAFETY INITIATIVES

Human and economic consequences of road accidents are devastating. As described in ***Chapter 1***, economic losses resulting from road accidents in developing and transition countries are greater than the total sum they receive from all donor agencies combined. Worldwide, more than $500 billion US is lost every year in road accidents. Although it is clear that road safety investments could relieve pressure on medical facilities and produce significant savings that would be better used on other public services, the funding of road safety initiatives is still grossly insufficient in many countries. But how can this situation be improved?

Firstly, governments need to realize that they have to invest a fair amount of their budget in the implementation of road safety initiatives. Only governments can accept full and overall responsibility for developing a road safety strategy and provide the funds needed for each agency's involvement.

For example, in Great Britain, the total annual expenditure in road safety is about £2 billion (including the cost of hospital services), compared to an estimated accident cost of around £11 billion (Department of the Environment, Transport and the Regions, 1997, 1999) (Table 2-2).

Table 2-2 Estimated expenditure on road safety in Great Britain (1997)

	AREA	£ MILLION
By government	Hospital and ambulance services	474
	Enforcement	271
	Local safety engineering	90
	Driver and vehicle licensing	73
	Education	29
	Vehicle standards, publicity, etc.	7
	SUB-TOTAL	944
By general public	Roadworthiness testing	683
	Driver/rider training and testing	469
	Driver licensing	38
	HGV/PSV operator licensing	27
	Enforcement	15
	SUB-TOTAL	1,232
	TOTAL	**2,177**

Source: Department of the Environment, Transport and the Regions, 1997

In addition, other funding sources should also be pursued. These include:

- international aids and loans (World Bank, Asian Development Bank, etc.);
- road-user charges (vehicle licensing, tolls, fuel levy);
- road fines;
- insurance companies;
- other private companies (motor vehicle manufacturers, oil companies, transport companies, road construction companies).

2.3.5 TECHNICAL EXPERTISE AND RESEARCH ACTIVITIES

Technical expertise

Skilled people are an essential part of the solution and strengthening technical expertise in road safety is thus essential. Decision-makers need to look at existing human resources:

- are there sufficient road engineers and technicians, police officers, trainers, etc., to ensure the implementation of the road safety action plan?
- if so, do they have sufficient skills, equipment and freedom of action to get on with the job?

In Great Britain, the Institution of Highways and Transportation (1990) recommends a staffing level of one engineer or technician for each 400 - 1,000 reported accidents per year, depending on who is responsible for the design and implementation of the proposed solutions.

Research activities

Road safety research is needed to increase the understanding of how road accidents occur. More efforts should be allocated to the conduct of multidisciplinary research that brings together road designers, vehicle designers, human factor specialists, and health specialists. Such projects allow better analyses of interactions between the various components of the road safety system and as such they may lead to the proposal of new and effective treatments. Traffic-calming measures are a good example of a relatively new family of solutions aimed at the level of human-road interactions[1].

Research on intelligent transport technologies (in-vehicle or in-road) will also play an increasing role in accident prevention and injury reduction.

The scale of research activities necessarily depends on the size of a country and its level of development, but in all cases:

- access to international knowledge is vital in order to avoid pointless effort duplications. Recent advances in Internet communication greatly improve possibilities in this area. Knowledge transfer at inter-regional forums, which are already held in some regions, constitute another powerful tool of research dissemination;
- international cooperation between research groups should also be encouraged as it provides a means to maximize the available research budget.

[1] Traffic-calming makes use of human-perception mechanisms to propose road (and roadside) design schemes that are likely to promote the adoption of "safe" speeds.

2.3.6 MONITORING AND EVALUATION

All road safety activities should be monitored and evaluated to ensure compliance with the established targets and to propose necessary adjustments.

In road safety, accident reduction is generally the preferred performance indicator, and it is evaluated through before/after accident analyses. The problem is that it is often necessary to wait several years in order to gather sufficient accident information to conduct reliable before/after accident analyses.

It is therefore essential to complement the use of such before/after accident analyses with appropriate ***technical studies*** and ***site observations*** that provide useful information on a treatment effectiveness soon after its implementation (***spot speed study***, ***traffic conflict study***, etc.).

Evaluation methods and techniques are discussed in ***Chapter 8***.

2.4 ROAD SAFETY ACTION PLAN

The information system should reveal the extent of the safety problem, its main features and its recent evolution. Based on this knowledge, an action plan may be prepared that describes where the action should be focused in order to improve the situation. The action plan should have the following characteristics :

- actions should be realistic (taking account of financial constraints and other types of constraints);
- actions should be selected in all key areas of road safety (balanced program);
- priority should be given to measures which have been shown to be cost-effective.

Action plans should provide detailed descriptions of what will be accomplished for each action, along with a timetable, costs and expected benefits.

Distinct road safety action plans should be prepared at the national, regional and local levels.

When selecting the action priorities, the following points should be kept in mind (Trinca et al., 1988):

1. *There can be no traffic safety panacea in a mobile society.*
2. *Traffic injury is a heterogeneous phenomenon and must be treated as such. Myriad individual problems need to be identified, understood and tackled by the application of scientific techniques.*
3. *As the component problems of traffic injury are too diverse for a single agency to tackle alone, a system-wide strategy with meaningful institutional integration is needed.*
4. *Rational decision-making, aided by cost-benefit and cost-effectiveness analyses, should always influence traffic safety policy and program development.*
5. *Countermeasure programs should be pilot tested where possible and in all cases evaluated to ensure that scarce resources are not wasted on ineffective measures.*

2.4.1 PRIORITIZED ACTIONS

In order to choose a set of safety priorities, a good understanding of the various possible measures is required. Different conceptual approaches have been developed that describe the set of available options. The following paragraphs describe:

- the 3Es approach;
- the injury reduction equation;
- the Haddon Matrix.

3Es approach

In the "triple E" system, the three Es stand for Engineering (road engineering and vehicle engineering), Education (training, traffic education) and Enforcement. A fourth E is sometimes added to the system, although its meaning is not universal. It stands for Encouragement, Emergency services or Evaluation.

Injury reduction equation

Fundamentally, the number of traffic injuries (I) can be expressed as a product of traffic exposure (Q), accident rate (A/Q) and injury rate (I/A):

$$I = Q \times \frac{A}{Q} \times \frac{I}{A} \qquad \text{[Eq. 2-1]}$$

As such, reductions in the number of road traumas may result from actions aimed at reducing the contribution of any of these 3 factors. Table 2-3 lists the possible actions that can be taken at each of these levels by road authorities.

Table 2-3 Accident reduction strategies, measures and actions (Road authorities)

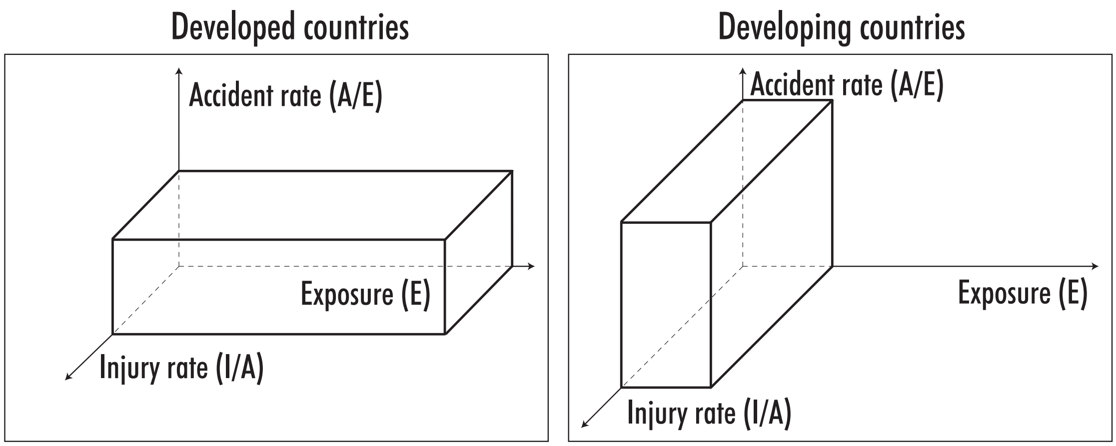
STRATEGIES	MEASURES	ACTIONS
CONTROL EXPOSURE	- reduce transport demand and road traffic; - promote safe, comfortable walking and biking; - provide and promote public transport; - promote transfer to safer modes.	- urban and transport policies; - urban renewal (increased densities, shorter distances); - pricing and regulations; - telecommunications (teleworking, teleshopping); - informatics for pre-trip, on-board information; - traffic-demand management (car pools); - logistics (rail, efficient use of transport fleet); - area-wide pedestrian and bicycle networks; - land use integrated with public transport; - efficient service (bus lane, fare systems, etc.).
REDUCE THE ACCIDENT RATE	- increase the homogeneity of the traffic flow; - separate traffic streams; - improve traffic control and road management.	- geometric design standards, etc.; - road classification with regard to function; - traffic management, pedestrian zones ; - traffic-calming, speed management; - grade separation (multilevel interchanges); - at-grade separation (traffic signals, roundabouts); - channelization (medians, road markings); - travel time distribution (staggered hours); - traffic control (information, warning, changeable message signs); - road maintenance and inspection.
REDUCE THE INJURY RATE	- reduce accident consequences: - preventive measures; - efficient rescue service. - reinstall the traffic apparatus.	- emergency zones without obstacles, breakaway poles; - installation of median and lateral barriers; - establishment of rescue service; - emergency operation (traffic regulation, rerouting); - road maintenance and inspection.

Source: Gunnarson, 1999

Typically, developed and developing countries are in different situations:

- in developed countries, accident rates and injury rates are relatively low while the exposure is relatively high (Figure 2-2);
- in developing countries, it is the reverse situation (Figure 2-2).

Figure 2-2 Traffic injury volumes



Source: Gunnarsson, 1996

Haddon matrix

This matrix, developed by engineer and physician William Haddon, consists of two axes:

- the vertical axis relates to the various components of the safety system: human, road environment, vehicle and socio-economic factors;
- the horizontal axis relates to the three phases in an accident (pre-event, event, post-event).

Each cell of the resulting matrix presents a set of actions that can be implemented to reduce accident occurrence or severity ***(Section 3.1.1 – The elementary system)***.

Table 2-4 lists a few actions that have been shown to be effective in reducing accidents and traumas; Table 2-5 shows the selected action priorities of some countries.

Table 2-4 Examples of effective road safety actions

ROAD INFRASTRUCTURE	VEHICLE	ROAD USER BEHAVIOUR	RESCUE SERVICES
- blackspot correction; - road safety audits; - ''road forgiveness'' principle (minimize the consequences of drivers' errors through road design and maintenance).	- safety regulations; - safer vehicles (crashworthiness); - vehicle inspections (roadworthiness).	- combination of measures aimed at reducing hazardous behaviour (e.g. drunk driving, excessive speed) or increasing safe behaviour (e.g. safety belt, child restraints) through combinations of legal sanctions, enforcement, education, information, road engineering.	- improvements in assistance given to road accident victims.

Table 2-5 Examples of priorities

GREAT BRITAIN	SWEDEN	DENMARK	PROPOSAL FOR CENTRAL AND EAST EUROPEAN COUNTRIES

- safer for children;
- safer drivers (training and testing);
- safer drivers (drinking, drugs and drowsiness);
- safer infrastructure;
- safer speeds;
- safer vehicles;
- safer motorcycling;
- safer pedestrians, cyclists and horse riders;
- better enforcement;
- promoting safer road use.
	- appreciation of road safety;
	- increased temperance in road traffic;
	- fewer speed offences;
	- fewer infringements of other traffic rules;
	- safer traffic environment;
	- increased use of vehicle safety equipment;
	- safer vehicles;
	- increased visibility in road traffic;
	- increased use of cycling helmets;
	- improved rescue operations;
	- improved medical care and rehabilitation.
		- education of road users;
		- campaigns on bicycle-helmet usage;
		- passive safety equipment;
		- faster and better assistance;
		- better care and rehabilitation;
		- automatic speed control;
		- more police enforcement;
		- point system for revoking licences;
		- elimination of fixed objects on roadsides;
		- blackspot works;
		- safety audits;
		- strengthened local road safety work;
		- local road safety plans;
		- improved co-operation;
		- plans for companies;
		- research.
			- raise awareness and support within society;
			- create public acceptance of safety measures;
			- integrate safety policies with other policies;
			- create networks (professionals and citizens);
			- use know-how when implementing policy;
			- check quality of implementation;
			- combine long-term strategy with short-term successes;
			- start with well-known, simple, cost-effective measures;
			- reduce chance of human error by:
			  - increasing predictability in traffic;
			  - making traffic more homogeneous;
			  - reducing speed;
			  - separating road user categories;
			  - improving vehicle safety;
			  - improving emergency services and hospital care.

2.4.2 MAIN ACCIDENT REDUCTION TARGET

A main accident reduction target clearly defines a country's objective in terms of road safety improvement. This target should be quantitative, time-dependent and easy to understand and it can be evaluated. It is generally expressed in terms of road fatality reductions (numbers or percentages) to be achieved within a given deadline, and sometimes includes an associated injury reduction target.

This target should be accepted by elected officials, who should make clear that the government is committed its attainment.

The main values of a quantitative accident reduction target are to:

- provide a rational basis for agreement on the identification and implementation of countermeasures;
- motivate those who can contribute to its achievement;
- encourage the ranking and implementation of actions according to their casualty reduction value;
- provide an opportunity to raise the general level of commitment to safety in the community;
- encourage different authorities with road safety responsibilities to set their own targets.

Elvik (1993) showed that those countries with quantified road safety targets have on average a better safety performance than those without such targets.

A main accident reduction target is generally established for a relatively long period, typically ranging from 5 to 10 years. This provides the opportunity for the implementation of short-term actions and also for initiatives that take a longer time either to implement or to become effective. Yearly monitoring of the progress being made is essential to verify the conformity to proposed objectives and initiate corrective measures whenever necessary.

Realistic accident reduction targets cannot be set without access to reliable accident data that provide sound information on the extent of the safety problem.

There are generally two approaches to the establishment of a main accident reduction target:

- **top-down approach**, which derives a main target from an ideal objective that is set first and then develops sub-targets for each prioritized strategy or action in order to meet this target;
- **the bottom-up approach**, which aggregates estimates of individual countermeasure effectiveness in order to calculate a main target.

The top-down approach can be described as idealistic while the bottom-up approach is more realistic.

The following steps should be conducted in a bottom-up approach:

1. analysis of the situation:

   develop an understanding of the extent of the road safety problem; identify the main system deficiencies and their recent evolution.
2. establishment of a list of priorities (e.g. Table 2-5):

   consider all the components of the road safety system to develop a balanced strategy.
3. development of actions for each priority:

   assess the cost-effectiveness of each action. Priority should be given to low-cost measures.
4. determination of quantified sub-targets and main target:

   make accident reduction sub-targets ambitious but achievable, so that they serve to motivate.
5. monitor in order to assess the effectiveness of countermeasures;
6. feedback and corrective actions whenever necessary.

Table 2-6 shows examples of national accident reduction targets.

Table 2-6 Examples of quantified accident reduction targets

COUNTRY	MAIN TARGET	PERIOD	
		FROM	TO
AUSTRALIA (NSW)	50% reduction – fatalities	2000	2010
CANADA	30% reduction – fatalities and serious injuries	1996-2001 (average of)	2008-2010 (average of)
DENMARK	40% reduction – fatalities and serious injuries	2000	2012
FINLAND	65% reduction – fatalities		2005
GREAT BRITAIN	40% reduction – fatalities and serious injuries	1994-1998 (average of)	2010
NETHERLANDS	50% reduction – fatalities and injuries	compared to 1986-1998	2010
POLAND	20% reduction – fatalities		2001
SWEDEN	50% reduction – fatalities	1998	2007
EUROPEAN UNION	50% reduction – fatalities	2002	2010

TARGETS

Must be measurable, achievable and acceptable to the community at large

2.5 CONCLUSION

Formal road safety management is critical in efficiently dealing with road safety problems. Its strategic substance, encompassed by a road safety program and expressed in a related action plan, forms a sound framework for integrated safety policies.

The main components of a road safety program and its related action plan have been described in this chapter, based on the accumulated experience of several countries that have been successful in reducing road fatalities. This information should be particularly useful to those countries that are still in the early stages of action in this field and have to initiate their own road safety management strategy.

However, one should keep in mind that such guidelines will never replace the need for an objective analysis of a country's safety problems, as well as the need for a proper consideration of a country's specificities when choosing a road safety management framework and a set of action priorities.

RECOMMENDED READING

On strategies

- *Targeted road safety programmes*, OECD Road Transport Research Publication, 1994.
- *Transport safety visions, targets and strategies: Beyond 2000*, K.Rumar, ETSC Publication, 1999. **http://www.etsc.be/eve.htm**
- *Sustainable safety: A preventive road safety strategy for the future*, 2nd edition, G.Schermers and P. van Vliet, AVV Transport Research Centre, Ministry of Transport, Public Works and Water Management, Rotterdam, The Netherlands, 2001.
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- *Road safety vision 2001*, Transport Canada, 2000. **http://www.tc.gc.ca/roadsafety/vision/2000/pdf/RSV.pdf**
- *Sustainable safety in Netherlands*, Theo Janssen, SWOV Publication, 2000. **http://www.rospa.org.uk/road/congress2000/proceedings/janssen.pdf**

On strategic programs and action plans

- *Every accident is too many, Road safety starts with you – Towards new objectives 2001-2012*, Danish Ministry of Transport, 2000.
- *National road safety action plan 2001 and 2002*. Australian Transport Council Publication. **http://www.dotrs.gov.au/atc/ACTIONPLAN.PDF**
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- *Road safety in Africa, methodological guide – feedback from experience 1994 – 2001*, ISTED Publication.
- *Keep death off your roads*, PIARC/GRSP Publication.
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CHAPTER 3

Road safety factors

Michel Labrousse

CHAPTER 3

Road safety factors

LIST OF FIGURES

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FOREWORD

As described in Chapter 2, road safety problems need to be addressed through the implementation of integrated actions that take into account each of the main components of the road safety system (human-environment-vehicle). In order to propose efficient actions, it is first necessary to understand why accidents occur. As background information to the diagnostic methods that are described in the second part of this manual, the first section of this chapter contains a brief description of the road safety system and then describes, in more detail, various analytical methods that have been proposed over the years to better understand the mechanisms leading to accident occurrence ***(Section 3.1)***.

Given that this manual is intended mainly for road engineers, a greater emphasis is placed in this chapter on the description of the "road environment" component of this system, and particularly on the presentation of three fundamental principles that are prerequisite to safer roads ***(Section 3.2)***. However, it should remain clear that these principles cannot be considered independently from the other two components of the system - human and vehicle.

Finally, ***Section 3.3*** provides a broad introduction to methods that can be used by road engineers to detect safety deficiencies (this topic is then discussed in more detail in ***Chapter 5*** of the manual).

3.1 HUMAN-ENVIRONMENT-VEHICLE SYSTEM

The following example illustrates how the various components of the human-environment-vehicle system may all contribute to the same accident (Table 3-1).

Example: A 20-year old man with little driving experience, is taking an unfamiliar road on his way to an important appointment. The rain makes the road slippery and his tires are not in good condition. During the trip, he enters a curve with a radius of curvature below minimum standards, loses control and runs off the road into a tree at the roadside.

Table 3-1 Representation of events and circumstances

SYSTEM COMPONENTS	EVENT	CIRCUMSTANCE
human	trip	young, inexperienced, stressed
vehicle	choice of vehicle	tires in poor condition
environment	rain	wet and slippery surface
environment	curve	below standard
human	steering manoeuvre	oversteering
human	loss of control	unstabilized (gravel) shoulder
environment	roadside conditions	tree
	IMPACT = ACCIDENT	

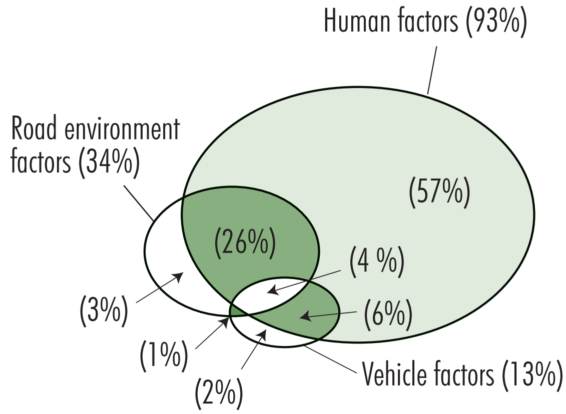
This example illustrates the following principles:

- each accident is the result of a succession of events occurring under precise circumstances;
- each event can be related to one of the components of the road safety system;
- an adverse conjunction of events is the explanatory cause of the malfunction;
- each separate event is largely determined by preceding events and their circumstances.

The human-environment-vehicle (HEV) system thus provides a conceptual framework for analyzing the accident in order to identify the factors on which to take action.

Several research papers have shown the predominant role of the "human" component in accidents. However, the fact that human factors are involved in most accidents does not mean that only this component of the system must be treated. Behavioral changes are very slow and progressive. In comparison, road environments can be quickly modified with immediate results. The Venn diagram in Figure 3-1 shows that significant safety benefits can be induced by working at the human-road-environment interface.

Figure 3-1 Accident contributing factors



Source: Treat et al., 1979

3.1.1 ELEMENTARY SYSTEM (HEV)

The HEV system may be represented by the Haddon matrix, which combines the three components of the system and the three phases of an accident (before, during, after):

Table 3-2 Haddon matrix - List of accident contributing factors

SYSTEM	BEFORE THE ACCIDENT	DURING THE ACCIDENT	AFTER THE ACCIDENT
HUMAN	physical condition - fatigue, illness, medication, alcohol - handicaps: sight, hearing, etc. physiological condition - stress, inattention, distraction, attitude socio-demographic profile - age, sex, professional occupation, level of education experience and skill - driving experience, knowledge of vehicle and itinerary, knowledge of regulations action - manœuvres before collision self-protection - seatbelt, helmet	physical condition - reflex error - poor mental image of the road - poor evaluation of distances and speeds - inappropriate manoeuvres action - speed - braking - positioning - warning	physical condition - resistance to impact physiological condition - emotional shock experience and skill - safety first - protection of accident-scene - raising the alarm action - manoeuvres after collision
VEHICLE	physical factors - type and make, colour, horsepower mechanical condition - brakes, tires, suspension, lights, etc. damage - external, internal running state - objects, position of passengers - obstructive luggage	activation of passive safety - resistance to deformation - airbag - mayday	handling of damaged vehicles
ROAD ENVIRONMENT	geometry - vertical alignment, cross-section horizontal alignment surface characteristics - skid resistance, roughness - debris, contamination surroundings - urban, rural - advertising, shops - traffic volumes - main users equipment - signs, markings, etc.	recovery area: - shoulders, emergency lane - central refuge roadside conditions critical zone: - transition zone - workzones, unusual surroundings defect - maintenance - obstacle on roadway	accident warning cleaning up the road

3.1.2 ACCIDENT ANALYSIS

An accident is a disruption of the balance among the three components of the human-environment-vehicle system.

Research

Research on road accidents has led to the progressive development of a theoretical and methodological framework for analyzing accidents (Organisation for Economic Co-operation and Development, 1984).

Accidents are random events with multiple causes, that are partly of a deterministic nature (it is possible to act on them) and partly stochastic (uncontrollable).

Recent research takes account of the dynamic nature of transportation and accident occurrence. The resulting approach is termed a dynamic multi-causal approach.

Dynamic multi-causal approach

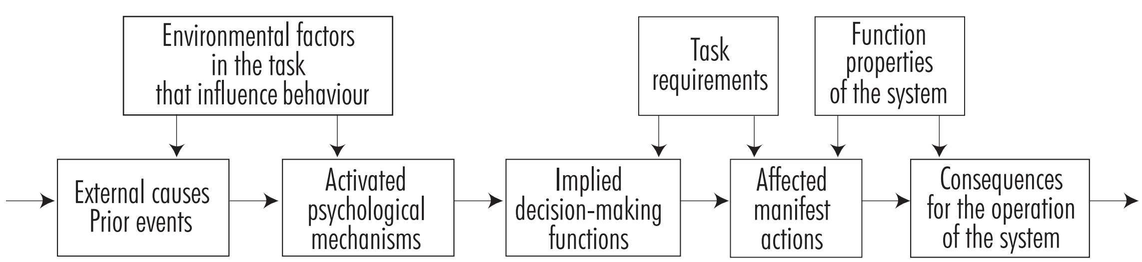
The dynamic multi-causal approach involves the development of:

- road accident models;
- tools and methods for conducting accident-reconstruction.

These methods are based mainly on the following:

- dynamic reconstructions, using tire marks, measured deformations and other material evidence after an accident;
- the application of fault-tree analysis methods to describe accident sequences. An example is shown in Figure 3-2.

Figure 3-2 Illustration of human involvement in a sequence of events



Source: Rasmussen, 1990 (in INRETS report No. 218)

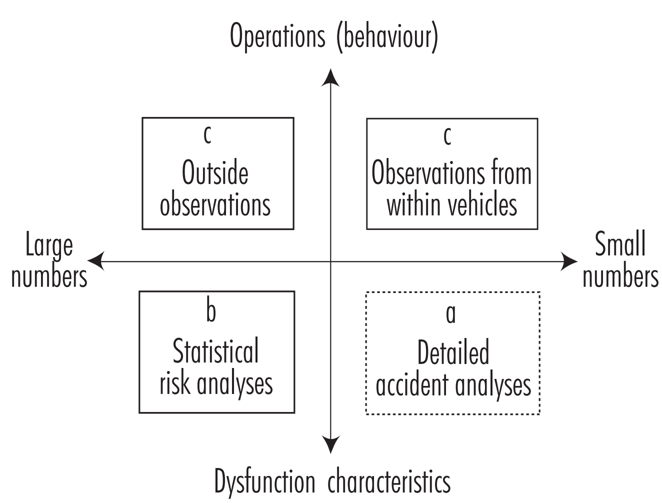
Typology of safety studies

Accident analyses (malfunctions) are not sufficient to understand the relationships in the human-environment-vehicle system. It is also necessary to analyze those situations in which the system works well.

Also, quantitative analyses (large numbers) must be differentiated from qualitative analyses (small numbers).

The following diagram (Figure 3-3) summarizes the typology and complementary nature of safety studies based on these considerations.

Figure 3-3 Complementarity of safety studies



Source: Van Elslande and Malaterre, 1996

This diagram (Figure 3-3) gives rise to the following comments:

a) with regard to detailed analyses of accidents that have occurred at a site, without losing sight that the aim is not to address these accidents but rather to extract from them information that will prevent future similar events. The basic question is to determine to what extent past accidents can accurately represent future phenomena, i.e. accidents to be prevented. The fewer the number of accidents studied, the less likely are these events to provide sufficient information on future accidents to be prevented. Consequently, on low-traffic roads, the method described under c) is primarily used. But the analysis of past accidents is always instructive and must never be neglected, even when accidents are relatively uncommon.

b) with regard to statistical risk analyses of large numbers of accidents in relation to user flows (vehicles, pedestrians).

The above comment remains valid: past accident data can only provide partial information on future accidents, and the fewer the accidents, the less information provided. This fully justifies the calculation of confidence intervals or the conducting of statistical tests, which are not just sophisticated refinements used by specialists.

A second, still more important comment is necessary here. Gross numbers of accidents and victims provide poor information on the level of safety at a site (apart from the importance of the “issues at stake” aspect), and only accident rates (accident/flow) allow the identification of hazardous sites. A large number of accidents may simply reflect a high exposure level (vehicle or pedestrian flow). For instance, there are often more accidents per kilometer of freeways than on minor rural roads even though freeways are significantly safer (in terms of number of accidents per kilometer traveled). Heavier traffic flows on freeways account for this fact.

Accident frequencies (f) result from the combination of a risk level or accident rate (f/Q) and an exposure level (Q):

$$f = \frac{f}{Q} * Q \qquad \text{[Eq. 3-1]}$$

Depending on whether an observed accident frequency can be explained by the risk level (f/Q) or by the intensity of the flows (Q), the treatment will not be the same.

- in one case (high risk level), the objective will be to reduce accident risk by modifying certain characteristics of the road environment or, in some cases, by changing the road environment itself (e.g. conversion of a conventional intersection to a roundabout);
- in another case (high traffic flows), actions will be targeted at improving traffic flow management (e.g. changing traffic priority rules and providing safer layouts for heaviest flows). The analyst should also verify whether some of the transportation demand could be reduced or transferred to safer modes.

The main objective of statistical accident analyses should therefore be to quantify risk levels, detect special risks or locally high risks, and examine accident clusters that cannot be explained by heavier flows.

Knowledge of flows (vehicles, pedestrians, etc.) and an assessment of accident rates is therefore essential.

- on rural roads, the rate is often expressed in terms of number of accidents recorded per 100 million vehicle-kilometers;
- on urban roads, other rates can also be calculated (e.g. ratio of accidents involving pedestrians crossing the road to flows of pedestrians crossing the road);
- at road intersections, various rates can be calculated by relating accidents to either the total incoming traffic or the traffic on the secondary road or by relating accident types to relevant traffic flows.

Statistical accident analyses should include validation procedures (confidence intervals, statistical tests) to assess the reliability of results.

Chapter 5 describes in further detail how to calculate ***accident rates*** and ***critical accident rates***.

c) on observations

The fact that past accident data provide only partial information on future accidents does not justify risk assessment based solely on intuitive judgment. The use of objective information resulting from large scale studies and research, rather than purely local data, must be encouraged.

Such studies can show that under certain combinations of road environments and road usages, one given type of road layout will generally be safe while another may be much less safe. They can also show that, at a given type of site, accidents occur according to a specific mechanism.

When analyzing a site to assess its safety level, an analyst must make use of the knowledge accumulated during previous studies conducted at similar sites. This should complete the analysis, especially when accident data are unavailable or very scarce, i.e. on low-traffic roads or new roads ***(problems at similar sites)***.

To sum up, road safety analyses are based on two sources of informations observations and accidents, and combine quantitative and qualitative analyses. An example of analysis methodology follows.

Sequential accident analysis

This type of analysis breaks down the course of an accident into an **initial disruption** caused by one of the parties involved (accident situation with a sudden change to a highly degraded situation), followed by a **second disruption** consisting of the impact (Table 3-3).

Brenac (1997) proposes a simple method for comparing various reports and material evidence that may be available during an accident analysis. The method is summarized in Table 3-4.

Table 3-3 Disruptions and accident sequence

DISRUPTION	ACCIDENT SEQUENCE
Initial disruption	Driving situation Accident situation
Second disruption	Emergency situation Impact situation

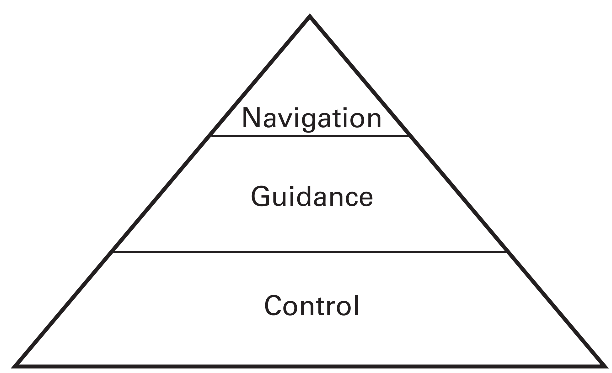
Source: Brenac, 1997

Human factors

Road safety analyses require that certain essential concepts of the driving task and the mechanisms that generate human error in driving be known. The description that follows is based on Lunenfeld and Alexander, 1990.

The driver's task can be described by a superposition of three levels of execution: control, guidance and navigation (Figure 3-4). The quantity of complex information that must be managed by the driver increases from control to navigation whereas the safety impact of each level decreases from navigation to control.

Figure 3-4 Driving task



Source: Lunenfeld and Alexander, 1990

Table 3-4 Sequential analysis of road accidents

1. Examine the entire report, paying special attention to statements of the parties involved and witnesses, pattern of events, photos.

For a statement to be used, it must have some credibility, but conversely, not everything that is not meaningful at the outset must be rejected, on the assumption that the statement is unreliable. For instance, it is possible that a driver does not perceive an object that is located in the person's field of vision and perfectly visible (due to sensory or psychological factors).

ANALYSIS OF THE COURSE OF THE ACCIDENT

2. Determine the event that constitutes the accident situation (initial disruption)

To identify the constituant elements of the disruption, one must try to answer the following question: If the accident was to be seen from an airplane, from what time and what event or conjunction of events can it be said that the situation becomes seriously degraded?

3. Describe the events that occurred throughout the course of the accident and situate them in each accident phase:

Driving situation	*What was the driver (or pedestrian) doing before the accident?*
Accident situation	*The testimony of all involved parties should be reconciled and reflect the accident in its entirety.*
Emergency situation	*Has one of the parties performed a manoeuvre and, if so, which one?*
Impact situation	*How did the impact occur?*

4. Try to throw some light on the facts reconstructed in each phase, stating what worked or failed in the human–environment–vehicle system

e.g. X stalled, X thought he had time to…, X did not see…

5. Complete an analysis sheet to record this description of the course of the accident

INVESTIGATING ACCIDENT-PRONE FACTORS

6. Look for accident-prone factors and severity factors and complete a descriptive sheet accordingly.

*An **accident-prone factor** is a state of a component of the human–environment–vehicle system that was necessary (but not in itself sufficient) for the accident to occur and on which it would be possible to take action.*

*A **severity factor** has no influence on the origins of the accident but contributes to the severity of the impact.*

WHERE APPROPRIATE, CONDUCT SITE OBSERVATIONS AND REVIEW THE ANALYSIS

7. Where appropriate, make observations or recordings at the site.

It is important not to make these observations and measurements before completion of the previous steps. The aim is to draw lessons from the accident under study and not to reveal all potential deficiencies of the site, many of which are irrelevant to the case under study. If site observations are conducted first, analysts might detect non-standard road features and then be tempted to refer to the report in order to justify their correction (rather than searching for the true causes of the accident under study).

Control includes all interface activities between the driver and his vehicle (actions on the controls, reading displays) that greatly depend on the type and model of vehicle (e.g. light vehicle with automatic transmission and power steering / heavy tractor with manual transmission). The information managed by the driver comes from his sensations from the vehicle, his instrument panel and the sensory perception of the road. The driver constantly adjusts his control but the tasks are mainly memorized and executed automatically.

Guidance combines the activities that allow the driver to manage at any time his speed and direction in relation to the road and other road users. These activities mobilize judgment, estimation and anticipation in a dynamic way as is the road environment.

Navigation combines the preparation of the trip (reading and remembering the road map, for example) and management of the trip (determining location according to the geography viewed and reading the direction signs). These are activities of a cognitive and mental nature.

A properly performed and effective driving task therefore requires the compilation and processing of all these activities. As explained by the *Users' guide to Positive guidance (Lunenfeld and Alexander, 1990)*, the driving task must take into consideration the physiological and mental capabilities and limitations of the driver:

- sensory perception, principally vision: visual acuity, visual field;
- timely reaction, which is the result of the information-decision-action process;
- memory;
- anticipation according to the driver's mental representation of the route and the situation to be managed;
- the ability to properly prioritize tasks.

The choice of road layouts and surrounding conditions (tree plantings, signs, roadside developments) strongly influence the mental representation that drivers make of a road. The *Positive guidance* distinguishes the a priori expectations (resulting from habit and experience learned over time) and the specific expectations (resulting from recent driving experience - during the trip).

If the road has characteristics that differ from those resulting from the mental representation, the driving task is maladapted and becomes a potential cause of human error.

Human error

There is no universal model that can reflect with total precision how errors are produced (Leplat 1985). As indicated by numerous authors (De Keyser 1989; Cellier 1990; Reason 1993; Neboit 1996), the models for analyzing and classifying errors have evolved according to different research trends. These can be described in four groups of error representation:

The error as resource overflow: an error occurs when the person's information processing system is saturated, resulting from decline in vigilance, alteration of functional capacities or, more generally, an imbalance between the requirements of the task and the resources available to perform it (Neboit 1996).

Example:

- Loss of vigilance from fatigue, habituation, stress.

Error as defect in elementary tasks: the error is committed in one of the control, guidance or navigation tasks, according to the above description of the driving task.

Examples include:

- inability to maintain the vehicle's trajectory;
- poor coordination of simultaneous tasks;
- poor appreciation of distances;
- misunderstanding of the road environment.

Error as a fault in a step of reasoning: this approach (Newell and Simon, 1972) insists on the breakdown of the reasoning steps made when seeking to solve a problem. One could compare the human to a computer processing symbolic information. The error would correspond to a fault in a certain step in the reasoning that did not respect the programming logic that would allow the problem solution to be reached.

Example: processing an unexpected event on a habitual route.

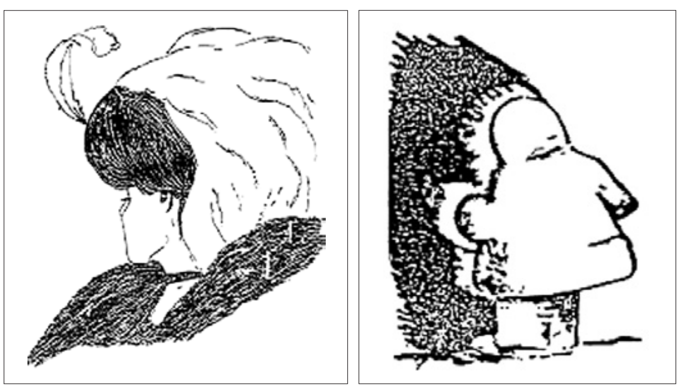
Error as a distortion between representation and the real world: this approach refers to recent work that describes human operation from the perspective of knowledge structures processes that allow the individual to represent to himself the situations he faces. The processing of a given situation will result from a confrontation between these representations and the data emanating from the situation. The error will be interpreted as a gap between the representation made and the reality it is supposed to represent (Figure 3-5).

Some work has used this approach to propose to practitioners a new way of preparing road projects: how to suggest to the user, through urban planning and road landscaping, a mental representation that complies with reality.

Summary

The analysis methods outlined above can be summarized by a standard error scenario, as illustrated in the following example (Figure 3-6):

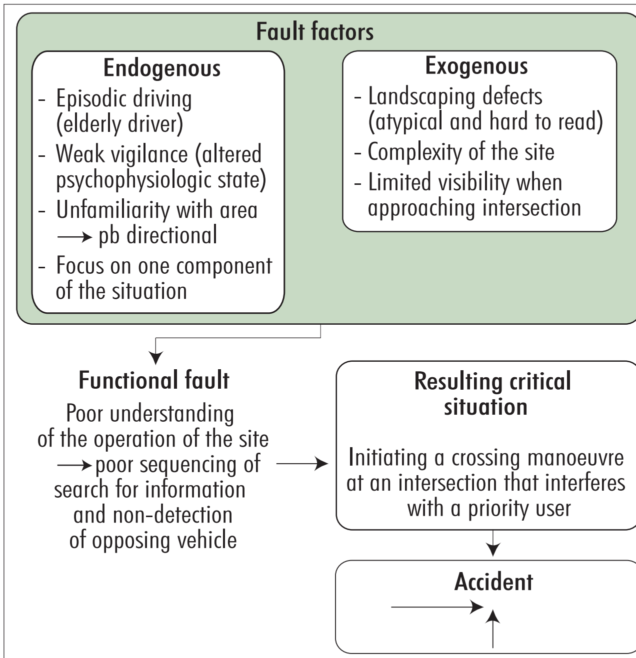
Figure 3-5 Different representations of the same reality



As with these images (left: young or old woman; right: Indian or Inuit?), complex or unexpected road designs can produce totally opposed interpretations or behaviour to users.

Source: Artaud and Julien, 1999

Figure 3-6 Example - Detailed accident analysis



3.2 IN PRACTICE: THREE PRINCIPLES

Road safety requirements cannot be expressed in a simple form. They must take into account both factors contributing to proper functioning and conclusions to be drawn from system malfunctions.

The main responsibility of road authorities is to take action on the "road environment" component. However, by looking at Figure 3-1, one easily comes to the conclusion that the proper consideration of the human-road environment interaction is of prime importance. This can be described as "road ergonomics". Also a concern are the road-vehicle interactions that focus on the adequacy of geometric characteristics for the dynamic performance of vehicles and human driving ergonomics.

In the years ahead, the new technologies - Intelligent Transportation System (I.T.S.) - will considerably modify interactions between the vehicle and the other two components of the system. It is now too soon to address this aspect but the principles that are described below will remain valid.

In order to allow safe traffic operation, road engineering must respect three basic principles:

The **QUALITY** principle: fully meeting five basic requirements

- visibility;
- self-explaining road design;
- adequacy of the infrastructure for dynamic vehicle stresses;
- avoidance and recovery possibilities;
- limitation of impact severity.

The principle of **CONSISTENCY** over **SPACE:**

- full consistency of all the elements of the road with its environment;
- road feature consistency along a route.

The principle of **CONSISTENCY** over **TIME**: planning road layouts

3.2.1 QUALITY PRINCIPLE

Five basic requirements must be satisfied:

Visibility

It is estimated that about 90% of the information used in driving is visual. As a basic requirement, one should therefore ensure that the quality of the visual information contained in the road environment contributes to facilitating the driving task.

Does visual information reach road users in time, hence allowing them to safely adapt their behaviour to the encountered situation (based on operating speeds)? Can pedestrians and other road users who want to cross the road see far enough to have time to process the information, decide when to cross and safely complete their manoeuvre?

In France, the recommended intersection sight distance is 8 seconds (with 6 seconds the absolute minimum) at the V_{85}[1] traveling speed on the main road. On 3-lane roads or divided dual two-lane roads, these values are increased to 9 and 7 seconds respectively (Service d'Études Techniques des Routes et Autoroutes, 1994).

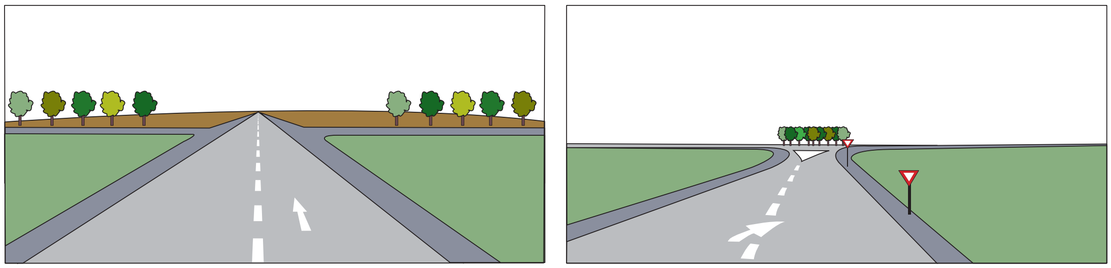
For more details, see the ***Sight distance*** technical sheet.

[1] V_{85}: Speed at or below which 85% vehicles travel.

Self-explaining roads

Can the infrastructure and its environment be easily understood so that road users can quickly identify where they are, determine which direction they must follow and easily anticipate events with which they may be confronted - vehicle and pedestrian movements, infrastructure changes, etc. - in order to adjust their behaviour accordingly (Figure 3-7)?

Figure 3-7 Example – Self-explaining roads through landscaping



Landscaping that helps to stimulate the driver's attention and facilitate understanding of the road alignment:

On the left: improving the visibility of a secondary road by means of a row of trees

On the right: emphasizing a road ending by a tree screen

Source: Service d'Études Techniques des Routes et Autoroutes, 1998

For more details, see the ***Human factors*** technical sheet.

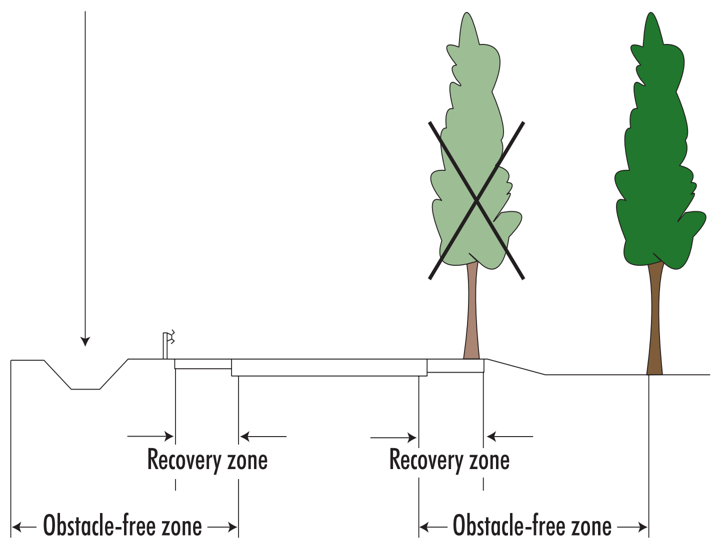
Adequacy of the infrastructure for dynamic vehicle stresses

Are road features adequate to minimize the risk of dynamic failures - skidding, overturning, etc. - based on operating speed?

Examples:

- sudden change in horizontal curve radius;
- degraded friction at intersection;
- road hump in road environments conducive to high speed (e.g. a major rural road);
- slippery road markings that are liable to destabilize two-wheeled vehicles.

Figure 3-8 Recovery zone and safety zone



Source: Service d'Études Techniques des Routes et Autoroutes, 1994

Avoidance and recovery possibilities

Are the infrastructure characteristics forgiving - i.e. do they allow evasive manoeuvres or recovery to be completed in critical situations (or is an accident likely to happen under such conditions)? (Figures 3-8 and 3-9)

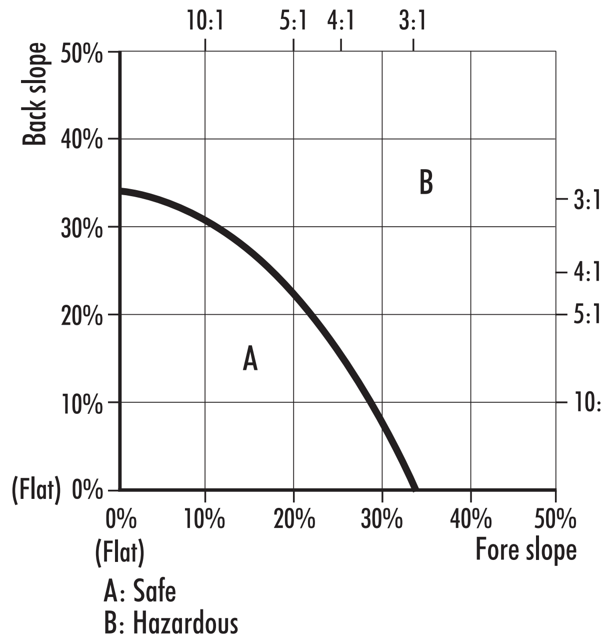
Limitation of impact severity

Are roadside obstacles few enough and far enough from the road so as not to aggravate the consequences of accidents? When this requirement cannot be satisfied, are rigid roadside objects shielded (e.g. guardrails) or made frangible?

Are roadside slopes (ditches, dikes, etc.) slight enough to prevent vehicles from crashing or overturning?

Is the likely impact speed, which largely depends on the speed before the ***accident situation***, slow enough (particularly in the case of a collision with a pedestrian or a two-wheeled vehicle)?

Figure 3-9 Example - Aggressiveness of fore slope and back slope



Source: Guide for Selecting, Locating and Designing Traffic Barriers, Copyright 1977, by the American Association of State Highway and Transportation Officials, Washington, D.C. Used by permission.

3.2.2 CONSISTENCY OVER SPACE PRINCIPLE

This consistency criterion cannot be considered independently. For instance, it must take into consideration road user speeds, which are partly conditioned by the “self-explaining road design” criterion. This leads to a two-fold consistency requirement.

Full consistency of all the elements of the road with its environment

Examples of hazardous situations:

- roads having characteristics that encourage high speeds, e.g. divided roads, at-grade intersections, but that retain critical points, e.g. private access, narrow shoulders, rigid obstacles nearby, etc.;
- residential streets having characteristics that are not adapted to the presence of pedestrians and other non-motorized road users (grid road network, straight road alignments, wide traffic lanes, etc.).

Consistency throughout the route

To safely adapt their driving behaviour, road users must understand on which type of road they are traveling and foresee upcoming situations. This requires the establishment of a sound system of road categorization in which each road category is characterized by a consistent set of features (Table 3-5):

- a proper standardization of road categories helps road users to recognize the level of service provided;
- a homogeneous treatment of each road of a given category improves safety;
- when constant road features cannot be provided along a route, transitions from one road type to another must be clearly signaled.

Table 3-5 Traffic volumes and access types on different road categories (France)

	ROAD TYPE	TRAFFIC VOLUME	ACCESS TYPES
MAIN ROADS	Divided highway: freeways	Intense	- new road - grade separated crossings - accesses are controlled - no town crossing
	Undivided highway: main rural roads	Moderate or low	
OTHER ROADS	Divided highway: inter-urban arteries	Intense	- existing roads - level crossings - accesses are possible - possible town crossings
	Two-lane: secondary roads	Moderate or low	

3.2.3 CONSISTENCY OVER TIME PRINCIPLE

Road safety is strongly influenced by planned and unplanned changes in traffic flows and patterns (Figure 3-10). Planned changes are generally developed through various stages of road studies that typically break down into three phases: preliminary studies, outline draft projects and detailed designs. Road safety must be properly considered at each of these phases.

Preliminary study

- consistency throughout the route;
- definition of staged improvements in relation to flows.

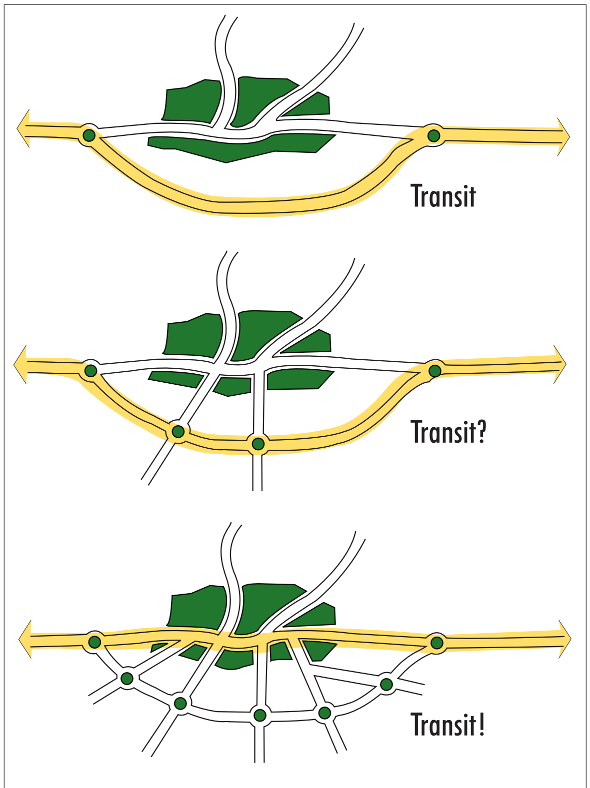
Outline draft project

- road layout and main characteristics (e.g. choice of intersection type, width, etc.).

Detailed design

- safety equipment, sign;
- treatment of critical points.

Figure 3-10 Progressive deterioration of a transit road



Source: Artaud and Julien, 1999

3.3 ROAD SAFETY ENGINEERING

Road safety engineering can be defined as all the investigative methods and measures that may be taken to improve the safety level of the road infrastructure. A summary of possible actions has been presented in ***Table 2-3***.

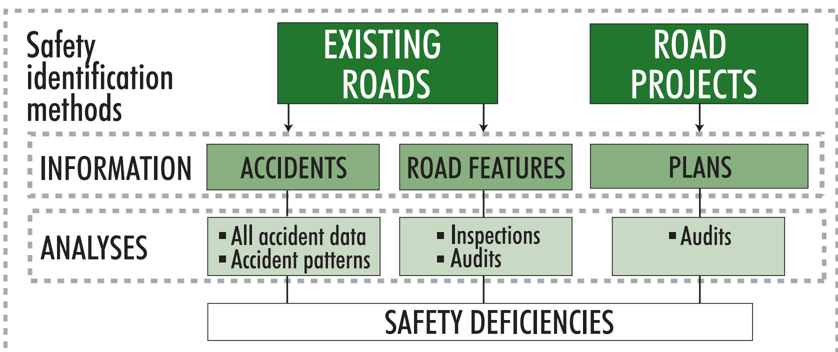
This section focuses on the description of basic methods that can be used to detect road related safety problems. Some of these aspects are further described in ***Chapter 5*** and hyperlinks are provided where appropriate.

3.3.1 HOW TO DETECT DANGEROUS SITES

Safety action plans should include the implementation of a hazardous-site improvement program, which is described in ***Part 2*** of this manual.

The first difficulty encountered in implementing such a program is of a methodological nature. It consists in knowing how to identify dangerous sites. Objective identification methods that may be used by road administrations are summarized in the following diagram, extracted from ***(Figure 5-9)***:

Figure 3-11 Identification methods



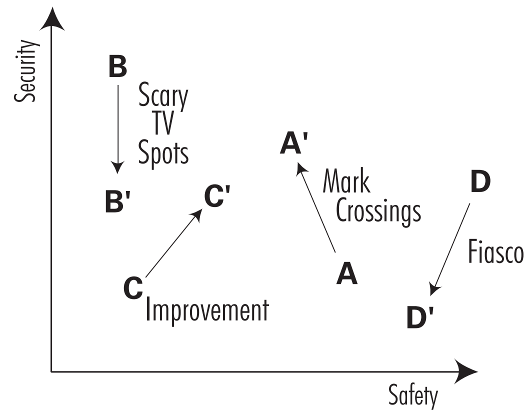
Objective and subjective safety

Social demand for road safety improvements can be expressed in four different ways, based on the nature of the hazard considered:

- proven hazard: (objective safety) — measured objectively, based on accident statistics;
- potential hazard: (objective safety) — scientifically assessed by measuring accident risk in relation to road characteristics and traffic levels;
- experienced hazard: (subjective safety) — expressed subjectively by users, most often with a major deviation from proven or potential hazard;
- intolerable hazard: (subjective safety) — types of accidents that are considered intolerable by society, even: e.g. accidents involving children, a vehicle crossing a freeway median.

There may be significant gaps between objective safety and subjective safety (also called "security" (Figure 3-12). For example, Hauer (1997) explains that while marked crossings are perceived by road users as a safety improvement, they have been shown to be detrimental to safety (based on Herms, 1972).

Figure 3-12 Objective and subjective safety



Source: Hauer, 1997

Treatment of *proven hazards* and *potential hazards* (objective safety) uses the following scientific, rational methods:

- accident data collection and processing ***(Chapter 4)***;
- objective identification methods:
  - based on accident data ***(Section 5.3)***;
  - based on observations (***Section 3.3.2*** and ***Section 5.4***).

Treatment of *experienced hazard* or *intolerable hazard* (subjective safety) should be based on communication and information, in order to explain to road users and residents the consequences of actions they may have suggested. The following actions should be taken:

- provide objective figures on accidents or risk and compare them with other situations;
- explain advantages and disadvantages of solutions spontaneously suggested by users.

Safety indicators

Various types of safety indicators may be used to detect and classify road hazards ***(Chapter 5)***. These indicators include:

Accident frequency indicator, which enables a road site to be identified when its accident number is abnormally high in relation to an established threshold value. For instance, a road section with a frequency of three accidents per km per year in a rural area may be considered hazardous if the equivalent mean accident frequency on the network is one. The "black spot" method is usually derived from this method. For example, in France, an area is defined as a black spot if more than ten serious accidents have occurred in five years over a distance of less than 850m.

Accident rate indicator, which enables a site to be identified when its accident frequency is abnormally high in relation to its traffic. The accident rate is the ratio of accident frequency over traffic volume and it reflects exposure to risk. It is calculated using the following equation[2] ***(Accident rate)***:

$$\text{acc. rate} = \frac{\text{Accident frequency} * 10^8}{365 * \text{AADT} * \text{road section length}} \quad \text{[Eq. 3-2]}$$

E.g. a major rural road can be considered abnormally dangerous if its accident rate is two times higher than the average rate for this type of road.

Accident typology indicator, which enables an abnormally high accident typology to be identified in relation to a reference indicator. For instance, a horizontal curve may be considered abnormally dangerous if the number of wet surface accidents is two or three times higher than the mean frequency of this type of accident on the road network ***(accident patterns)***.

[2] In Chapter 5, accident rates are calculated using a 10^6 (instead of 10^8) multiplying factor on the numerator. This is because ***Chapter 5*** assumes that property damage only accidents are available, while here it is assumed that only injury accidents are available. The value of this multiplying factor is chosen to facilitate the reading of resulting accident rate values.

3.3.2 ROAD SAFETY AUDITS

Preventive actions draw on knowledge gained from previous safety analyses to implement remedial measures at sites that have similarities with those where accidents have accumulated in the past (an abnormal accident occurrence is not necessarily required at theses sites to justify a safety action). Preventive actions are necessary although they may not be as cost effective as remedial actions taken at blackspots. They are necessary because they meet a social requirement and also because they are mandatory by law in many countries.

Some people may question the economic justification of preventive measures on existing roads, based on the fact that budgets are rarely sufficient to enable the treatment of all sites where accidents accumulate. However, recent advances in the field of road safety audits have increased the rationality of preventive actions.

A safety audit is a systematic procedure for the examination of a road project (in its various stages of development) or an existing road by a qualified technical authority (auditor alone or in a team), independent of the designer and the managers, in order to detect any defects liable to result in an accident or increase accident severity.

Safety audits are conducted in many countries, in various contexts - urban and rural - and at different project stages:

- feasibility study: choice of road type, intersection type, etc.;
- preliminary design: choice of alignment and details on the preliminary studies;
- detailed design;
- before opening the road;
- after opening the road;
- existing roads.

While most road designers seek to improve safety, experience has shown that safety problems sometimes occur shortly after a road opening. Among the many reasons put forward are the lack of standards or their inadequacies, the difficulty in gaining access to the most recent knowledge on road accident research, or the difficulty in updating standards quickly. Audits are consequently complementary instruments to existing standards.

An audit must be conducted according to a very formal procedure in which the roles of every party involved are clearly specified. The client financing the audit must state in writing what the audit is to cover.

The auditor or the audit team submits a report, the present form of which varies according to the country. This report:

- may be based on standard checklists or may be suited to the needs of a specific project;
- may simply answer a list of questions or it may contain recommendations or even suggestions for solutions;

A report prepared by PIARC road safety experts identifies a number of points that will need to be clarified in the coming years (Herrsted, 1999):

- concept of auditor independence;
- qualification process for auditors;
- evaluation of audits: cost/benefit comparison;
- audit regulations and legal consequences;
- possibility of a universal checklist;
- development of an audit database to improve knowledge of defects;
- development of an audit procedure in emerging countries.

3.4 CONCLUSION

In the elementary human-environment-vehicle system, human factors contribute to almost all accidents while road environment factors contribute to about one third of accidents This observation must not lead to the hasty conclusion that the road is safe two times out of three. In fact, a road user error or hazardous behaviour may sometimes be strongly encouraged by the features of the road environment. For instance, an accident due to speeding may simply be attributable to behaviour (liking for speed) but it may also in many cases be attributable to the presence of road characteristics that are conducive to high speeds.

A 20% reduction in road accidents can generally be expected from road improvements. In comparison, actions aimed at modifying behaviour are likely to improve safety by 30% to 40%. However, one big advantage of measures taken at the infrastructure level is their long-lasting effectiveness.

The development of effective safety treatments requires very good knowledge of the accident mechanisms and, more particularly, a good understanding of hazardous traffic features. Expertise and experience, which allow the development of sound engineering judgment, are key elements in road safety engineering (road safety is often achieved from details).

Two levels of road infrastructure improvements, with differing budgetary impacts, can be identified:

- **network modernization:** development of new infrastructures that are safer in design (application of recent design standards, safety audits, etc.). This requires substantial investments;
- **improvement of the existing network through safety studies** conducted at hazardous sites. Remedial measures are local in this case, such as improvement of an intersection, correction of a horizontal curve, removal of a roadside obstacle, etc. Investment requirements are less significant. But if they are to be fully effective, they must sometimes be supplemented or accompanied by measures applied elsewhere on the treated road (to prevent ***accident migration***). This type of action is highly effective ***(Chapter 7)***.

In summary, to be really effective, road managers should implement a logical, continuous series of tasks, as described in the following Table 3-6.

Table 3-6 Safety improvement process

	TASKS	RELEVANT MEASURES FACTORS ENABLING EFFECTIVE ACTION
KNOWLEDGE OF ELEMENTARY FACTORS	- Data collection and management (accidents, traffic, road features)	- accidents: location, circumstances, profile of victims - traffic levels per user category, according to period and trip purpose - road features
	- Observation of road users' behaviour	- speed measurements - police statistics on offences - traffic cameras
	- Monitoring of road characteristics and users	- measurements of road surface roughness and skid resistance - surveys on users and local residents - city planning processes
SAFETY DIAGNOSES	- Quantitative analysis	- statistics: accident indicators and rates - comparison with reference values - blackspot detection
	- Qualitative analysis	- detailed accident analyses - sequential accident analyses - safety audits
IMPROVEMENT STUDIES	- Planning	- road network typology - development of a road categorization system - coordination of transportation planning and urban planning
	- Specific preventive/remedial improvements	- modification of elements on which the road manager can act: - geometric characteristics - safety facilities - traffic flow management: - road signs, information
EVALUATION	- Ex-ante evaluation	- evaluation of the existing situation and establishment of the safety objective for the future project (acceptable risk, targeted risk)
	- Ex-post evaluation	- monitoring of the situation at road opening: - upon opening the road: detection of defects - after opening the road (at least one year later) checking the anticipated objectives, interpreting discrepancies

Each of these elements is described in further detail in the second part of the manual.

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PART 2

Analysis process

CHAPTER 4
Data

Peter Vasi

CHAPTER 4

Data

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INTRODUCTION

Road accidents are rare events with extreme outcomes that statistically represent a small proportion of real-life interactions between drivers and the road environment or between drivers themselves. Even though accidents are rare, all information that can be derived from such events is of great value to road safety engineers when tracing the possible causes of an accident. Accident data thus are a crucial element of a safety diagnosis. This chapter describes the various ways of collecting accident data ***(Section 4.1)***.

In addition to accident data, there are other pieces of information that help road safety engineers reveal the hidden relationships between the contributing factors (roadway data, traffic data, etc.). The contents of these files and the need to establish links between them are described in ***Sections 4.2*** and ***4.3***.

Finally, some advanced data collection technologies are discussed in ***Section 4.4***.

4.1 ACCIDENT DATA

A road network must satisfy the mobility needs of people and goods while satisfying a number of requirements that have been established by the collectivity: minimize accident risks and environmental impacts, respect budgetary constraints, stimulate economic development, etc.

Continuous monitoring of a road network from a safety perspective is required to ensure it meets society's demands. Although a variety of methods are available to detect safety problems - such as ***traffic conflicts*** and ***driving task analysis*** - the occurrence of real-life road accidents remains the number one indicator of a network's deficiencies. Experience gained from the analysis of such accidents is also the most useful key to solving these problems.

The types of accidents on which efforts should be focused or the sections of a network requiring immediate remedial actions need to be determined. With systematic monitoring, the formation of "black spots" can be observed so that the location and time of future problems can be anticipated. This knowledge greatly facilitates budget planning and should have a strong impact on strategic elements, such as the determination of the ***main accident reduction target*** and the development of the ***road safety action plan target***. An efficient road safety program must be based on these data since realistic targets can only be established by using accident-related information. Some fine-tuning will also be required at local levels, where politicians and civil organizations may have their own goals. They may, for example, want to focus on the safety of a particular district or road user age group in their community.

In order to conduct these various safety studies, in addition to accident data, data are also required on:

- the road environment;
- the traffic characteristics;
- the people involved;
- the vehicles involved;
- the result and duration of hospital treatment;
- the contributing factors.

All this information can be retrieved from:

- the accident data file,
  where information about the accident is stored;
- the roadway data file,
  where the characteristics of the accident site can be found;
- the traffic data file,
  where information on the traffic flow is kept (volumes, manoeuvres, vehicle classification);
- the hospital file,
  where description of the injuries and the outcome of the accident are more accurate than police estimations;
- the vehicle registration file,
  where records are kept on every vehicle with a registration number;
- the driver file,
  where everyone with a driving license has a record.

4.1.1 DATA USERS

Information on road accidents is extremely valuable:

- for traffic engineers:
  who then have the technical tools required to eliminate hazardous situations on existing roads and to prevent such problems on future roads;
- for police forces:
  who can use the data for planning their actions, and focusing on hazardous locations and traffic situations;
- for researchers:
  who use the data in carrying out preventive investigation studies, making recommendations for improving the situation in similar locations elsewhere in the network or introducing restrictive measures for a particular group of road users (for example, graduated driver licencing for young people);
- for policy-makers:
  who set accident reduction targets and develop ***road safety action plans*** at the national, regional, and local levels based on the findings of safety analyses;
- for prosecutors:
  who can use the data on the circumstances of the accident, eyewitness statements, police accident reports and evidence provided by the parties involved;
- for insurance companies:
  who set their insurance rates and premiums based on driving records, types of vehicle, safety devices used and risks entailed by a particular road network;
- for vehicle manufacturers:
  who may use these data to develop safer cars.

There are other user groups at both the national and local levels that occasionally or frequently use road accident information. These groups, including politicians, decision-makers, civilian agencies, education boards and the press, keep the public aware of risks and the need for actions.

In view of the wide range of user groups, it is advisable that the data collection be initiated and regulated at the government level. This certainly requires an expenditure of effort and money, while it is often the various user groups that enjoy the benefits and take advantage of such a comprehensive information system. This contradiction is difficult to overcome. However, all governments must recognize the importance of data collection and should expend all necessary efforts to establish a sound accident information system.

4.1.2 ACCIDENT REPORT

The police are the ideal data collectors, since they are the first people called to the accident scene. Since the work of many organizations relies on the efficiency of their data-collecting activity, it is essential that police forces recognize and assume their responsibilities with respect to accident data.

Data collection begins with the completion of a road accident report form. This is a pre-printed standardized form on which the needed information can be recorded either in narrative form or on a checklist. In addition, all documents associated with the accident, such as eyewitness statements, photographs and sketch diagrams of the scene are attached to the report. An easy-to-use, well-designed form is a pre-requisite to a consistent data-collection system. The accident report form should be the only data document required and be used nationwide, thereby avoiding duplication and other possible errors.

Nearly all patrolling police officers complete road accident report forms at least occasionally, and their ability to do so depends on their training and experience. In most cases, such training takes place at the police academy. Consistent training is essential for consistent data. It is important that the reporting officers understand and follow the reporting conventions.

Police officers tend to believe that accident data collection is done primarily for insurance purposes. Those who fail to recognize the benefits of having quality accident data often do a poor reporting job. Training sessions, in which a representative of the road authority discusses with police officers the importance of various data items and the purpose for which they are used, are a good example of harmonizing efforts.

It is equally important for the various stakeholders to communicate by:

- publishing newsletters with articles on common subjects;
- holding informal meetings and communication forums;
- providing complementary feedback to the information providers;
- setting up a reward system to recognize proper completion of report forms or data entry (even giving a token gift, such as a good quality ballpoint pen bearing the logo of the city or jurisdiction, which may then be used to complete report forms).

All these actions may strengthen the working relationship between road authorities and the police.

Once the accident report is completed, it should be checked for consistency before being microfilmed or entered into a computer. This consistency check may be performed by the computer at data entry. A thoroughly structured algorithm can highlight or even correct some of the data deficiencies (for example, the pavement surface cannot be icy in summer, or a “head-on” collision involves at least two participant vehicles, etc.). If a data item is missing or there is a contradiction between certain data items that cannot be resolved by the software or the person carrying out the consistency check, the report form should be sent back to the police officer for correction. This may cause some delay for the data to be included in statistics, but any effort that leads to a more reliable database is rewarded indirectly when a safety problem is tackled successfully as a result of an accurate analysis.

Speed and accuracy

The completion of an accident report form can also be computerized, saving time and effort.

Form readers can scan and extract data from a standardized form. Many data items can be presented as multiple-selection choices, in which the police officer simply checks off the appropriate box. When the form is scanned at the data centre, the data can be extracted and put into a database record automatically. Although many software packages have an optical character recognition (OCR) feature, it is reliable only if the text is completely legible. Additional keypunching is thus sometimes required for entering location information, drivers' and passengers' confidential data, and other narratives.

The form is designed to be fed into a form reader, which can then extract the previously coded data.

Portable computers can further improve the legibility of accident reports and reduce input errors and demands on report- processing personnel. They may, however, increase the workload of the police officer at the scene, where precious time is better used ensuring safety and minimizing delays and road closures caused by on-site investigation activities. It is therefore important to ensure that proper use is made of portable computers' interface capabilities, which may significantly reduce the time required to complete the report ***(advantages and disadvantages)***.

Computerized accident report form

Source: Sûreté du Québec

Pen-based computers (or clipboard computers) permit data entry in the old-fashioned way (pen and form), while their character or pattern recognition features convert marks made on an electronic screen table into recognizable characters, thus generating an electronic database at the same time. Customized software can be developed specifically to assist in the completion of accident report forms.

Palmtop computers are ideal for simple data collection tasks, using either a pen-based screen or a small keyboard. Palmtop computers may be very useful in police cars, where they can be mounted on the dashboard, taking up little space.

Magnetic stripe systems use the magnetic field of an encoding head to record magnetic flux reversals. All information is placed onto a magnetic material layer (magnetic stripe) similar to that used for audio and video tapes. The decoder reads the flux reversals and translates them into letters and numbers. Magnetic stripes can hold a considerable amount of data (e.g. the licence number of the vehicle identification number and some additional information can be stored on the approximately 120-byte track).

Bar codes consist of a series of black and white bars of varying thickness and patterns representing alphabetical characters or numbers. Scanning this code with a "bar code reader" can retrieve a large amount of data, hence avoiding errors that are linked to the transcription of vehicle identification numbers and driver/passenger names. Cars have bar code labels that may save officers from writing/typing all vehicle information. Obviously, the officer needs to have a bar code reader and use it on the label. Bar code labels can also be placed on registration certificates and driver's licences along with other information such as vehicle type, size, airbags, anti-lock brakes and names. Even the licence photograph can be recorded on the bar code.

Driver's licence with bar code

Source: Société d'assurance automobile du Québec.

Radio frequency modems can be used to relay digital data communication between a portable computer and a mainframe computer. A police officer may retrieve data on a vehicle or its owner within seconds by simply entering the licence plate data into a portable computer or terminal carried in the patrol car. Electronic report forms can be forwarded by modem to a data centre.

"Smart" cards are electronic cards, similar to credit cards, that store and transmit information. Smart cards could be used to store all vehicle status and operational data.

Digital cameras can produce excellent-quality pictures in digitized format, which can then be copied into a computer and easily attached to an accident database or electronic report form. Digital cameras are useful tools for an investigating police officer.

Advantages of using portable computers in data collection:

- field data entry eliminates errors caused by illegible handwritten reports;
- automated software error and logic checks improve data accuracy;
- using computers to create the original report can be significantly faster than preparing handwritten reports, provided that a proper use is made of the interface capabilities of portable computers; they can be connected to and receive data from other data collection devices such as bar code readers, magnetic stripe readers, digital cameras, GPS receivers, etc. This makes data entry much easier in the case of multi-vehicle crashes;
- a portable computer can be used for other police tasks;
- with pen-based computers, an accident diagram can be sketched directly onto a computer;
- pen-based computers require less training than ordinary computers since the process is similar to writing a report by hand.

Disadvantages of computerizing a data collection:

- officers may feel a certain aversion to using computers if they have never used them before. They may also have trouble typing on a keyboard, especially for the narrative parts;
- portable computers are cumbersome to use outside the vehicle and are easily damaged;
- electronically printed reports may not be accepted by prosecutors, who often demand handwritten reports and signatures.

4.1.3 CRITICAL AND DESIRABLE INFORMATION

A lot of information is required to satisfy every user group's needs. Potential user groups should therefore be consulted before defining the range of data to be collected. A data collection system is entirely meaningless if the data are not useful to those for whom they are intended. The potential combinations of data are infinite, but there is a minimum set of data that can be considered as critical to understanding events at the scene. This critical set of data must, at the very least, answer the following questions:

- Where did the accident happen?
  location by geographic coordinates, road/street name, distance from known point;
- When did the accident happen?
  year, month, day of month, day of week, time of day;
- Who was involved?
  people, vehicles, animals, roadside objects;
- What was the result of the collision?
  number of casualties in each category (fatalities, severe injuries, light injuries);
- What were the environmental conditions?
  weather, light and road surface conditions;
- Why or how did the collision occur?
  direction of road users, collision type, error and reason for error.

In addition to the above-mentioned set of data, additional information may be included in an accident database. Collecting a narrow range of information is economical, but it may be insufficient for research purposes. A well-organized and comprehensive system, on the other hand, may attract additional users, but is costly to maintain. Costs can, however, be shared among the users (for example, insurance companies and car manufacturers can be asked to contribute since they use the data for business purposes).

The potential contents of an accident data file are shown in Table 4-1.

Not only is the decision on the range of information to be collected indispensable, but a well-established terminology must be created including the following:

What is the definition of:

- road accident (is it a road accident if a roller skater hits a pedestrian on a footpath?);
- death, serious injury, light injury resulting from an accident (how many days must elapse between the day of the accident and the death of a participant to declare it fatal? Most countries use a 30-day period for a fatality and the need for hospitalization to distinguish serious injuries from light injuries);
- vehicle, motor vehicle (are roller skates and skateboards vehicles?);
- the difference between a motorcycle and a moped (in many countries, only vehicles with engines greater than 50 cc are classified as motorcycles, whereas those with smaller engines are considered mopeds).

Table 4-1 Accident data – Recommended information

ACCIDENT IDENTIFICATION NUMBER	LOCATION
- A unique number, which prevents accident data from being entered twice (should be combined with police station reference number).	- The exact road location where the accident occurred. It can be described by: - narratives; - X, Y coordinates of a uniform coordinate system; - highway number and kilometer post rounded off, for example, to the nearest 100 m; - distance from node; - distance from known point. ***Accident location methods***
DATE AND TIME	**COLLISION TYPE**
- The exact date (preferably with four digits for the year, two digits for the month and two digits for the day). - Although the day of the week can be computed from the date, it may be useful to have a separate data item to store this piece of information. This is especially true in the case of a non-computerized database.	- By one or some combinations of the followings: - narrative description; - sketch; - code.
VEHICLE	**VEHICLE MANOEUVRES AND SKETCH**
- For each involved vehicle: - type; - make; - year of manufacture; - vehicle identification number (VIN). - The VIN is a multi-character identification number placed either on the body of the vehicle or included on the vehicle registration certificate. Through the VIN, a number of variables, such as type, model, year of manufacture, body type, engine size, restraint system, etc., can be easily accessed in the vehicle registration file.	- The description codes of the manoeuvre of each vehicle/ participant or an accident sketch. - To be useful, this sketch must include the following information: - each vehicle's direction and manoeuvre; - vehicle identification (veh1, veh2, etc.); - reference points; - important measures; - scale.
DIRECTION OF TRAVEL	**CONTRIBUTING CIRCUMSTANCES**
- The direction of each participant, for example: - from A to B; - the direction of increasing/decreasing mileage.	- What were the environmental conditions such as: - whether (rainy, windy, foggy, etc.); - road surface conditions (icy, wet, debrid on the road, etc.); - other contributing factor.
CASUALITIES	**DRIVER / PASSENGER**
- By severity of injury for each casualty, for example: - fatal; - serious injury; - light injury. - The injury severity, determined by a police officer, is often largely subjective and does not always reflect the injury scale used by a hospital. A more accurate injury severity number can be retrieved from hospital files.	- name, sex, age; - location in the vehicle; - driving licence number; - driving experience.
RESTRAINT USE	**ALCOHOL / DRUGS**
- seat belt, helmet, children safety seat; - whether air bag (deployed or non-deployed).	- By the result of the alcohol test: - on the spot; - in the police station or hospital.
SPEED	**EXTENT OF PROPERTY DAMAGE**
- driver and eyewitness statement; - length of skid marks on the road - tachograph of the truck.	- By estimation
NARRATIVES	
- Narratives are key elements of a report form. They often complete the picture about the accident with some useful additional information that cannot be coded. It is also the most time consuming part of the process, therefore tends to be lacking. Enough space should be provided on the report form to accommodate all information that the police officer finds important.	

The following questions should be answered without any ambiguity:

- What accidents in what locations are to be reported?

  Should all accidents occurring on public highways be reported or only accidents resulting in death or injury? Should "property damage only" accidents be involved in data collection, only those exceeding a certain level of damage, or only those in which a vehicle had to be towed away from the scene ("towaway accident")?
- What procedures must be followed when collecting information and from what sources must this information be taken?

  Prosecutors may prescribe that hospital reports have to be handwritten and include a detailed description of the injury resulting from the accident, or they may insist on receiving data on road and roadside conditions as reported by police instead of being taken from a roadway inventory, etc.
- What methods and indices must be used to measure and describe the characteristics of a roadway?

  For example: IRI (International roughness index) for road surface evenness, IFI (International friction index) for road surface friction, etc.
- What method must be used to assess the injury level?

  Countries are increasingly using the so-called Abbreviated injury scale (AIS), in which a number is assigned to each type of casualty and the figures are then averaged to determine overall severity. It ranges from 0 (uninjured) to 6 (unsurvivable).

Definitions such as these can ensure the consistency of the information in a road accident file and enable users to make comparisons, since they know exactly what the various data items mean. The information also allows for international comparisons. At this level, the development of the International road traffic and accident database is worth mentioning[1] (IRTAD). It offers a framework for international comparisons of accident statistics:

- up-to-date information accessible worldwide;
- detailed and comprehensive data;
- international comparability;
- consistent time series;
- computer-assisted updating and processing of data.

4.1.4 ACCIDENT LOCATION METHODS

Inaccurate reporting of road accident locations represents one of the most pressing problems in accident studies aimed at improving road-related features. The availability of an accurate road location reference method is therefore seen as the most important element of a traffic information system.

1. Firstly, because a road authority cannot effectively tackle hazardous locations, i.e. accident blackspots, on its road network if there is any uncertainty in pinpointing accident locations. Inaccurate location of accidents may not only preclude an identification of the worst sites, which, after all, means a waste of money, but it may also make it impossible to evaluate the effectiveness of any countermeasures.
2. Secondly, because the location reference system provides the link between the various files (accidents, traffic data, roadway inventory). In order to successfully merge these files, the location reference methods used in each of them should be identical or, at the least, compatible, hence allowing the development of a location conversion file to translate one reference method to the other *(Section 4.3.1)*.

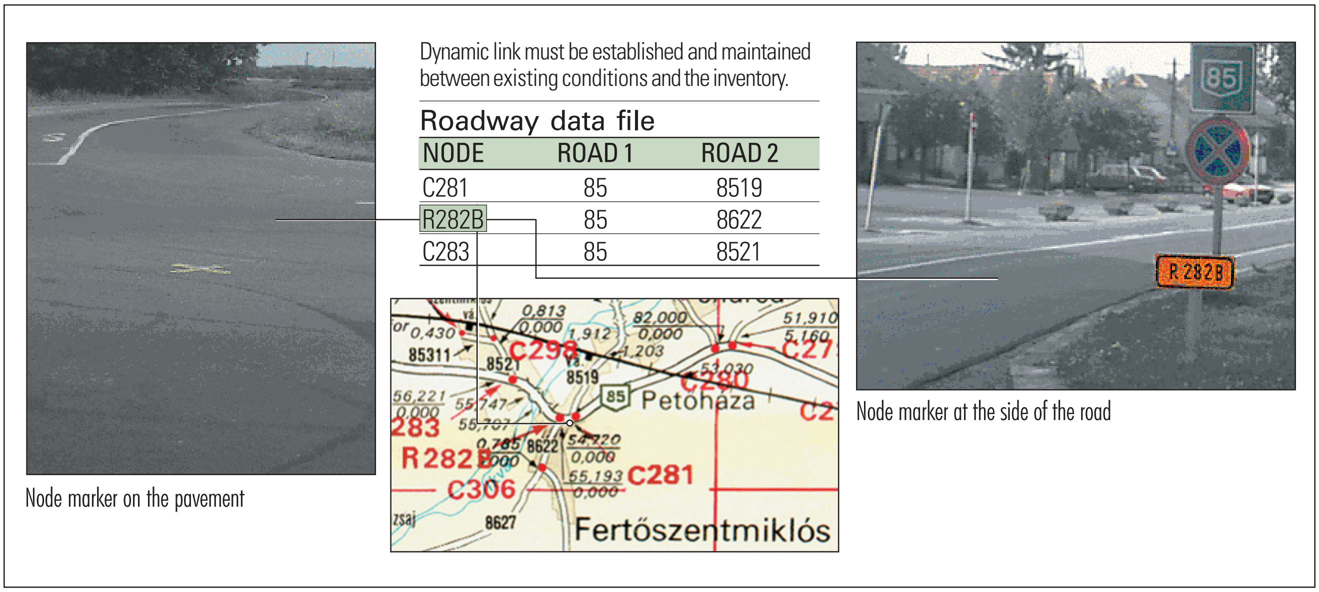
[1] Source: ***http://www.bast.de/htdocs/fachthemen/irtad/index.htm***

An accurate location reference system should then allow the:

- accurate location of a particular road element or site, based on the location data contained in the database;
- storage of data collected at a site at the right location in the database.

This means that any location reference system must provide a “one-to-one” identification in both directions.

Figure 4-1 Site inventory system



Three basic location methods are known:

- ***link - node;***
- ***route - km post;***
- ***X, Y coordinates (GPS)***.

Although many more exist, they are mere variations of these three methods.

Link - node

Known points along the road may be identified as nodes, which form the basis of this location method. Nodes are usually intersections and are assigned a unique number. Each node is connected to at least one other node by a section of road, called a link. Any location can then be easily identified using the distance from a node and the direction of the measurement, which is defined by the two adjacent nodes. The simplest network can be pictured as a web in which each node is an intersection of roads.

Example – Bridge identification

Other objects or locations along the road may also function as nodes, such as bridges, culverts and city boundaries, etc. These auxiliary nodes can be extremely useful if intersections are too far from each other and measuring the distance even from the nearest node would take too long.

Route - km post

The route - km post location method is similar to the node - link method in that both use the distance from a known point to identify locations. This method, however, uses unique route numbers that are assigned to a continuous section of road. Route numbers may coincide with the numbers shown on roadside signs or official road maps. However, they can also be any other number that is used for inventory purposes only. In that case, special maps and lists are required to equate the two numbers. On each road, a zero km point is chosen, and the distance measured from that point identifies a particular location. Distances are indicated by km posts along the route.


Route-km post

Police may have trouble locating rural accidents if the nearest km post sign is missing or too far from the scene. A good km-post system with appropriate sign density (200-m posts on main roads, 500-m posts on secondary roads, for example) can help ensure accurate accident location.

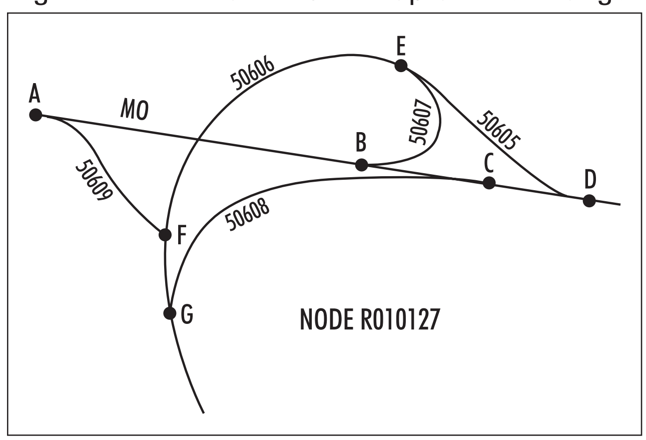
Reference map

Location accuracy depends not only on the officer's description but also on the level of detail and accuracy of the maps the officer uses to identify the location. Detailed maps are crucial when an accident occurs at an intersection with many legs or on a freeway ramp. A unique reference number may be assigned to entrance and exit ramp junction points.

The prerequisites of a successful accident location method (link-node or route-km post) are in general (Figure 4-2):

- easily recognizable reference landmarks along the road;
- a sufficiently detailed map accurately reflecting the road inventory file.

Figure 4-2 Link and node map at interchange



Links between each pair of nodes are assigned a unique number. Such maps help police officers at the scene of an accident identify the location quickly and accurately.

When roadworks have changed the length of a road and the km posts have not been altered to reflect the real distances, the posts no longer indicate the true km point of a location. Calculation algorithms must then be used to convert the reported km posts into true values.

X, Y coordinates

This method uses the X and Y coordinates of a given location in a geographic coordinate system, preferably used nationwide. The advantages of this location method are being increasingly recognized as GIS (Geographical information system) applications are becoming more generally available.

GPS (Global positioning system) is the fastest and cheapest way of obtaining the X, Y coordinates of a given point.

GPS (Global positioning system)

Real geographic coordinates are easy to measure with this method. A GPS uses a number of satellites orbiting the Earth at an altitude of 20,200 km (Figure 4-3). The satellites function as known reference points that broadcast (free) satellite identity, position, and time information via codes on two carrier frequencies.

The receiver in the field collects the radio signals and automatically calculates the geographical coordinates of the receiver's location. The calculation is based on the time it takes for the signal to get from satellites to the GPS receiver; trilateration is then used to establish the receiver's position. The equipment is able to convert the result of the measurement into a national coordinate system.

There are two ways to measure and calculate coordinates:

1. Applying differential processing against a base station

   This requires simultaneous readings at the accident site and at a base station. The results of the two readings must be correlated by software. This method produces much more accurate results, but it is more expensive (Figure 4-4);

2. Without using differential processing

   A base station is not required. Only one receiver is needed, and it can be the size of a pocket calculator. Even with inexpensive GPS receivers and brief readings, accuracy is still within 20m.

Figure 4-3 GPS (Global Positioning System)

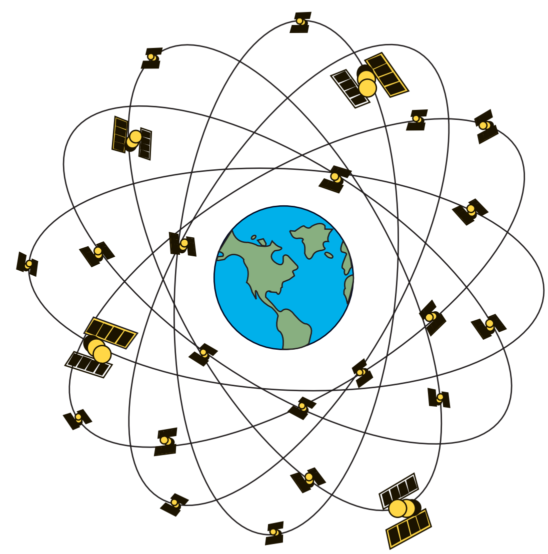
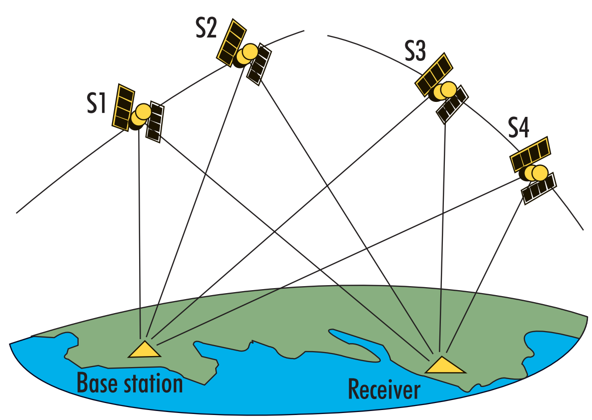


Figure 4-4 Differential GPS



Accuracy within 5-10m is considered appropriate. It avoids accidents being displayed "off the road" on a GIS map and is also appropriate for safety analysis purposes, where blackspots have to be identified unambiguously.

Advantages of a GPS:

- it provides a more accurate X, Y and even Z co-ordinate than any other method;
- reading and calculation are fast, completely automatic and free of human error;
- conversion of co-ordinates to the local co-ordinating system is possible;
- GPS equipment can be connected to the computer and the coordinates can be directed into the electronic report form, avoiding the possibility of transcription errors;
- using GPS is easy and needs minimal training for the officers;
- provides better navigation information for emergency vehicles responding to the scene;
- reasonable price when the benefits are considered.

Disadvantages of a GPS:

- a “sky-view” and a clear sightline to obtain the signals of at least four satellites are required. This may be difficult, if not impossible, in densely populated urban areas, under trees, or in canyons;
- since very few reference systems use X, Y coordinates, an algorithm is needed to convert GPS X, Y coordinates to the actual reference system and vice versa;
- handheld units are subject to damage;
- GPS location system cannot be used if police officers do not go to the accident scene; in some countries the report form is completed at the police station and not at the scene. Also, if police officers forget to turn on the equipment at the site of the accident, they will have to return to the scene later to take the reading. If they do not have time to do so or fail to recognize its importance and turn on the device on the way back to the police station (or elsewhere), the accident location is inaccurate;
- inaccuracy is often thought of laterally and not in terms of radius. Especially in urban areas, this may result, for example, in an accident being coded onto a nearby intersection or one of the side streets instead of on the main road;

4.1.5 ACCIDENT DATA STORAGE

Modern computers provide the most efficient way to store and maintain data. A computerized database can be pictured as a structured table in which each column represents a variable or data item and each row contains all available information on a particular accident.

Although computerization of accident data requires computer facilities, relatively little manpower is needed (compared to manual methods). Computerized data storage and retrieval is essential for agencies with a large amount of such data to maintain. In order to save space on a computer’s hard disk and to make data handling easier, some of the information in a database is coded such that a unique number or character is assigned to each possible value of a variable or data item. The outcome of an accident, for example, can be coded as F (fatal), S (serious injury) or L (light injury). A unique number can be assigned to each city or town so that long names do not use up the computer’s capacity.

In coded databases, however, the real meaning of the data is hard to see. A variety of specially designed software packages available on the market help solve this problem. With such programs a user can easily enter or retrieve accident data without even seeing the codes. The software does the coding and only the original information is displayed to the user.

Computerized accident data storage enables the user to:

- make quick computations of rates, severity indices and other statistical analyses;
- make cross-tabulations;
- examine the result on user-friendly graphs.

Hazardous locations can also be automatically flagged when the number or severity of accidents exceeds a given threshold.

Increased storage capacity and the development of optical scanners and optical disks represent breakthroughs in data storage. With an optical scanner, a computer image of each report form can be produced. These images can then be stored and made available later to a wider group of users, including such stakeholders as researchers who are not always satisfied with coded databases and who want to see the original report form. They are especially interested in the narratives and collision diagrams that may be omitted from the computer file but that contain valuable information.

4.1.6 ACCIDENT DATA LIMITATIONS

When working with accident data, it is always important to remember that:

- not all accidents are reportable;
- not all reportable accidents are reported;
- reported accidents may contain errors.

Not all accidents are reportable

The threshold for reporting an accident varies from country to country. A few of the most common definitions of the reporting threshold for a motor vehicle accident are listed below:

- **If the accident entails personal injury**:

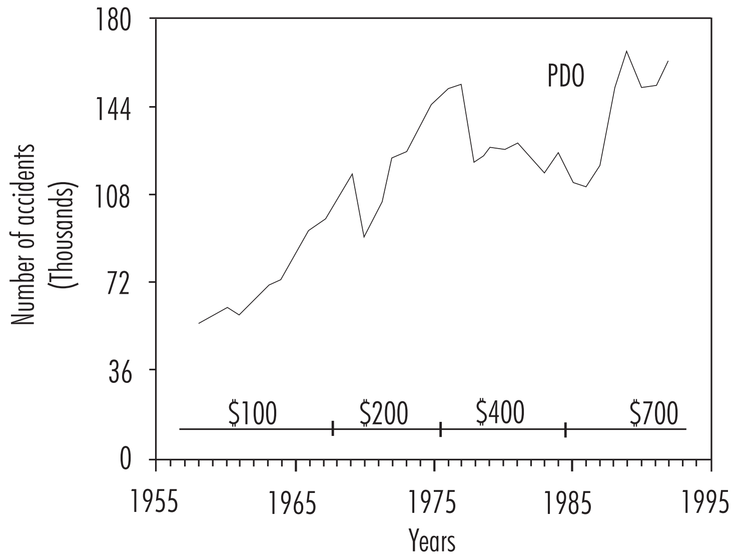
  Fatal accident statistics in two different countries or jurisdictions may not be comparable if they are using different definitions for the severity of injuries sustained during an accident. This may have an effect at both the ***identification*** and ***evaluation*** stages. As previously mentioned, there is a general tendency throughout the world to define a fatal accident as an accident in which one or more involved person(s) suffer(s) injuries that result in death within 30 days following the accident.

  It should also be noted that improvements in medical services that have taken place over the last decades have introduced some bias in terms of statistical data continuity. As a result of advanced medical technology and continuously improving emergency services, doctors keep more victims alive for 30 days than ever before. The number of fatal accidents is, therefore, decreasing. This is certainly fortunate, but it cannot be considered as an improvement in road safety.

- **If the accident results in property damage only**:

  In some countries, all "property damage only" accidents must be reported; in others, none. In cases, the accident reporting threshold is based on property damage exceeding a certain limit. This reporting limit is adjusted from time to time to reflect increased repair costs due to inflation. However, if repair costs increase without a corresponding increase in the reporting limit, a greater number of "property damage only" accidents that were not previously reportable get into the files. This may distort accident statistics (Figure 4-5).

Figure 4-5 Number of reported PDO accidents and reporting thresholds



Source: Hauer, 1997

Adjusting the threshold value of reportable PDO accidents is always risky. A country or a jurisdiction may certainly save money if it raises the reporting threshold to a point where much less accidents are recorded. However, the unavailability of many less severe accidents may then make it more difficult to determine the most probable accident “causes” and appropriate remedial measures.

Studies show that urban accidents and certain types of impacts (e.g. rear-end, sideswipe, parking, animal) are more sensitive to increased reporting thresholds than those involving pedestrians, cyclists or run-off-the-road accidents. If certain types of accidents are omitted from the database due to a higher reporting threshold, hazardous situations may take their tolls without even being noticed by safety engineers.

- **If a motor vehicle must be towed away from the scene**:

  These are accidents where at least one of the participant vehicles is unable, at least safely, to leave the scene on its own wheels and therefore needs to be towed away. This definition seems to provide a clear reporting threshold. However, it is not free of uncertainties as it is not always clear whether an accident meets the criteria. Let us say, for example, that a rear-end collision disables the headlights of a vehicle. If the accident occurs at night, the vehicle is obviously unsafe to drive. If, however, the collision takes place during the daytime, the vehicle can be driven and the damage may not be noticed.

- **If a motor vehicle caused injury to a person other than the driver**:

  This definition entails the exclusion of accidents where a driver was the only vehicle occupant, no matter of the accident severity.

- **If the accident occurred on a public highway**:

  This definition means that certain types of accidents, which typically occur in off-the-road locations such as parks, sidewalks or parking lots, are not recorded. However, they are very likely to be included in hospital files. This is especially true for bicycle accidents.

Not all reportable accidents are reported

It is important to be aware that many road accidents that are reportable to the police are not reported. It may be due to:

- ignorance of the legal obligation to report;
- the victim's unawareness of injury at the time of the accident;
- the desire to avoid bureaucracy;
- the desire to avoid insurance company penalties (or other types of penalties).

The level of under-reporting may vary by:

- road-user group (bicycle and pedestrian accidents have lower reporting rates than those of motor vehicles);
- type of accident (single-vehicle accidents have lower reporting rates);
- police station (the commitment and experience of police officers in different police stations may vary).

And also depends on:

- the severity of the accident;

  Fatal accidents have the highest reporting rate and, therefore, fatal accident data are believed to be the most reliable. "Property damage only" accidents are the least reliable as their reporting rate may be very low. In such cases, these records should not be used in an evaluation, but they may still provide valuable information on the deficiencies of the road system.
- the age of the injured person;

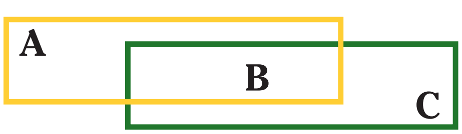
  Studies show that the probability of reporting an injury resulting from a motor vehicle accident increases with the age of the injured person.
- the workload of police officers;

  The workload of police officers may vary according to police station and season; the importance given to the completion of the accident report form may also vary between stations;
- the weather.

  In bad weather, police may not be able to handle the sudden increase in accidents.

The proportion of unreported cases needs to be assessed, in order to be able to estimate the real size of safety problems. Studies should be conducted from time to time to determine the actual reporting or under-reporting level. Most methods compare police accident files with hospital files. However, even this simple method may use at least three different definitions, as shown in Figure 4-6:

Figure 4-6 Comparison of accident files (police and hospital)



A = accidents recorded by the police only
B = accidents recorded by the police and the hospital
C = accidents recorded by the hospital only

Definition 1 $= \dfrac{B}{B+C}$ This definition covers those hospital file cases for which a police report is found.

Definition 2 $= \dfrac{A+B}{B+C}$ This definition compares the total number of records found in the police file with the total number of cases in the hospital file.

Definition 3 $= \dfrac{A+B}{A+B+C}$ This definition, theoretically the most correct, compares the proportion of the total police records with the total number of cases in both the police and the hospital files.

International comparisons are meaningless if the data of the different countries under study are not adjusted to take into account differences in accident reporting levels.

The level of accident reporting varies, among other things, by injury severity, road user group, type of accident, age of victim. It may also change over time. It could therefore be misleading to correct the incomplete accident reporting by using an overall mean reporting level.

Data of reported accidents may contain errors

Reporting completeness seems to depend very much on the difficulty of completing the report form. Data items that are difficult to observe or record tend to be incomplete. For example, if police officers are asked to enter data on the condition of the road surface or drainage system, they may very well not complete these fields or may provide inaccurate information. Roadway data should be taken from the road authority's inventory files instead.

The golden mean

The number of questions in a report form also has a direct impact on the percentage of answered questions and the quality of the data (Figure 4-7).

Figure 4-7 Accident report – The golden mean

An increase in the number of questions on a report form may lead to a sharp drop in the number of reported accidents. Some questions may not be answered by the police officer because of oversight rather than any intention not to answer.

A short, one page report form may lead to higher reporting rates, but provides less detailed information. This may result in insufficient data to carry out comprehensive studies.

Other methods to study inconsistency

Analyses based on incomplete or inaccurate data files may be misleading, and the resulting actions may lead to unnecessary expenditures. Most often, inconsistency results from misinterpreting or misunderstanding the definition of a data item (e.g. reporting thresholds, definitions of injury severity classes, etc.).

Completeness and consistency checks can be done by the coder, if the coding is done manually, or by software, if the data collection is computerized. This can take place either at data entry, where the software does not allow the user to proceed to the next data item unless the inconsistency is corrected, or after data entry, by making it impossible to close and forward incomplete reports.

It is strongly recommended that consistency checks be made at least for the following variables: location, time, number of vehicles involved, accident type, number of casualties, accident severity.

4.2 OTHER DATA

4.2.1 ROAD INVENTORY FILE

Table 4-2 presents the roadway information that is most useful when conducting safety studies.

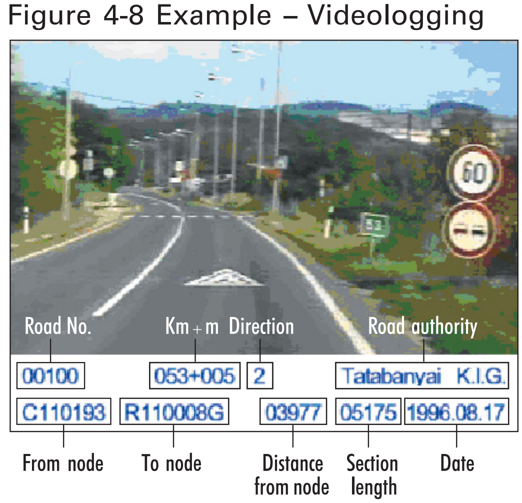
Table 4-2 Roadway data – Recommended information

LOCATION REFERENCE DATA	NUMBER, CLASS AND LENGTH OF ROAD
- obtained by using one or a combination of the following: - X, Y co-ordinates - route number and kilometer post rounded off (for example, to the nearest 100m) - link-node	- number or identification of the road - road category (e.g. freeway, main road, secondary road) - road length
ROAD TYPE	LANE NUMBER, LANE WIDTH
- divided / undivided - width of median	- number of lanes in each direction - lane width
CROSSING TYPE	TRAFFIC CONTROL
- intersection (number of legs) - railway crossing (control) - other type of crossing	- traffic signal - stop sign(s) - yield sign(s)
ROAD ALIGNMENT	ROAD SURFACE TYPE
- horizontal curve - grade	- asphalt - concrete - brick - unpaved
ROAD SURFACE CONDITION	SHOULDERS
- roughness - rutting - potholes - skid resistance	- width - type (paved, unpaved) - condition
DRAINAGE	SPEED LIMIT
- surface drainage - sewage system	- permanent - temporary
ROAD LIGHTING	PARKING
- type - location - above the roadway - on one or both side(s) of the road	- on one or both side(s) of the road

4.2.2 PHOTOLOGGING AND VIDEOLOGGING

A widely used method for collecting roadway data consists of taking pictures of the road and its environment. Images are stored either as photos taken at equal increments (e.g. 10-25m) or on videotape shot from a moving vehicle. Generally, photos provide a clearer image than a video, but a video allows comments and images to be recorded continuously and simultaneously. Basic roadway data may also be included in the roadway video, such as the actual location and direction of the vehicle from which the video was taken. The video can then be viewed at the office and the roadway information coded and entered in the computer (Figure 4-8).

Figure 4-8 Example – Videologging



4.2.3 TRAFFIC DATA FILE

Table 4-3 presents the traffic data that are most useful when conducting safety studies:

Table 4-3 Traffic data – Recommended information

LOCATION REFERENCE DATA	TRAFFIC VOLUME
- obtained by using one or a combination of the following: - X, Y co-ordinates - route number and the kilometer post rounded off (for example, to the nearest 100m) - link-node	- vehicles/day (AADT) - may be based on short-term counts with seasonal, daily and hourly adjustment factors
TRAFFIC MIX	**TRAFFIC VARIATIONS**
- percentage of: - cars - light trucks - heavy trucks - motorcycles - mopeds - bicycles	- hours, days, months, years
TURNING MOVEMENTS	**SPEED DISTRIBUTION**
- at intersections - percentages	- cumulative distribution

4.2.4 HOSPITAL FILE

Table 4-4 presents data from the hospital files that are most useful when conducting safety studies:

Table 4-4 Hospital data – Recommended information

PATIENT	TIME AND DATE OF ACCIDENT
- by description: - name, age, sex - identification number	- by statement of police /patient
CASUALTY CODES	**TRACE OF USE OF SAFETY DEVICE**
- IIS (Integrated injury score) for every part of the body - AIS (Abbreviated injury scale)	- sign of bruise on shoulders, etc.
EMERGENCY VEHICLE RUN NUMBER	**NUMBER OF DAYS IN HOSPITAL**
- way bill id.	- no. of days
EXPECTED NUMBER OF DAYS UNTIL FULL RECOVERY	
- no. of days	

4.2.5 OTHER POTENTIAL DATA FILES

Other data files may also contain relevant information for the conducting of safety studies:

- maintenance and operations files (road markings, snow/ice removals, etc.);
- project history files (containing information related to the implementation of corrective measures);
- insurance companies' accident files (the accident history of the driver and the car);
- weather report file.

4.3 INTEGRATED DATA SYSTEM

Once the range of data required for an information system is established, a study should be carried out on the potential sources of each data item. A decision should be made after considering the following:

- the control and maintenance of such a system should preferably be assigned to a national agency (Department of Transport, road authority, statistical bureau, etc.). An accident information system must be reliable and up-to-date. This is best achieved by government guarantees;
- clear responsibilities and tasks concerning data collection, data entry, consistency checks, programming, etc. should be assigned. The frequency and method of supervision must also be defined.

  All parties involved in a road accident data collection and information system should be fully aware of their tasks and responsibilities. All persons should know:
  - what is expected of them;
  - what they are supposed to do and when;
  - what resources they may use;
  - what method they must follow;
  - what the implications would be if they, for example, failed to meet a deadline.
- As a general rule, a data file should be controlled by the organization that most needs the data. Accordingly:
  - traffic data and roadway data are most efficiently collected and maintained by national and local highway authorities that need these data for their maintenance and design work;
  - hospital files containing patient records are indispensable in health care administration.

Most likely, different user groups will want to make use of the available information contained in the accident databases. Convivial query systems should be developed while ensuring that the confidentiality of information is provided whenever required. For examples:

- politicians and decision-makers will tend to ignore the advantages of an accident information system if it cannot be accessed quickly and easily and produce simple reports (preferably with graphs and maps). Mayors may only be interested in the road user groups that are the most exposed to road accidents in their community with regard to launching a new educational campaign;
- car manufacturers may need to access accident databases in order to assess the effectiveness of safety devices that are available in their vehicles; however, they should not be given access to drivers' personal data;
- road engineers need to link accident, traffic and roadway databases in order to identify hazardous locations, determine the causes of safety problems and propose appropriate remedial actions ***(Section 4.3.1)***;
- researchers need to have the chance to complete complex queries, often using data at a very disaggregated level.

Key elements of an information system

The key elements to success in maintaining a safety information system are the following:

- clear definitions and terminology (this ensures that everyone knows what information a particular data item contains);
- a continuous dialogue with potential users, with changes being made to the system to meet their needs;
- fast and easy access for all user groups and levels;
- provision of timely information;
- modest centralization (data should be entered near source);
- reducing data-maintenance costs (by choosing the right program language and making sure the system is flexible enough and open to future upgrades);
- consistency in the same data item across different files (attention to data items that make linking possible).

4.3.1 LINKING FILES

The identification of road-related deficiencies is based on a comparison of safety levels between road sites, roads, parts of a network or even countries. A few commonly used indices are listed below:

- casualty accident per 1,000 inhabitants (town, area);
- casualty accident per 1,000 registered vehicles;
- casualty accident per 100 kilometers of road;
- casualty accident per 1,000,000 vehicle-kilometers.

These figures cannot be computed directly on the basis of data stored in accident files. Other pieces of information are needed as well: the number of inhabitants in a town or country, the number of vehicles using the network every day, the number of registered vehicles, etc. The required data can be found in:

- the road inventory file;
- the traffic data file;
- the driver data file;
- the vehicle registration data file;
- the population statistics, etc.

The most obvious way to make the desired information available to users is to store all the data together with the accident data in the same file. This, however, would result in a gigantic and difficult-to-handle database, containing pieces of information that are rarely, if ever, used. Moreover, since in most cases these pieces of information are collected, stored and maintained in files that are administered by different agencies, the simultaneous storage of data in two different locations not only entails unnecessary and costly duplication of effort but also makes the system uncertain and unreliable.

Therefore, it seems more sensible to link the different databases in a way that permits retrieval of different data items from the separate files. By linking two or more data files as components for safety analysis purposes, a safety information system is created.

Database linkage can be temporary or permanent and is achieved by including at least one identical and unique data item(s) in each file of the pair to be linked (Figure 4-9). A safety information system may have a large number of component files. There is no upper limit. As a minimum, however, it should include:

- accident data;
- road inventory files;
- traffic data.

Other potential files are:

- motor vehicle file;
- driver file;
- hospital file;
- any other inventory that contains useful information.

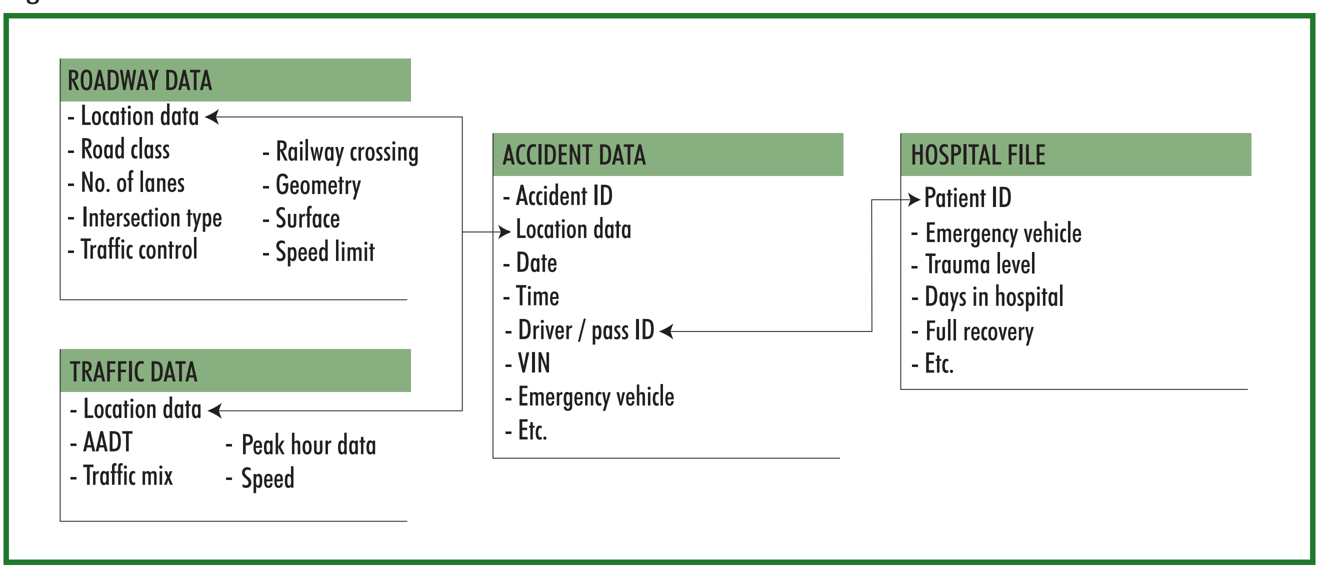
The linkage field can be, for example:

- the driver license number (linking accident and driver files);
- the location reference (linking the accident file with the road inventory and the traffic data file);
- the vehicle registration number or vehicle identification number (linking accident and motor vehicle files).

Other possible linkage fields:

- bridge number;
- railway - highway crossing number;
- accident report number;
- blood alcohol test number;
- emergency vehicle run number;
- etc.

Figure 4-9 Linked file

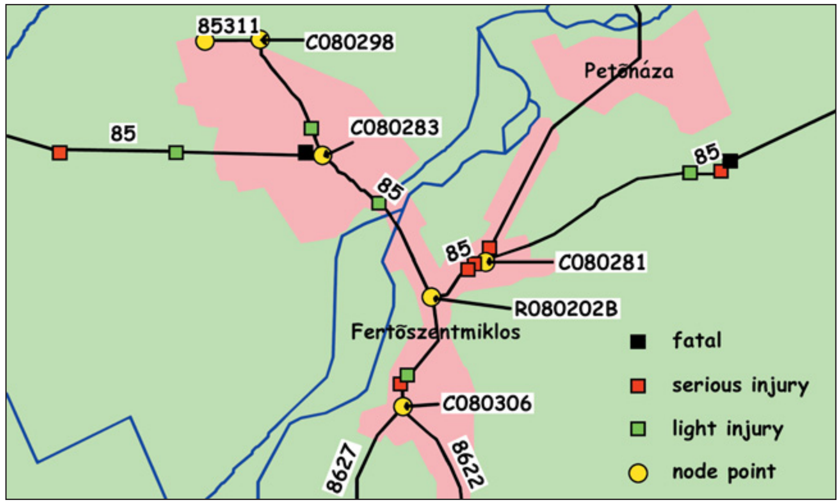


As can be seen, data that are stored in computers are more valuable if the database is designed to allow linkage with other databases. When structuring an information system, such linkage fields must be created.

In a Geographic information system (GIS), a large amount of information can be stored with their individual location coordinates in a database and easily displayed on a map showing their actual location.

For example, several elements of information contained in a road inventory file, such as nodes, roadside objects, city boundaries, bus stops, road signs, changes in pavement type, etc., can be displayed on a map. And the attributes of each element of information can be displayed (e.g. the type, dimension, installation date of a specific road sign). Similarly, hazardous locations can be shown on a map, based on pre-selected and calculated identification criteria (Figure 4-10).

Figure 4-10 Example – GIS application



4.4 OTHER ACCIDENT DATA COLLECTION TOOLS

4.4.1 ACCIDENT RECORDING DEVICES

New, modern technology may help to collect valuable information on the circumstances of accidents.

Accident data recorder

The absence of skid marks (due to the use of ABS) or of evidence of the actions taken or omitted by the driver right before the accident may increase the difficulty of the accident investigation. The Accident data recorder is a "black box" that acts like a flight recorder, recording the most important data about the circumstances of the accident. This provides road safety engineers with objective data on the course of an accident. Such equipment can record data on (Figure 4-11):

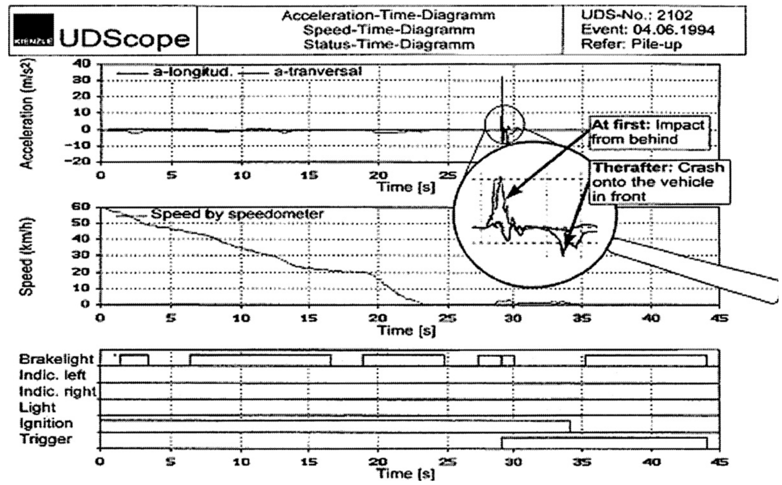
- transversal and longitudinal acceleration;
- speed;
- vehicle rotation;
- skidding;
- activation of ignition, lights, flashers and brakes;
- etc.

Accident recognition is fully automatic and the data are recorded with high precision from 30 seconds before until 15 seconds after the accident. The device can be installed in any kind of vehicle and is able to store data for more than one accident.

Photogrammetric measurement

This involves taking a standard set of pictures of the exterior and interior of the vehicle with specially adapted small-format cameras. The pictures are then used to create three-dimensional images. Fieldwork is completed in a few minutes. Evaluation is done separately using the data collection and involves experts when needed. This device can be used to determine the efficiency of restraint equipment.

Figure 4-11 Example of automatic data recorder



4.4.2 EXPERT SYSTEMS

Although police officers are in a unique position to collect accident data, this task is not their only responsibility at an accident location. They also have to secure the site, care for the injured persons and re-establish traffic flow. On-scene data collection systems must consider the officers needs and work constraints when implementing new technologies.

Expert systems developed for accident data collection can ease the workload of police officers on-site in addition to increasing the accuracy and consistency of reported data. Expert systems are computer programs that contain knowledge in a specific field.

While collecting the necessary information on the circumstances of an accident a police officer has to make certain judgments such as: Did the driver/passengers really wear their safety belts as stated? What is the extent of vehicle damage? How should the severity of the crash be classified? Answering these and other questions not only takes valuable time at the scene but may also lead to inconsistent statistics as officers may judge situations differently. Expert systems have embedded rules that help police officers in providing more accurate answers to such questions.

Expert systems also allow them to collect both state-required data and specific pieces of information that are particularly relevant to a given road context (e.g. roadside conditions in the case of a single-vehicle accident or lighting conditions in the case of a night accident).

4.5 CONCLUSION

The information technology developments of the past few decades have made it possible to achieve major progress in database collection and management:

- on the one hand, it is possible to collect more precise, better validated and more relevant information than before, which can thus better meet the needs of the users of these data;
- on the other hand, it is also much easier to benefit from all of the information collected and stored in computerized databases, provided that existing technologies are properly used;
- all at much more reasonable costs than in the past.

Despite this progress, we note today that in several countries, police forces are exerting major pressures to reduce the efforts invested in collecting accident data. In most cases, they have to assume all of the costs of this activity, while the benefits resulting from access to reliable information are shared by several groups of stakeholders.

If such a situation arises, it will then be necessary to analyze the problem systematically and renew the dialogue between the various stakeholders affected by this question, with the aim of arriving at a solution in the interests of society as a whole. The legitimate concerns of a specific group should not run contrary to the well-being of the population. The costs associated with collecting accident data are quite marginal compared to the economic and social harm that could result from the loss of this fundamental information.

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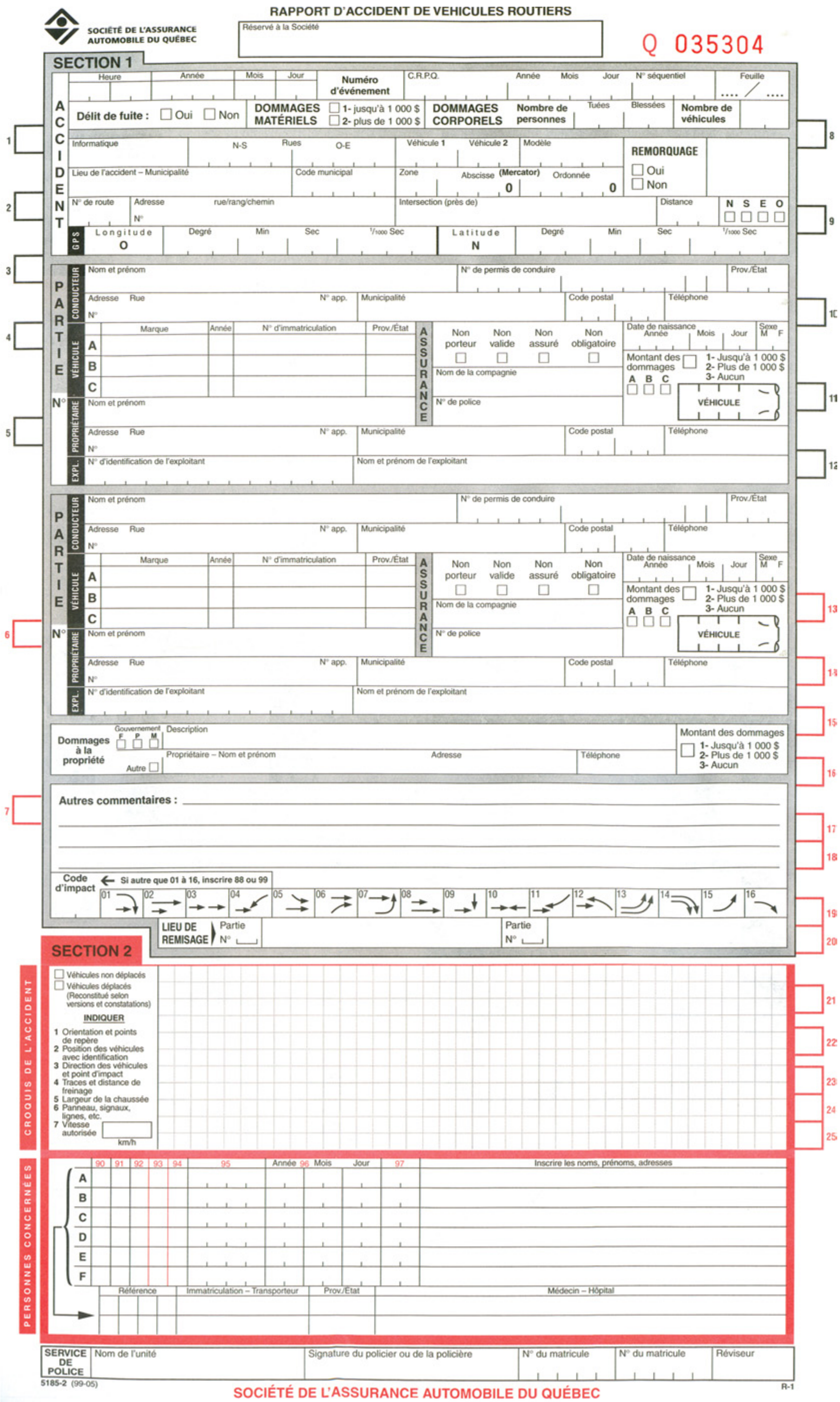
APPENDIX 4-1

Example - Accident report



SOCIÉTÉ DE L'ASSURANCE AUTOMOBILE DU QUÉBEC

RAPPORT D'ACCIDENT DE VEHICULES ROUTIERS

Réservé à la Société

Q 035304

SECTION 1

ACCIDENT

Heure | Année | Mois | Jour | Numéro d'événement | C.R.P.Q. | Année | Mois | Jour | N° séquentiel | Feuille

Délit de fuite : ☐ Oui ☐ Non | DOMMAGES MATÉRIELS ☐ 1- jusqu'à 1 000 $ ☐ 2- plus de 1 000 $ | DOMMAGES CORPORELS | Nombre de personnes | Tuées | Blessées | Nombre de véhicules

Informatique | N-S | Rues | O-E | Véhicule 1 | Véhicule 2 | Modèle | REMORQUAGE ☐ Oui ☐ Non

Lieu de l'accident – Municipalité | Code municipal | Zone | Abscisse (Mercator) 0 | Ordonnée 0

N° de route | Adresse N° | rue/rang/chemin | Intersection (près de) | Distance | N S E O

GPS | Longitude O | Degré | Min | Sec | 1/1000 Sec | Latitude N | Degré | Min | Sec | 1/1000 Sec

PARTIE N°

CONDUCTEUR: Nom et prénom | N° de permis de conduire | Prov./État
Adresse Rue N° | N° app. | Municipalité | Code postal | Téléphone

VÉHICULE: Marque | Année | N° d'immatriculation | Prov./État — A, B, C

ASSURANCE: Non porteur ☐ | Non valide ☐ | Non assuré ☐ | Non obligatoire ☐
Nom de la compagnie
N° de police

Date de naissance Année | Mois | Jour | Sexe M F
Montant des dommages ☐ 1- Jusqu'à 1 000 $ 2- Plus de 1 000 $ 3- Aucun
A B C ☐ ☐ ☐
VÉHICULE

PROPRIÉTAIRE: Nom et prénom
Adresse Rue N° | N° app. | Municipalité | Code postal | Téléphone

EXPL.: N° d'identification de l'exploitant | Nom et prénom de l'exploitant

PARTIE N°

CONDUCTEUR: Nom et prénom | N° de permis de conduire | Prov./État
Adresse Rue N° | N° app. | Municipalité | Code postal | Téléphone

VÉHICULE: Marque | Année | N° d'immatriculation | Prov./État — A, B, C

ASSURANCE: Non porteur ☐ | Non valide ☐ | Non assuré ☐ | Non obligatoire ☐
Nom de la compagnie
N° de police

Date de naissance Année | Mois | Jour | Sexe M F
Montant des dommages ☐ 1- Jusqu'à 1 000 $ 2- Plus de 1 000 $ 3- Aucun
A B C ☐ ☐ ☐
VÉHICULE

PROPRIÉTAIRE: Nom et prénom
Adresse Rue N° | N° app. | Municipalité | Code postal | Téléphone

EXPL.: N° d'identification de l'exploitant | Nom et prénom de l'exploitant

Dommages à la propriété | Gouvernement F P M ☐ ☐ ☐ | Autre ☐ | Description | Propriétaire – Nom et prénom | Adresse | Téléphone | Montant des dommages ☐ 1- Jusqu'à 1 000 $ 2- Plus de 1 000 $ 3- Aucun

Autres commentaires :

Code d'impact ← Si autre que 01 à 16, inscrire 88 ou 99
01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16

LIEU DE REMISAGE | Partie N° | Partie N°

SECTION 2

CROQUIS DE L'ACCIDENT

☐ Véhicules non déplacés
☐ Véhicules déplacés (Reconstitué selon versions et constatations)

INDIQUER

1 Orientation et points de repère
2 Position des véhicules avec identification
3 Direction des véhicules et point d'impact
4 Traces et distance de freinage
5 Largeur de la chaussée
6 Panneau, signaux, lignes, etc.
7 Vitesse autorisée km/h

PERSONNES CONCERNÉES

90 | 91 | 92 | 93 | 94 | 95 | Année 96 Mois Jour | 97 | Inscrire les noms, prénoms, adresses
A, B, C, D, E, F
Référence | Immatriculation – Transporteur | Prov./État | Médecin – Hôpital

SERVICE DE POLICE | Nom de l'unité | Signature du policier ou de la policière | N° du matricule | N° du matricule | Réviseur

5185-2 (99-05) R-1

SOCIÉTÉ DE L'ASSURANCE AUTOMOBILE DU QUÉBEC

Société de l'assurance automobile Québec

MOTOR VEHICLE ACCIDENT REPORT

* Specify in "Additional Remarks"

SECTION 1

1 V1
2 V2

DIRECTION OF VEHICLES PRIOR TO IMPACT

N, NE, E, SE, S, SW, W, NW
1, 2, 3, 4, 5, 6, 7, 8

ROADWAY CONDITIONS — 8

1- Dry
2- Wet
3- Snow-covered
4- Ice-covered
5- Muddy
6- Oily
9- Other*

WEATHER — 9

0- Sleet
1- Clear
2- Cloudy / Overcast
3- Rain / Drizzle
4- Snow / Hail
5- Fog
6- Shower
7- Strong winds
8- Blizzard
9- Other*

MOVEMENT OF VEHICLES — 3 V1, 4 V2

11- Going straight ahead
12- Turning right except on right light
13- Turning left
14- Starting in traffic
15- Slowing or stopping
16- Stopped in traffic
17- Parking
18- Legally parked
19- Illegally parked
20- Leaving curb parking
21- Backing up
22- Leaving / entering traffic
23- Leaving / entering express lane
24- Passing on the left
25- Passing on the right
26- Changing lanes
27- Making U-turn
28- Avoiding an obstacle on pavement
29- Breakdown
30- Unknown movement
31- Turning right on right light
99- Other*

LIGHT — 10

DAY
1- Clear
2- Dusk

NIGHT
3- Lighted road
4- Unlighted road

TYPE OF ACCIDENT — 5

Motor vehicle collision with
11- Motor vehicle
12- Pedestrian
13- Train
14- Non-motorized vehicle
15- Animal
16- Temporary obstacle

Stationary object
17- Lamp post / Utility post
18- Tree
19- Guard rail / Crash barrier
20- Pillar (Bridge / Tunnel)
21- Impact absorber
29- Other*

No collision
61- Overturned
62- Submersion
63- Fire / Explosion
64- Left roadway
99- Other no collision*

TYPE OF VEHICLE — V1 11, V2 12

41- Automobile
42- Light truck
43- Truck
44- Truck tractor
45- Vehicle used for transporting dangerous substances
46- Special mobile equipment
47- Specialized-task vehicle
48- Bus
49- School bus
50- Minibus
51- Taxi
52- Emergency vehicle
53- Motorcycle
54- Moped
55- Recreational vehicle
56- Snowmobile
57- Bicycle
99- Other*

SECTION 2

ZONE — 6

1- School
2- Residential
3- Business / Commercial
4- Industrial / Manufacturing
5- Rural
6- Forest
7- Recreational / Park / Camping

LOCATION — 13

21- Roadway intersection
22- Roadway between intersections
23- Median
24- Shopping centre
25- Private land or road
26- Level crossing
27- Tunnel / viaduct / bridge
28- Sidewalk
29- Curb
99- Other*

ROADWAY SURFACE FEATURES — 14

1- Level / straight
2- Level / curve
3- Slope / straight
4- Slope / curve

ROADWAY COMPOSITION — 15

1- Asphalt
2- Concrete
3- Gravel
4- Earth
9- Other*

ROAD CATEGORY — 7

1- Numbered highway
2- Street
3- Road
4- Lane
5- Forest / Mining road
6- Parking lot
9- Other*

STATE OF THE ROADWAY — 16

1- Good
2- Under construction
3- Being repaired
4- Hole / rut / bump
9- Other*

ROAD SIGNS AND TRAFFIC SIGNALS — V1 17, V2 18

11- None
12- Traffic light
13- Flashing red light
14- Flashing yellow light
15- Advanced green light
16- School crossing light
17- Pedestrian crossing light
18- "STOP" sign
19- "YIELD" sign
20- Police / Crossing Guard / Signaler
21- Level crossing (light / barrier)
22- Warning sign
23- Flashing school bus lights
99- Other*

VISIBILITY — V1 19, V2 20

11- Good
Reduced due to
12- Tree / hedge / fence
13- Building
14- Embankment
15- Vehicle
16- Blinding headlights
17- Blinding other than by headlights
18- Dirt / Sleet / Snow on vehicle
19- Steam / Smoke / Dust
20- Weather
99- Other*

SEAT BELT

1- None 2- Not used 3- Used 4- Not properly fastened

FUNCTION

8, 7, 4, 1, 5, 2, 6, 3, 8, 8

1- Driver
2-7- Passenger
8- Hanging onto vehicle
9- Pedestrian

VICTIM'S STATE

1- Dead
2- Seriously injured
3- Minor injuries
4- No apparent injury

PEDESTRIAN MOVEMENT — Pedestrian 1 21, Pedestrian 2 22

11- Crossing with signal
12- Crossing against signal
13- Crossing without signal, marked road surface
14- Crossing without signal, unmarked road surface
15- Crossing diagonally
16- Walking on curb, with traffic
17- Walking on curb, against traffic
18- Hitch-hiking
19- Coming out, in front / behind, parked vehicle
20- Child boarding / alighting from school bus
21- Boarding / alighting from, except school bus
22- Pushing / working on vehicle
23- Working on road surface
24- Playing on road surface
25- Not on road surface
99- Other*

RESERVED FOR THE SOCIÉTÉ — 23, 24, 25

OCCUPIED VEHICLE Party Number — 90

91 92 93

SEX M / F — 94

HEALTH INSURANCE NUMBER — 95 96 97

5188A-6 (2002-11)

CHAPTER 5
Identification

Carl Bélanger and Patrick Barber

CHAPTER 5

Identification

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LIST OF ABBREVIATIONS	
I_T	= investigation threshold value
P	= period of analysis [years]
SITE	
EPDO	= equivalent property damage only index
$\overline{EPDO}$	= average EPDO
f	= accident frequency [acc./period]
f_e	= expected accident frequency [acc./period]
f_{EB}	= EB adjusted accident frequency [acc./period]
f_{ei}	= expected frequency of a type i accident
f_i	= frequency of a type i accident [acc./period]
f_p	= predicted accident frequency [acc./period]
IC	= value of the identification criterion
K	= statistical constant (critical accident rate)
L	= section's length [km]
m	= safety level
$\hat{m}$	= estimated safety level
P.I.	= potential for improvement
Q	= average annual daily traffic (AADT) [vehicles/day]
R	= accident rate [acc./Mveh.-km]
R_c	= critical accident rate [acc./Mveh.-km]
RSI	= relative severity index
$\overline{RSI}$	= average RSI
REFERENCE POPULATION	
C_i	= average cost of a type i accident
$EPDO_{rp}$	= average EPDO
f_{rp}	= average accident frequency [acc./period]
IC_{rp}	= average value of the identification criterion
n	= number of sites
p_i	= average proportion of type i accident
Q_w	= weighted annual average daily traffic [(AADT) vehicles/day]
R_{rp}	= average accident rate [acc./Mveh.-km]
RSI_{rp}	= average relative severity index
s	= standard deviation
s^2	= variance
w_i	= weighting factor for type i accident

5.1 INTRODUCTION

This chapter describes several methods of identification of road safety deficiencies. Given the scope of this manual, the description focuses on the identification of problems that are likely to be treatable through road engineering actions. To this end, there are now two main identification approaches that can be used by safety engineers. These are discussed in this chapter:

- a reactive approach ***(Section 5.3)*** that relies on analyses of available accident data to detect deviant situations. This chapter's descriptions are adapted to the identification of ***blackspots***, which is generally the first safety action taken at the road level. However, the tools and methods that are described may also help in the detection of:
  - safety problems occurring at sites that are larger than blackspots (a road, an area of a road network or a group of sites of a given category);
  - deviant accident patterns that require action (even though the total number of accidents is not abnormal).

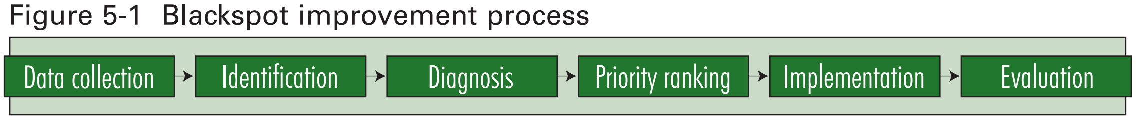
  Clearly, the accident-based identification should not be limited to a search for blackspots.
- a proactive approach ***(Section 5.4)***, which relies on the analysis of physical and operational characteristics of existing roads or road projects to identify actual or future safety deficiencies. This is the field of road safety audits that developed rapidly over the 1990's.

At the end of this chapter, it is explained how road authorities should also seek for improvement opportunities apart from these two formal identification approaches. After all, most actions that are taken by these authorities do have an impact on road safety, whether they are initiated for safety reasons or not. If these impacts were properly assessed prior to implementation, accidents could be avoided, often at little or no cost. As suggested in ***Section 5.4.2***, the identification task should be envisioned in a broader perspective. On the whole, the objective should not be limited to the detection of existing or potential safety deficiencies, but should also include, in a more positive manner, the search for improvement in practices of an organization.

Blackspot improvement process

The typical steps of a blackspot improvement process are:

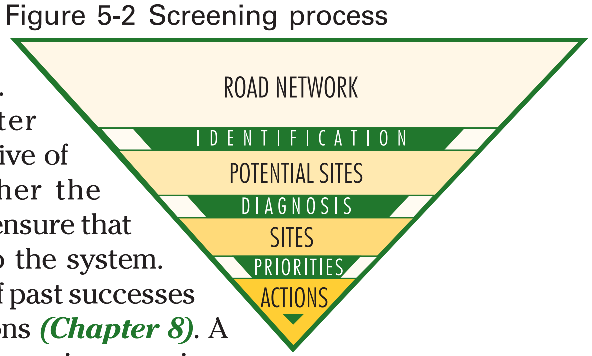
Figure 5-1 Blackspot improvement process



At the end of the identification step, the nature of the problem(s) is generally unknown and the potential treatments have yet to be determined. As such, sites that have been detected are seen as “potential sites”. It is only during the diagnosis step of the blackspot improvement process that analysts will determine if road engineering actions are needed and what those actions are ***(Chapter 6)***.

Projects that have been developed during the diagnostic phase must then be ranked according to their respective costs and benefits in order to choose the actions that will be taken first ***(Chapter 7)***. The evaluation of the impact of actions after implementation completes this process. The objective of the evaluation is not only to determine whether the anticipated benefits have been achieved but also to ensure that negative side effects have not been introduced into the system. By doing so, it becomes possible to take advantage of past successes and failures to improve the efficiency of future actions ***(Chapter 8)***. A blackspot improvement process can be seen as a screening exercise; as the analysis progresses, the number of sites progressively decreases (Figure 5-2).

Figure 5-2 Screening process



5.2 TARGETS

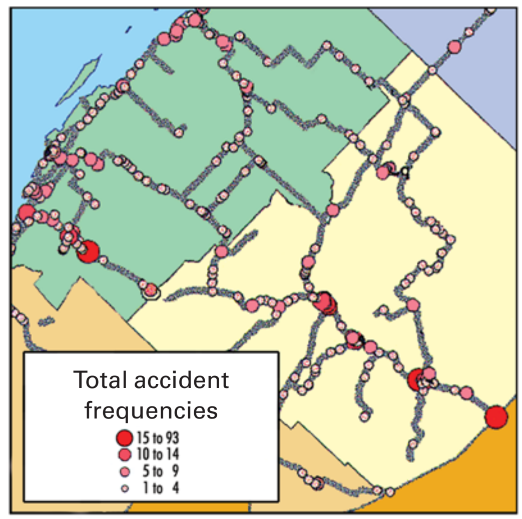
In the first years of implementation of a road safety improvement program, sites that are identified as hazardous are generally of small dimension - typically blackspots - ***(Section 5.2.1)***, but as these are gradually treated, the site dimension increases ***(Section 5.2.2)***.

5.2.1 BLACKSPOTS

The term "blackspot" is said to derive from the method that was originally used to identify hazardous sites. Accidents were pinpointed on a map using colored pins to represent the trauma severity of each of these events. Black was reserved for accidents having caused property damage only and the significant proportion of these accidents created black dots at concentration points. The method is still quite popular, although geographic information systems (GIS) and computerized databases have generally replaced pins and paper maps (Figure 5-3).

There is no universally accepted definition of a blackspot. The terms "hazardous location" and "high accident locations" often used as a synonym. As discussed above, a blackspot was originally a road location of limited area with a high concentration of accidents. This definition has progressively evolved as several researchers now recommend including the concept of ***potential for improvement***, a central consideration in this chapter (McGuigan, 1981; Elvik, 1988; Hauer, 1996).

Figure 5-3 Accident frequency map



Blackspot correction is usually seen as a highly profitable action in terms of accident reduction and cost-effectiveness. As such, it is often the focus of a road authority, particularly during the first years of interventions.

It should be mentioned that some authors have expressed concerns about the true benefits of a blackspot correction program. They believe that some accidents that are eliminated from treated blackspots might simply migrate to a nearby location ***(Section 8.3.2)***. Although a confirmation of this hypothesis has yet to be found, migration obviously occurs in some specific cases (e.g. the correction of a sharp curve that shifts accidents to the next curve down the road, or the conversion of an intersection into an interchange at the end of a freeway, which shifts accidents to the next intersection). Safety analysts must clearly look beyond the limits of the site being investigated in order to avoid such situations.

Potential for improvement (P.I.)

In theory, the maximum accident reduction that can be achieved from road safety actions at a site corresponds to its long-term average accident frequency or ***safety level***. In practice, the situation is more complex.

The only sure way to avoid all accidents is to eliminate all traffic, which is rarely an option. Given the actual state of technology, a wide range of human errors, road deficiencies and vehicle defects may all contribute to the occurrence of accidents. Consequently, a more realistic value of the achievable accident reduction lies somewhere between a site's long-term average accident frequency and zero accidents.

The different types of roads and sites that constitute a road network do not have the same safety level. For example, accident frequencies are in general higher at 4-leg intersections than at 3-leg ones, where there are substantially fewer traffic conflicts. Consequently, two sites may have the same number of accidents but different safety improvement potentials.

At the identification stage, the objective is to identify those sites that have an abnormal accident concentration, with this number likely to be efficiently reduced through road safety engineering (RSE) actions, rather than those sites that have a high number of accidents for reasons that cannot be changed[1]. Hauer (1996) uses the term "sites with promise".

In order to identify such sites, the recommended approach is to:

1. define different ***reference populations***, e.g. subsets of sites that have similar features and, as such, are expected to have similar safety performances.

   If all the variables influencing road safety could be taken into account in the determination of the set of reference populations - not only geometric and traffic variables but also other features such as road users' behavior and traffic regulations - all the sites of the same reference population would have the same long-term average accident frequency. The only difference between the observed accident frequency at a site and the average accident frequency of its reference population would result from random variations ***(random nature of accidents)***.

   In practice, and due to data limitations, only a limited number of the most significant geometric and traffic variables (in terms of accident occurrence) are considered in the determination of the set of reference populations. For example, such a population could include all rural four-legged intersections with heavy traffic volumes and stop signs on minor legs; another one could group all intersections having similar features but less traffic, and so on. The determination of the set of reference populations requires expertise in road safety engineering, as well as in-depth knowledge of the road network and information available in existing databases.
2. calculate the difference in safety between the site and the reference population. This yields a value for its potential for improvement (P.I.):

   If the accident frequency is the selected identification criterion ***(Section 5.3.1)***, the P.I. value represents the estimated accident reduction expected from road improvements. Those sites with the highest P.I.s should be selected first for ***safety diagnoses***.

$$P.I._j = f_j - f_{rp} \qquad \text{[Eq. 5-1]}$$

where:

$P.I._j$ = potential for improvement at site j

f_j = accident frequency at site j

f_{rp} = average accident frequency (reference population)

[1] Preferably, this objective should be enlarged to include sites where accident frequencies are likely to be efficiently reduced through actions that are not related to road safety engineering.

Criteria other than accident frequency are often computed to identify deviant road locations ***(Section 5.3.1)***. Accordingly, a more generic form for the equation 5-1 is:

$$P.I._j = IC_j - IC_{rp} \qquad \text{[Eq. 5-2]}$$

where:

IC_j = value of the identification criterion at site j

IC_{rp} = average value of the identification criterion (reference population)

More details and a numerical example are provided in ***Appendix 5-1 – (Reference population)***.

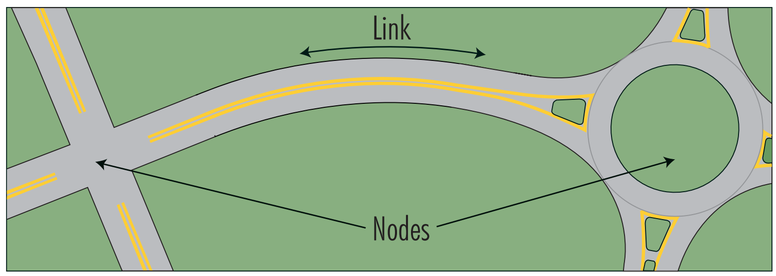
Nodes and links

Blackspots are often located at ***nodes*** of the road network, i.e. at crossing points between two or more roads. Several types of nodes should be distinguished as they have different safety performances:

- conventional intersections (cross, T, X, Y, multiple legs);
- roundabouts;
- interchanges.

Road segments between two nodes are called links. Accident concentrations are also often found on short links such as sharp curves or steep hills.

Figure 5-4 Nodes and links

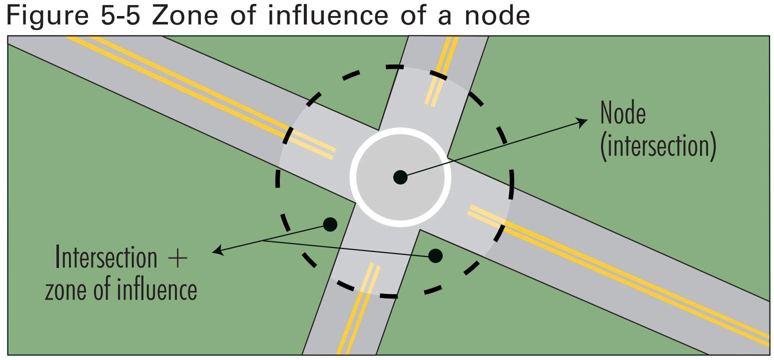


Since accident densities differ at nodes and along links, these two types of sites must be distinguished during the identification process. Otherwise, some links could be identified as deviant simply because they contain one or more nodes.

Nodes

For identification purposes, the dimension of a node needs to be extended beyond its physical location to include a zone of influence in which accidents may be linked to the presence of the node (Figure 5-5). A typical example is that of a rear-end collision occurring away from the intersection due to the presence of a line of vehicles.

Figure 5-5 Zone of influence of a node



The dimension of the zone of influence may range from a few tens of meters to some one hundred meters, depending on the site's features and context. Larger zones reduce the probability of overlooking relevant accidents but increase the likelihood of taking into account unrelated events (and vice-versa). The relevance of accidents occurring in the zone of influence must therefore be verified during the diagnosis.

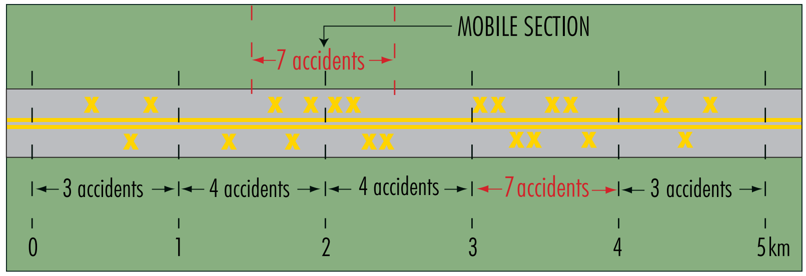
To avoid biases at the identification stage, the same zone of influence should be used for all similar nodes in similar road environments.

Links

The unit length for a road link that is used at the identification stage has an impact on the choice of sites that are detected. Overly long links can prevent the detection of local accident concentrations, which will be diluted in the surroundings, and on the other hand, overly short links will have either 0 or 1 accident, in which case the information is of little use. Link lengths ranging from 500 m to 1,000 m are usually adequate for identification purposes.

Either *fixed sections* or *mobile sections* can be used to identify hazardous links. The use of fixed sections is simple: a fixed origin is determined and the road is subdivided from this point into n successive sections of equal length. However, it can prevent the detection of accident concentrations located at the boundary of two adjacent sections. The use of mobile sections that shift a constant section length, e.g. 1 km, along the road by means of a short increment, e.g. 100 m, eliminates this problem. Figure 5-6 illustrates the usefulness of this method. Assuming a detection threshold of 7 accidents/km, the accident concentration located between kilometers 1.5 and 2.5 would not be detected with a fixed section, but it would be with a mobile section.

Figure 5-6 Comparison - Fixed and mobile sections



Computerized databases now simplify the use of mobile sections and increase the possibilities. For example, the beginning of each constant section could coincide with the exact location of each accident in the database, which increases accuracy while avoiding useless computations. Hauer (2004) instead recommends using not only variable starting points but also sections of variable lengths.

5.2.2 OTHER TARGETS

As previously mentioned, sites that are identified as deviant do not necessarily need to be of limited dimension. In fact, a comprehensive road related safety program should be based on the detection of different types of problem areas. There are a number of possible combinations. In France for instance, the "Service d'études techniques des routes et autoroutes" (1992) distinguishes 4 types of targets: specific points (blackspots), cross-town links, routes, and networks. In Great Britain, four action strategies are proposed: single sites (blackspots), mass action, route action and area action. The accident-reduction objectives vary according to the strategy adopted:

Table 5-1 Accident reduction strategies (Great Britain)

STRATEGY	DESCRIPTION	OPERATIONAL OBJECTIVES
SINGLE SITE (blackspots)	Individual locations considered to be hazardous due to the total number of accidents recorded within a specific, recent period of time. The location might be a confined area (up to 400 m in diameter), or a short length of road (around 300 to 500 m).	- average accident reduction of 33% - minimum first-year economic rate of return of 200% at each site
MASS ACTION	Accident data for the whole or a selected part of a highway authority area are sought to identify the locations of accidents having factors for which there is a well-tried engineering remedy, e.g. skidding on a wet road surface/improving skid resistance. A selection of several sites should be made from those having the highest number of accidents involving a particular factor.	- average accident reduction of at least 20% - minimum first-year economic rate of return of 100%
ROUTE ACTION	The distribution of accidents on routes of a particular category is determined in order to identify those road sections having more accidents than expected for that type of road and level of traffic. The search process uses a highway unit of up to 25-30 km in length within a time period of 3 or 5 years.	- average accident reduction of 25% - minimum first-year economic rate of return of 100%
AREA ACTION	The area-wide approach looks at the distribution of accidents throughout an urban area or within a selected part, for a specific period of time. The time period can be 3 or 5 years.	- average accident reduction of 30% - minimum first-year economic rate of return of 50%

Source: Royal Society for the Prevention of Accidents, 2002

5.3 ACCIDENT-BASED IDENTIFICATION

In this chapter, emphasis is placed on the description of methods that rely on accident analyses to identify safety problems. These are often called "reactive methods" since a number of accidents must first have occurred (and have been reported) to trigger action.

The beginning of ***Section 5.3.1*** describes simple criteria that have long been used to detect road safety deficiencies: accident frequency, accident rate and accident severity. Then, more sophisticated criteria are discussed (accident prediction models - also called "safety performance functions" - and empirical Bayes methods). Again, these various criteria can detect not only blackspots, but also larger targets.

Section 5.3.2 then describes how accident data can alternatively be used to identify road locations that deserve further investigation because of an abnormal concentration of a specific accident pattern.

Calculators have been included in the CD-ROM version of the manual to facilitate the computations associated with the use of these criteria. The icon indicates that a calculator is available and it can be accessed by clicking with the mouse on its name.

Appendix 5-1 discusses methodological issues that may have a significant impact on the outcome of an accident-based identification (***reference population, random nature of accidents, accident period, selection bias*** and ***regression to the mean***).

5.3.1 ALL ACCIDENT DATA

A simple location of reported accidents on a road map suffices to reveal accident clusters. When the number of accidents in these clusters is added up, the various sites of a road network can then be ranked according to their ***accident frequency***. This constitutes the oldest way to identify road safety deficiencies and it is still widely used as it minimizes both data requirements and computations. However, this method suffers from a number of shortcomings ***(Accident frequency – main shortcomings)*** that have led to the development of several other identification criteria described in this section.

Example

An example is presented along with the description of accident-based criteria. The characteristics of the sites considered are as follows:

- 55 rural road sections;
- section length (fixed): 500 m;
- accident period: 3 years;
- number of accidents per section: from 0 to 14;
- average annual daily traffic (AADT) on each section: from 800 to 8,500 vpd.

Detailed data and results are shown in ***Appendix 5-2***.

ACCIDENT FREQUENCY

Description

Accident frequency is the simplest identification criterion. Each accident is located at its point of occurrence on the road network and the total number of accidents reported at each site being considered is added up. Sites are ranked in decreasing order of accident frequency.

A detailed safety analysis is warranted at each site where the accident frequency exceeds a selected investigation threshold (I_T). This threshold may be set arbitrarily, e.g. five or more accidents per year, although it should preferably take into account the available budget.

Procedure - Accident frequency	Example (see *Appendix 5-2*)
1. Locate all accidents reported during the period of analysis.	
2. Define the different reference populations.	
3. For each reference population:	Two-lane rural roads
• calculate the accident frequency at each site;	Accident frequencies range from 0 to 14 accidents. (Column 3 in Table 5-A4)
• calculate the average accident frequency in the reference population: $$f_{rp} = \frac{\sum f_j}{n} \quad \text{[Eq. 5-3]}$$ where: f_{rp} = average accident frequency; f_j = accident frequency at site j of a reference population; n = number of sites	f_{rp} = 258 accidents / 55 sites = 4.69 accidents / site
• determine the minimum accident frequency that warrants a detailed safety analysis (I_T).	I_T = 2 * f_{rp} = 9.38 (9 accidents). Sections 1, 10, 12, 45, 48 and 52 are detected.

Advantages

- simplicity of the criterion;
- sites with a high accident frequency are necessarily detected.

Disadvantages (see box below)

- bias towards high traffic volume sites;
- does not take into account accident severity;
- does not take into account the random nature of accidents.

Accident frequency – Main shortcomings

Bias towards high traffic volume sites

Accidents are generally seen to increase with traffic flow. The strength of the relationship between these two variables has allowed the development of numerous statistical models that estimate the number of accidents at a specific location solely on the basis of traffic flow functions[2]. Relying on the accident frequency criterion to identify deviant sites may then prevent the detection of such sites with low traffic flows. Various identification criteria that take into account traffic flow have been defined, with the accident rate being the most popular.

Accident frequency and severity are not necessarily linked

The trauma severity sustained in an accident depends on several factors, some of which are directly related to road characteristics: impact speed, roadside conditions, collision type, etc. For example, traumas are on average much less severe in rear-end collisions occurring in urban areas than in head-on collisions occurring in rural areas. Some accident types and road environments are therefore likely to cause more severe accidents than others. Identification criteria that take into account the trauma severity have been developed.

Accident frequency varies between two observation periods

Even if all conditions could remain unchanged at a site, the number of accidents occurring each year might fluctuate significantly. The relative importance of these fluctuations is directly related to the long-term average of the annual number of accidents at the site considered - the lower this average, the higher these variations. This is a result of the random nature of accidents and it introduces two types of bias to the identification process: some sites that are not deviant will be identified as being so and vice versa ***(selection bias)***. Some identification criteria reduce these biases.

[2] However, the relationship between accident and traffic is not necessarily linear (e.g. Satterthwaithe, 1981). The functional form "Accidents = a(traffic volume)^b" is often used.

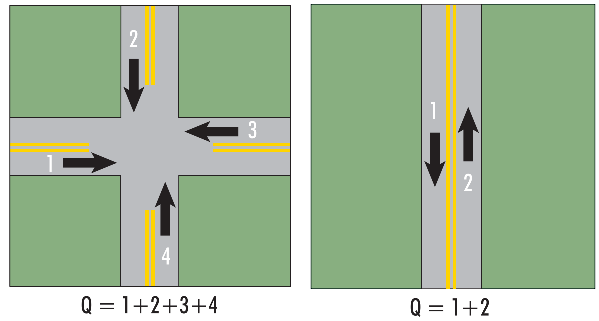
ACCIDENT RATE

Description

By definition, an accident rate is a ratio between a number of accidents and an exposure measure. In road engineering studies, traffic volume is the most commonly used exposure unit (Figure 5-7):

- at road intersections ***(nodes)***, the traffic considered is the sum of entering vehicles[3];
- on road ***links***, it is the sum of vehicles travelling in both directions. The length of the link must also be accounted for.

Figure 5-7 Traffic volumes – Accident rates



Procedure - Accident rate	Example (see *Appendix 5-2*)
1. Locate all accidents reported during the period of analysis.	
2. Define the different reference populations.	
3. For each reference population: • calculate the accident rate at each site: $$R_j = \frac{f_j \times 10^6}{365.25 \times PL_jQ} \quad \text{[Eq. 5-4]}$$ where: R_j = accident rate of site j (acc./Mveh-km) f_j = accident frequency at site j P = period of analysis (years) L_j = section's length of site j (km) Q_j = average annual daily traffic of site j (AADT)	Two-lane rural roads For section # 1: $$R_1 = \frac{9 \times 10^6}{365.25 \times 3 \times 0.5 \times 6{,}050}$$ = 2.72 acc./Mveh-km Column 4 in Table 5-A4; Accident rates range from 0 to 4.73 acc./Mveh-km.
• calculate the average accident rate for the reference population: $$R_{rp} = \frac{\sum f_j \times 10^6}{365.25 \times P \times \sum L_j \times Q_w} \quad \text{[Eq. 5-5]}$$ where: R_{rp} = average accident rate (acc./Mveh-km) f_j = accident frequency at site j P = period of analysis (years) L_j = length of section j (km) Q_w = weighted average annual daily traffic (AADT) $$Q_w = \frac{\sum (Q_j \times L_j)}{\sum L_j}$$ Q_j = AADT of site j	$$R_{rp} = \frac{258 \times 10^6}{365.25 \times 3 \times 27.5 \times 4{,}406}$$ = 1.94 acc./Mveh-km
• determine the minimum accident rate that warrants a detailed safety analysis (I_T).	$I_T = 2 \times R_{rp}$ $= 2 \times 1.94 = 3.88$ acc./Mveh-km Sections 10, 33, 35 and 39 are detected.

Note: For intersections, L_j is not considered and accident rates are expressed in terms of acc./Mveh.

[ACCIDENT RATE]

[3] Although intersection accident rates are generally calculated by summing up the total entering volume, the product of major and minor flows raised to a power has often been shown to be more representative of the accident risk at intersections ($Acc = F1^a \times F2^b$). Using this relationship to calculate the Q value in equation 5-4 could improve accuracy.

Advantages

- takes into account traffic exposure;
- is the most widely used identification criterion, which facilitates comparisons.

Disadvantages

- traffic volume must be known at each site;
- does not take into account the random nature of accidents;
- bias towards low-traffic roads (a random variation of a few accidents per period will significantly modify the accident rate value at such sites);
- does not take into account accident severity;
- assumes a linear relationship between traffic volume and accidents; this may be a source of error ***(accident rate - linear hypothesis)***.

CRITICAL ACCIDENT RATE

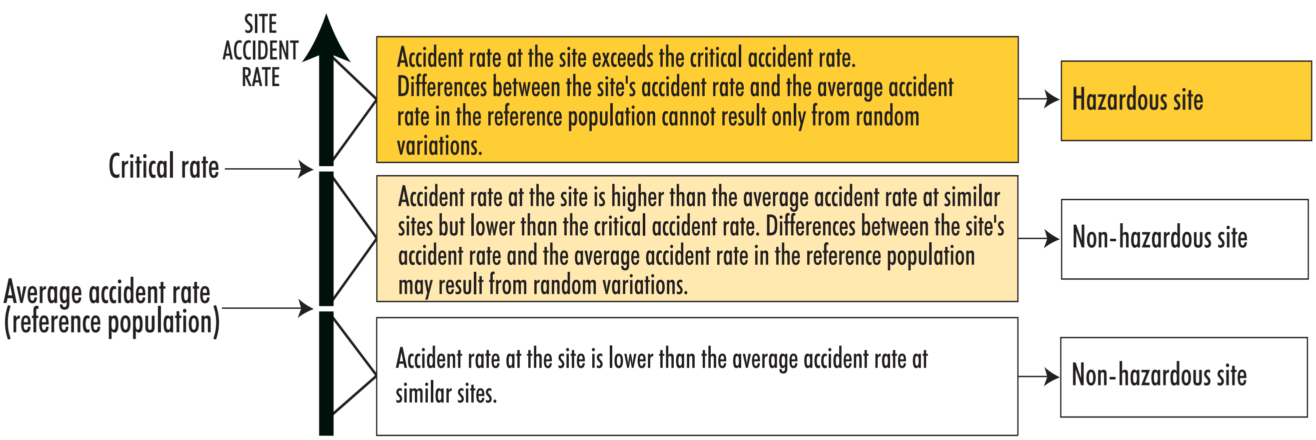
Description

This criterion makes use of methods originally developed to conduct quality controls in industry (Norden et al., 1956). It compares the accident rate at a site with the average accident rate calculated in a group of sites having similar characteristics ***(reference population)***.

As for the other criteria described in this section, the basic assumption is that sites having similar characteristics should have similar ***safety levels***. Despite this assumption and due to the random nature of accidents, a site's accident rate may very well exceed the average accident rate of its reference population without being necessarily hazardous. However, when a site's accident rate becomes too high compared to similar sites, random variations no longer suffice to explain the observed difference. The site is then considered to be deviant.

This criterion calculates the minimum accident rate value at which the site is considered hazardous. This value - the critical accident rate - increases with the chosen statistical level of confidence.

Figure 5-8 Average accident rate and critical accident rate



Procedure - Critical accident rate	Example (see *Appendix 5-2*)
1. Locate all accidents reported during the period of analysis.	
2. Define the different reference populations.	
3. For each reference population: • calculate the accident rate at each site (equation 5-4) • calculate the average accident rate for the reference population (equation 5-5) • calculate the critical rate at each site:	Two-lane rural roads Column 4 in Table 5-A4 For section 1: $R_1 = 2.72$ acc/Mveh-km $R_{rp} = 1.94$ acc./Mveh-km
$R_{cj} = R_{rp} + K\sqrt{\frac{R_{rp} \times 10^6}{365.25 \times PL_jQ_j} + \frac{1 \times 10^6}{730.5 \times PL_jQ_j}}$ [Eq.5-6] where: R_{cj} = critical accident rate at site j (acc./Mveh-km) R_{rp} = average accident rate at similar sites (acc./Mveh-km) K = statistical constant 1.036 for a level of confidence of 85% 1.282 for a level of confidence of 90% 1.645 for a level of confidence of 95% 2.326 for a level of confidence of 99% P = period of analysis (years) L_j = length of section j (km) Q_j = average annual daily traffic at site j (AADT)	For section No.1, with a level of confidence of 85% $R_{c1} = 1.94 + 1.036\sqrt{\frac{1.94 \times 10^6}{365.25 \times 3 \times 0.5 \times 6{,}050} + \frac{1 \times 10^6}{730.5 \times 3 \times 0.5 \times 6{,}050}}$ $R_{c1} = 2.89$ acc. /Mveh-km Column 5 in Table 5-A4; Critical accident rates range from 2.72 to 5.27 acc. /Mveh-km.
• compare the accident rate and critical accident rate at each site. A detailed safety analysis is justified when the accident rate is higher than the critical rate.	Sections 10, 35 and 45 are detected (85% level of confidence).

Note: For intersections, L is not considered and critical accident rates are expressed in terms of acc./Mveh.

[CRITICAL ACCIDENT RATE]

Advantages

- takes into account the random nature of accidents;
- takes into account traffic exposure.

Disadvantages

- complexity of the method;
- does not take into account accident severity;
- assumes a linear relationship between traffic volume and accidents; this may be a source of error ***(critical accident rate - linear hypothesis)***.

EQUIVALENT PROPERTY DAMAGE ONLY INDEX (EPDO INDEX)

Description

The EPDO index attaches a greater importance to more serious trauma by ascribing to each accident a weight that is a function of the worst level of injury sustained by one of the accident victims. Thus, an accident causing minor injuries to two individuals and a serious injury to a third person is rated a serious accident. An accident that seriously injures two people has the same rating. Various weighting factors have been suggested. Agent (1973) proposed:

- property damage only accident (PDO): 1;
- minor injury accident: 3.5;
- serious injury or fatal accident: 9.5.

Procedure - EPDO	Example (see *Appendix 5-2*)
1. Locate all accidents reported during the period of analysis.	
2. Define the different reference populations.	
3. Select the weighting factors for each trauma category.	The weighting factors proposed by Agent (1973) are used in this example: 1.0 for property damage only accidents (PDO) 3.5 for minor injury accidents 9.5 for serious injury or fatal accidents
4. For each reference population:	Two-lane rural roads
• calculate the EPDO index and the average EPDO index ($\overline{EPDO}$) at each site:	For section No. 1:
$EPDO_j = \sum w_i \times f_{ij}$ [Eq.5-7]	$EPDO_1 = 2 \times 9.5 + 3 \times 3.5 + 4 \times 1 = 33.5$
where:	Column 6 in Table 5-A4.
$EPDO_j$ = equivalent property damage only index at site j w_i = weighting factor for an accident severity i f_{ij} = frequency of a severity i accident at site j	EPDO range from 0 to 33.5
$\overline{EPDO}_j = EPDO_j / f_j$ [Eq.5-8]	$\overline{EPDO}_1 = 33.5 / 9 = 3.72$
where: $\overline{EPDO}_j$ = average EPDO index at site j	Column 7 in Table 5-A4.
f_j = total accident frequency at site j	$\overline{EPDO}$ range from 0 to 4.67
• calculate the average $\overline{EPDO}$ in the reference population ($\overline{EPDO}_{rp}$): $\overline{EPDO}_{rp} = \dfrac{\sum \sum w_i \times f_{ij}}{\sum f_j}$ [Eq.5-9]	$\overline{EPDO}_{rp} = 2.16$
• determine the minimum EPDO value that warrants a detailed safety analysis (I_T)	$I_T = 2 \times \overline{EPDO}_{rp}$ $I_T = 2 \times 2.16 = 4.32$ Sections 33 and 49 are detected.

[EPDO INDEX]

Advantages

- takes into account accident severity;
- simplicity of the criterion.

Disadvantages

- does not take into account traffic exposure;
- does not take into account the random nature of accidents;
- bias towards high-speed sites (rural roads).

The weighting factors attributed to each category of severity usually fall well below the actual cost of these accidents. The values recommended by Agent (1973) are still often used in North America (9.5 for serious injury or fatal accidents, 3.5 for slight injury accidents and 1 for PDO). With similar values, greater but not disproportionate attention is given to more severe accidents.

The use of weighting factors that correspond to the real cost of accidents could lead to the under utilization of less serious accident data as it would take up to several hundred PDO accidents to equal one serious accident (e.g. Table 5-2). However, the repeated occurrence of accidents at the same location is a good indicator of road-related deficiencies that should not be overlooked, and the occurrence of a single severe accident at a location may very well not be related to prevailing road conditions.

Table 5-2 Example – Weighting factors based on accident costs

	UNIT COST OF ACCIDENT (US $)	WEIGHTING FACTOR
FATAL	2,600,000	1
SEVERE	180,000	14
SLIGHT	19,000	37
PDO	2,000	1,300

Source: Federal Highway Administration, 1994

RELATIVE SEVERITY INDEX (RSI)

Description

This criterion is based on the following considerations:

1) the severity of trauma sustained in any given accident is affected by several factors, such as the impact speed, impact point on the vehicle, type of vehicle, age and health condition of the occupants, protection devices, etc. Consequently, two accidents of the same type occurring at the same location may cause quite different trauma levels.

2) the average accident severity, as computed on a large number of similar accidents having occurred in similar road environments, is seen as a more stable indicator than the trauma level sustained in a single accident.

The relative severity index (RSI) therefore ascribes to each accident type a weight that is not related to its actual severity but instead to the average severity of several accidents having occurred under similar conditions (e.g. Table 5-3).

Table 5-3 Australian accident costs

CRASH COSTS FOR VICTORIA - 2001

	AU $	
One-vehicle	**Urban**	**Rural**
pedestrian hit crossing road	166,300	183,800
hit permanent obstruction	162,400	163,400
hit animal on road	102,300	79,500
off road, on straight	119,900	146,100
off road, on straight, hit object	177,500	206,600
out of control on road, on straight	98,100	115,700
off road, on curve	146,900	175,900
off road, on curve, hit object	191,700	219,700
out of control on road, on curve	120,100	112,100
Two-vehicle		
intersection (adjacent approaches)	124,000	173,200
head-on	240,300	341,600
opposing turns	132,700	168,600
rear-end	64,200	109,700
lane change	88,500	132,800
parallel lanes, turning	79,900	104,600
U-turn / through	124,600	135,600
vehicles leaving driveway	93,200	129,100
overtaking same direction	97,000	138,000
hit parked vehicle	112,500	202,700
hit railway train	384,400	559,100

Source: Andreassen, 2001 (reproduced with permission)

Procedure - RSI	Example (see *Appendix 5-2*)
1. Locate all accidents reported during the period of analysis.	
2. Define the different reference populations.	
3. For each reference population: • calculate the average cost of each accident type in the reference population; • calculate the RSI and the average $\overline{RSI}$ (RSI) at each site; $$RSI_j = \sum f_{ij} \times C_i \quad [Eq.\ 5\text{-}10]$$ where: RSI_j = relative severity index at site j f_{ij} = frequency of a type i accident at site j C_i = average cost of a type i accident $$\overline{RSI}_j = RSI_j / f_j \quad [Eq.\ 5\text{-}11]$$ where: f_j = total accident frequency of site j	Two-lane rural roads A cost grid must be developed, based on nationwide data. Values of Table 5-3 are used in this example. For section No. 1: RSI_1 = (2 x \$104,600) + (2 x \$173,200) + (1 x \$175,900) + (2 x \$109,700) + (2 x \$341,600) = \$1,634,100 $\overline{RSI}_1$ = \$1,634,100 / 9 = \$181,567 Columns 8 and 9 in Table 5-19 RSI range from \$0 to \$2,707,500 $\overline{RSI}$ range from \$0 to \$237,200
• calculate the population average RSI ($\overline{RSI}_{rp}$); $$\overline{RSI}_{rp} = \frac{\sum\sum (C_i \times f_{ij})}{\sum f_j} \quad [Eq.\ 5\text{-}12]$$ • determine the minimum value of $\overline{RSI}$ that warrants a detailed safety analysis (I_T).	$\overline{RSI}_{rp}$ = \$162,817 $I_T = 2 \times \overline{RSI}_{rp}$ I_T = 2 x \$162,817 = \$325,634 No section is detected by this criterion.

Advantages

- takes into account accident severity;
- reduces the influence of exogenous variables having an impact on accident severity.

Disadvantages

- the development of the cost grid may be complex;
- does not take into account traffic exposure;
- does not take into account the random nature of accidents;
- bias towards high-speed sites (rural roads).

COMBINED CRITERIA

Description

Various combinations of criteria can be used to reduce the shortcomings of individual criteria (Table 5-4).

For illustration purposes, three possible variants are described:

- combined thresholds;
- individual threshold;
- individual threshold with minimum values.

Table 5-4 Typical bias of single criteria

CRITERION	BIAS TOWARDS
ACCIDENT FREQUENCY	high-volume sites
ACCIDENT RATE	low-volume sites
EPDO, RSI	high-speed sites

Combined thresholds

- more than one investigation criterion is used to detect deviant situations, e.g. an accident frequency of 5 or more accidents per period and an accident rate of 3.0 or more acc./Mveh-km;
- all investigation thresholds must be reached in order for a site to be detected.

Individual threshold

- more than one investigation criterion is used to detect deviant situations, e.g. an accident frequency of 5 or more accidents per period and an accident rate of 3.0 or more acc./Mveh-km;
- a site is detected if at least one investigation threshold is satisfied, regardless of the value of the other criteria.

Individual threshold and minimum criteria values

- sites are ranked in decreasing order of one criterion. Minimum investigation thresholds are set for the other criteria considered, e.g. ranking sites by accident rate and keeping only those sites with a minimum of 3.0 accidents per period.

The following procedure describes how to use accident frequency and accident rate with combined thresholds.

Procedure – Combination of frequency and rate	Example (see *Appendix 5-2*)
1. Locate all accidents reported during the period of analysis.	
2. Define the different reference populations.	
3. For each reference population:	Two-lane rural roads
• calculate the accident frequency and accident rate at each site (Equation 5-4);	Columns 3 and 4 in Table 5-A4.
• calculate the average accident frequency and the average accident rate in the reference population (Equations 5-3 and 5-5);	f_{rp}: 4.69 accidents per site R_{rp}: 1.94 acc./Mveh-km
• determine the minimum accident frequency and the minimum accident rate that warrant a detailed safety analysis;	Minimum investigation thresholds: $2 \times f_{rp}$ and $2 \times R_{rp}$ $I_T = 2 \times f_{rp} = 2 \times 4.69 = 9.38$ accidents $I_T = 2 \times R_{rp} = 2 \times 1.94 = 3.88$ acc./Mveh-km
• rank the sites according to these detection criteria.	According to this combination of criteria, section 10 warrants a detailed analysis.

ACCIDENT PREDICTION MODELS

As previously indicated, the identification approach described in this chapter is based on a comparison of the safety level at a specific site with the average safety level in the chosen reference population. When this comparison is based on the accident frequency criteria, the potential for improvement (P.I.) at site j is[4]:

$$P.I._j = f_j - f_{rp}$$

where:

$P.I._j$ = potential for improvement at site j

f_j = accident frequency at site j

f_{rp} = average accident frequency (reference population)

In practice, it may be impossible to estimate f_{rp} with adequate accuracy when a sufficient number of sites having similar characteristics cannot be found ***(reference population)***. In such cases, the development of accident prediction models may alleviate this problem. These models estimate the number of accidents based on functions of independent variables. The following model form is often used:

$$\text{Accidents} = a(\text{traffic function})^b \qquad \text{[Eq. 5-13]}$$

With this simple form, the influence that geometric features have on accident occurrence is taken into account by establishing a distinct reference population for each group of sites having similar features and by developing a model for each of these populations. For example, a model could be developed for rural cross intersections, another model for rural T intersections, and so on.

Alternatively, the effect of key geometric road features could also be assessed by developing more complex models that include not only traffic variables (as in equation 5-13), but also geometric variables. Numerous forms of accident prediction models (also called *"safety performance function"*) have been proposed in the literature. Details of methodological issues go beyond the scope of this manual and are described in related publications (e.g. Maycock and Hall, 1984, Hauer, 1997, Hauer, 2004).

When accident prediction models are available, they can be used to calculate the second term of equation 5-1, which becomes:

$$P.I._j = f_j - f_{pj} \qquad \text{[Eq. 5-14]}$$

where:

f_{pj} = estimated accident frequency at site j

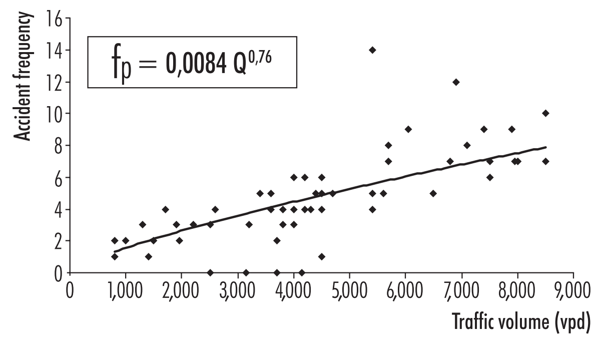
Advantage

- improves the accuracy of the estimated potential for improvement.

Disadvantages

- relative complexity;
- does not take into account the random nature of accidents.

[4] Equation 5-1 is repeated for convenience.

Procedure - Accident prediction models	Example (see *Appendix 5-2*)
1. Locate all accidents reported during the period of analysis.	
2. Define the different reference populations.	
3. For each reference population:	Two-lane rural roads
• determine the accident frequency and traffic volume at each site;	Columns 2 and 3 in Table 5-A4
• develop the accident prediction model for the reference population;	The following model has been fitted to the 55 sections of this example: $f_p = 0.0084\ Q^{0,76}$ where: f_p = predicted accident frequency / 3 years; Q = average annual daily traffic (AADT) 
• calculate the estimated accident frequency at each site using the accident prediction model ($f_{p\,j}$);	For section 1: $f_{p1} = 0.0084 \times 6050^{0,76} = 6.07$ acc./3 years. Column 10 in Table 5-A4: f_p range from 1.31 to 7.84 acc./3 years
• calculate the potential for improvement (P.I.) at each site; $P.I._{\cdot j} = f_j - f_{p\,j}$	For section 1: $P.I._{\cdot 1} = 9 - 6.07 = 2.93$ acc./3 years. Column 11 in Table 5-A4: P.I. range from −4.56 to 8.43 acc./3 years
• rank the sites according to their potential for improvement.	Sections 10, 45, 1, 36 and 52 have the highest potential for improvement.

EMPIRICAL BAYESIAN METHODS

Up to now, the first term of equation 5-1 or 5-2 has been computed based on the accident frequency reported at the site over a relatively short period of time ***(accident period)***. As previously mentioned, this value may be submitted to strong random variations, particularly when the average accident frequency is low ***(random nature of accidents)***.

In order to reduce the extent of this problem that may introduce biases in the identification results ***(selection bias)***, researchers have proposed the use of empirical bayesian (EB) methods. EB methods are based on a concept that is somewhat similar to that of potential for improvement, i.e. that a site's safety level is influenced by its characteristics. Consequently, the knowledge of the average safety level at sites having characteristics that are similar to those of the site being analyzed offers some indication of its expected safety performance.

EB methods provide a way to combine a site's accident history with the accident history of several sites having similar characteristics ***(reference population)*** in order to calculate the site's adjusted accident frequency (f_{EB}). This adjusted frequency is seen as a better approximation of the long-term average accident frequency on which safety decisions should be based[5]. At first, the method of moments has been proposed to combine these two pieces of information but multivariate statistical models are now seen as a more practical method for this purpose. The EB method of moments is nevertheless described in the following paragraphs, as it is based on the use of two simple statistics, the mean and variance of the reference population, which facilitates the understanding of the underlying principles of the EB method.

EB – Method of moments

The method of moments requires calculating the population's *mean accident frequency* and its *variance*. These two statistics are then used to adjust the accident frequency at the site under study:

$$f_{EB_j} = f_j + \frac{f_{rp}}{s^2}(f_{rp} - f_j) \qquad \text{[Eq. 5-15]}$$

where:

f_{EB_j} = EB adjusted accident frequency at site j

f_j = accident frequency at site j

f_{rp} = average accident frequency (reference population) $= \frac{\sum f_j}{n}$

n = number of sites (reference population)

s^2 = variance of the accident frequency (reference population) $= \frac{\sum (f_j - f_{rp})^2}{n-1}$

The EB adjusted accident frequency consists of 2 terms:

f_j = observed accident frequency at the site during the period considered (classical estimate),

$\frac{f_{rp}}{s^2}(f_{rp} - f_j)$ = correction factor, the importance of which varies according to the homogeneity of the reference population. As the homogeneity increases, s^2 decreases, thus increasing the magnitude of the correction (and inversely).

EB – Regression method

The main problem associated with the use of empirical Bayes methods lies in the difficulty of defining homogeneous reference populations (Elvik, 1988). In order to overcome this problem, Hauer suggests using statistical regression techniques to develop accident prediction models (or *"safety performance functions"*) that serve as reference populations. Details are explained in recent Hauer's articles (Hauer, 1992, 2002, 2004), but the basic principles are as follows :

1. A multivariate statistical model (safety performance function), that relates accident frequencies to a set of independent variable first needs to be developed and the value of the overdispersion parameter must be estimated during this development. This model is used to calculate a site's predicted accident frequency (f_{pj}).
2. The adjusted accident frequency at the site f_{EB} is computed by combining this predicted accident frequency (f_{pj}) and the number of accidents reported at the site (f_j). The relative weight attributed to f_{pj} and f_j is related to a weight parameter (w), as shown in equation 5-16.

$$f_{EBj} = w * f_{pj} + (1\text{-}w) * f_j \qquad \text{[Eq. 5-16]}$$

where :

f_{pj} = predicted accident frequency at site j

w = weight of the predicted accident frequency

5 To be more accurate, the estimated safety level of a site, ($\hat{m}$) rather than its accident frequency, should have been used as the first term of equation 5-1. However, since classical methods use a few years of accident data at the site to estimate $\hat{m}$, the two terms are equivalent and the more intuitive concept of accident frequency has been used.

When “w” increases, more importance is given to the accident frequency calculated with the safety performance function and when it decreases, more weight is given to the site accident frequency.

3. The value of “w” is influenced by the relative homogeneity of the reference population that has been used to develop the statistical model (as expressed by the over dispersion parameter) and it is also influenced by the value of the number of accidents predicted by the safety performance (as this frequency increases, more importance is placed on the site accident frequency).

A procedure describing the use of EB method of moments is described below. In order to apply the more practical EB multivariate statistical method, the reader should beforehand get familiarized with the above suggested references related to statistical modeling and EB methods.

Potential for improvement

In summary, the basic equation of the potential for improvement is (equation 5-1):

$$P.I._j = f_j - f_{rp}$$

When the EB accident frequency is calculated, and an accident prediction model is also available, Equation 5-1 then becomes:

$$P.I._j = f_{EBj} - f_{pj} \qquad \text{[Eq. 5-17]}$$

Procedure - EB method of moments	Example (see *Appendix 5-2*)
1. Locate all accidents reported during the period of analysis.	
2. Define the different reference populations.	
3. For each reference population:	Two-lane rural roads
• calculate the accident frequency at each site;	Column 3 in Table 5-A4
• calculate f_{rp} and s^2 for the reference population: $f_{rp} = \frac{\sum f_j}{n}$ $\quad s^2 = \frac{\sum (f_j - f_{rp})^2}{n-1}$	f_{rp} = 4.69 s^2 = 8.85
• calculate the EB adjusted accident frequency at each site (f_{EB}): $f_{EBj} = f_j + \frac{f_{rp}}{s^2}(f_{rp} - f_j)$	For section 1: $f_{EB1} = 9 + \frac{4.69}{8.85}(4.69 - 9) = 6.72$ Column 12 in Table 5-A4 f_{EB} range from 2.49 to 9.06.
• calculate the potential for improvement (P. I.) at each site: $P.I._j = f_{EBj} - f_{pj}$ where: f_{EBj} = EB adjusted accident frequency at site j f_{pj} = estimated accident frequency at site j	Column 13 in Table 5-A4 indicates the P.I. of each section. For section 1: $P.I._1 = 6.72 - 6.07 = 0.65$ P.I. ranges from −2.07 to 3.50
• rank the sites according to potential for improvement.	Sections 10, 39, 35, 33 and 7 have the highest potential for improvement.

Advantages

- takes into account the random nature of accidents;
- improves the accuracy of the estimated potential for improvement.

Disadvantage

- relative complexity.

5.3.2 ACCIDENT PATTERNS

A road network's safety deficiencies are usually identified by using one or more of the criteria described in ***Section 5.3.1***. Such criteria detect accident concentrations, although the nature of the problems encountered is generally unknown at the time of identification. A complementary identification approach, which consists of searching for deviant accident patterns, may also be considered.

If a clear accident pattern can be found for which a cost-effective treatment is known, an action may be justified even though the overall accident frequency is not abnormally high. For example, a concentration of night-time accidents at a site may justify the installation of a road lighting system even though the overall number of accidents is not abnormal.

Given that the “normality” is strongly influenced by the characteristics of the site being analyzed, a comparison between accident features at the site and corresponding features at similar sites is once again recommended ***(reference population)***.

In order to identify deviant patterns with an acceptable level of confidence, the number of accidents considered must be sufficiently high. Consequently, this identification approach is more suited to the most frequent collision types, at locations where traffic volumes are high and for larger sites (route, area, network).

Various statistical techniques can be used to identify deviant accident patterns. The following paragraphs describe how the properties of the binomial distribution can be applied to this end.

Binomial proportion

The properties of the binomial distribution can be used to calculate the probability of observing a number of accidents of a given type i at a site j (f_{ij}) when the total number of accidents at this site (f_j) and the average proportion of this type of accident in a population of similar sites (p_i) are known:

$$p(f_{ij}) = \frac{f_j!}{f_{ij}!\,(f_j - f_{ij})!} \times p_i^{f_{ij}}(1 - p_i)^{f_j - f_{ij}} \qquad \text{[Eq. 5-18]}$$

where:

f_{ij} = frequency of type i accidents at site j
f_j = total accident frequency at site j
p_i = average proportion of a type i accident in the reference population.

Accordingly, the probability of observing fewer than f_{ij} accidents of type i at site j is:

$$P(F_{ij} < f_{ij}) = \sum_{k=0}^{f_{ij}-1} \frac{f_j!}{k!(f_j - k)!} p_i^k (1 - p_i)^{f_j - k} \qquad \text{[Eq. 5-19]}$$

And the probability of observing f_{ij} or more accidents is:

$$P(F_{ij} \geq f_{ij}) = 1 - P(F_{ij} < f_{ij}) \quad \text{[Eq. 5-20]}$$

When $P(F_{ij} \geq f_{ij})$ is low, the frequency of the type of accident under study is abnormally high.

Procedure - Binomial proportion

1. Locate all accidents reported during the period of analysis.
2. Define the different reference populations
3. For each reference population:
   - calculate the total accident frequency and the frequency of each type of accident considered, at each site;
   - calculate the proportion of each type of accident considered in the reference population;
   - calculate $P(F_{ij} \geq f_{ij})$, based on equation 5-20.

Example

Two-lane rural roads

Surface conditions (reference population and section #45): Of the 12 accidents reported on section #45, 7 have occurred under wet-surface conditions (58%). The equivalent proportion in the reference population is 27%.

	REFERENCE POPULATION		SECTION #45	
Surface	Frequency	Proportion	Frequency	Proportion
Dry	145	0.56	5	0.42
Wet	69	0.27	7	0.58
Icy	30	0.12	0	0.00
Other	14	0.05	0	0.00
TOTAL	258	1.00	12	1.00

For wet-surface conditions:

The probability of observing 0, 1, ...6 wet surface accidents on section #45 and the corresponding cumulative distributions are shown in the table below.

f	$p(f_{ij})$	$P(f_{ij})$
0	0.0229	0.0229
1	0.1016	0.1245
2	0.2068	0.3313
3	0.2549	0.5862
4	0.2122	0.7984
5	0.1255	0.9239
6	0.0542	0.9781

The probability of observing 6 or fewer wet-surface accidents is 98%. Consequently, the probability of observing 7 or more accidents is only 2%.

(the frequency of wet-surface accidents at the site is abnormally high).

[BINOMIAL TEST]

Additional notes - Accident patterns

This section has described how to determine whether the occurrence of a given type of accident is abnormally high at a given site. By extension, similar methods can also be used to detect other types of problems and even some potential treatments. For instance:

- road deficiencies that contribute to more than one type of accident.

  Example: hazardous horizontal curves are often characterized by a high proportion of head-on collisions, sideswipes and off-the-road accidents. It might then be useful to identify those curves having a high proportion of these three types of accidents in order to submit them to a detailed safety diagnosis;

- sites that may be well suited to the application of a given treatment.

  Example: asphalting shoulders is a relatively low-cost measure that contributes to a reduction of the three types of accidents considered in the previous example (head-on, sideswipes and off-the-road accidents). It might therefore be useful to search for horizontal curves having a high proportion of these types of accidents in order to verify if asphalting is indeed an appropriate treatment at these locations.

There are many possibilities, depending on the available information. If accident data, road data and traffic data can be linked, queries that integrate these various types of information can be made (e.g. a search for urban intersections with a high proportion of right-angle accidents and heavy conflicting traffic flows at peak hours, that may be potential candidates for traffic signals). Alternatively, it is also possible to make a gross estimate, right from the identification stage, of the maximum amount that could be allocated at a site for safety reasons, by calculating the cost of accidents occurring at this site and again, assuming that the treatment will bring its safety level to the average level observed at similar sites.

Moreover, when the cost of a treatment and the cost of accidents it could eliminate are also known, the identification can go one step further and include a preliminary estimate of the cost-effectiveness of a given type of action (Persaud et al., 1999).

With current technologies and knowledge, identification procedures can now be much more sophisticated than a few decades ago. Analysts should make good use of these possibilities in order to improve the efficiency of their work, rather than relying only on traditional identification methods.

5.3.3 CONCLUDING REMARKS – ACCIDENT-BASED CRITERIA

The main accident criteria that can be used to detect road safety deficiencies have been described in this section. Some are quite simple (accident frequency, accident rate and accident severity) while others are more sophisticated (accident prediction models and empirical Bayesian methods).

Sites identified as hazardous may differ depending on which identification criterion is used. As mentioned previously, the accident frequency tends to detect more sites with higher traffic flows, while the accident rate detects more sites with lower traffic flows and accident severity detects more sites in rural environments. Each of them highlights problems from a different perspective and it appears as a good practice to analyse the safety performance of a road network from more than one angle:

- a high concentration of accidents at the same location is in itself a strong indicator of a road related problem that should warrant a safety diagnosis;
- the accident rate measures the level of risk faced by road users (remember that accident rate is a ratio of accidents over exposure). When road users travelling at a specific location face an abnormally high risk, corrective actions should be taken;
- reducing road fatalities and injuries should be the ultimate objective of any road safety action and accordingly, it is sensible to give special attention to those sites where more severe accidents occur.

The combination of empirical bayesian methods and multivariate statistical models are now seen as a more accurate method of identification of road safety problems (than traditional methods) as it reduces selection biases related to the random nature of accidents. While this increased sophistication might not be necessary when problems are obvious, which is likely to be the case in the early stages of road safety interventions, the application of these methods can be greatly facilitated by making a proper use of inexpensive computer technologies.

Throughout this chapter, the identification has been based solely on the concept of potential for improvement, i.e. on comparing a site's safety level with that of a group of sites having similar characteristics (reference population). As a result, the worst sites of a given type are identified. It should be recognized that other identification strategies can also be quite useful for detecting deviant sites:

- detection of the worst sites of a road network, using the criteria described in ***Section 5.3.1*** and ranking sites in decreasing order without considering the reference population to which they belong;
- detection of a safety deterioration at a site between two accident periods; the Poisson test is recommended for this purpose.

[POISSON TEST]

In the example of ***Section 5.3.1***, two main investigation thresholds have been used:

- the value of the identification criterion at the site is at least twice that of the average value of the criterion in the reference population, and
- ranking of sites in decreasing order of ***potential for improvement***.

Several other investigation thresholds could have been used. For example, when the standard error of the reference population is known, the scaled deviation of the potential for improvement can be calculated and sites can be ranked based on the statistic *"potential for improvement/standard error"*. This reduces the risk of identifying a site because of a random peak in accidents.

Example – Summary results

The following table presents a summary of the results obtained with the numerical example given in Section 5.3.1 (see ***Appendix 5-2*** for details).

Table 5-5 Summary of sections identified as hazardous

	SECTION											
CRITERION	1	7	10	12	33	35	36	39	45	48	49	52
ACCIDENT FREQUENCY	X		X	X					X	X		X
ACCIDENT RATE			X		X	X		X				
CRITICAL ACCIDENT RATE			X			X			X			
EPDO					X						X	
RSI												
COMBINED (RATE AND FREQUENCY)			X									
ACCIDENT PREDICTION MODEL	X		X				X		X			X
EMPIRICAL BAYESIAN METHOD		X	X		X	X		X				

It shows that:

- Section 10 has been detected by 6 of these 8 identification criteria. Clearly, this section has a safety problem. When the problem is obvious, the choice of the identification criteria has less impact on the selection of sites;
- The *accident frequency* criterion detected mostly those sections with high traffic volumes (with the exception of section 10, every section detected has a daily traffic volume of more than 6,000 vehicles, while the average AADT is 4,400 vehicles). On the other hand, the *accident rate* criterion detected mostly sections with low traffic volumes (with the exception of section 10, every section detected has a daily traffic volume of fewer than 2,000 vehicles). This is a typical result for these criteria;
- Three criteria make direct use of the concept of potential for improvement to rank sections based on equation 5-1 or its derivative: accident frequency, accident prediction model and empirical Bayesian (EB) methods. However, there are differences in the sections identified. Results obtained with the accident prediction model are deemed to be more reliable than those obtained with the accident frequency criterion as the estimate of the second term of equation 5-1 is more accurate. Similarly, the result obtained using EB methods is seen to be more reliable than those obtained with the prediction model since it also improves the accuracy of the first term of equation 5-1.

While definitive conclusions cannot be derived from an example, it nevertheless illustrates how the detection of sites may differ depending on the detection criterion used. For this reason, it is strongly recommended to make use of more than one identification criterion and to compare the obtained results.

5.4 PROACTIVE IDENTIFICATION

As the knowledge evolves, safety actions can become more proactive in their nature, seeking to avoid future accidents by:

- treating safety deficiencies of existing networks before accidents occur at these locations;
- ensuring that the proposed features of road projects or traffic schemes are compatible with safe traffic operations.

Various types of proactive actions have long been included in the practices of road authorities, including:

- road network inspections in order to detect hazardous elements. Since the 1960s, guides have been published to help in the identification of these features. (e.g. American Association of State Highway Officials, 1967). For instance, ***Table 5-6*** provides a list of hazardous elements as identified in 1986 by North American practitioners;
- observations at selected sites using procedures and techniques that have been developed to assist in the detection of unsafe features, behaviour or manoeuvres. The *Positive guidance* procedure (Lunenfeld and Alexander, 1990) and ***traffic conflict techniques*** are of particular interest in this area;
- the conduct of impact studies or public inquiries during the development of road projects in order to assess their expected effects on safety, mobility, environment, operating costs, public acceptance, etc.

At the end of the 1980s, formal road safety audit procedures (RSA) were introduced, providing a structured framework to identify safety deficiencies of proposed projects or existing roads, based on an analysis of their features. The main principles of RSA procedures are outlined in ***Section 5.4.1***.

However, even in countries in which RSA procedures have been implemented, several actions that have an impact on safety are still taken without a prior assessment of this impact. Critical evaluations of existing procedures and practices could therefore offer more opportunities for safety improvement, often at low cost. This is discussed in ***Section 5.4.2***.

Road inspection at low speed with a patrol vehicle.

Table 5-6 Hazardous features (identified by U.S. practitioners)

- Slippery pavements; - Concrete or rigid bridge abutments; - Rigid drainage structures; - Rigid supports for signs, luminaires, and signals; - Large rocks or rock walls close to the roadway (particularly along winding roads); - Large trees next to roadway; - Utility poles near roadway; - Improperly placed urban street furniture (plant boxes, benches, etc); - Rigid rural mailboxes; - Locations where large animals often cross the road (deer, cattle, etc.); - Fire hydrants; - Trash and abandoned vehicles next to roadway; - Narrow tunnels, particularly in conjunction with horizontal curves; - Rigid overpass supports or bridge piers; - Buildings near road or street; - Spear-end guardrail or inadequate guardrail (too low, structurally inadequate); - Gore areas with rigid obstacles or steep slopes; - Narrow bridges with restricted sight distances or near horizontal curves; - Bridges that are structurally deficient; - Railroad grade crossings, particularly on high-speed roads with restrictive geometrics and inadequate motorist warning; - Sight-distance restrictions caused by severe horizontal curvature, steep grades, or foliage near road;	- Rough or uneven pavement surface; - Rigid barriers, stone walls, and fences; - Intersections that are hidden, that have multiple (i.e. 5 or more) approaches, or that have restricted sight distances; - Sharp horizontal curvature, particularly with narrow roadways and little or no roadside recovery area; - Points of intersection between auto traffic and other highway users (cyclists, pedestrians, etc.); - Shoulder or pavement drop-off; - Narrow lanes and shoulders, particularly in conjunction with sharp curvature, cluttered roadside, and steep side slope; - Roadway discontinuities (lane drop, change from two-way to one-way road, drastic change in roadway cross-section, etc.); - Numerous driveways, particularly on high-speed or high-volume roadways; - On-street parking too close to intersections or on narrow streets; - Construction zones; - Combinations of elements (e.g. narrow lanes and no shoulders at sharp curve locations with steep side slopes and numerous rigid roadside obstacles); - Inadequate illumination; - Steep grades; - Steep roadside slopes; - Short tapers and/or lack of turn lanes; - Improper signing, delineation, or signal timing; - Traffic circles[6].

Source: Zegeer, 1986

5.4.1 SAFETY AUDITS

Austroads (2002) defines a road safety audit as:

> *"A formal examination of a future road or traffic project or an existing road, in which an independent, qualified team reports on the project's crash potential and safety performance."*

Road safety auditors should assess the safety needs of all road users (motorized and non-motorized).

[6] Not to be confused with "roundabout" (see Federal Highway Administration, 2000, p. 8 ***(http://www.tfhrc.gov/safety/00-0671.pdf)***)

As mentioned in the introduction, safety assessments of existing roads or road projects that are based on the examination of their characteristics are not completely new. What the road safety audit (RSA) movement has done is to formalize these reviews into a systematic process and give then a higher profile (PIARC, 2001). RSAs have been rapidly introduced in several countries, most of which have developed their own RSA manual e.g. Australia (Austroads, 2002), Canada (Transportation Association of Canada, 2001), Denmark (Gaardbo, 1997), England (The Institution of Highways and Transportation, 1996) and New Zealand (Transit New Zealand, 1993). RSA is voluntary in some countries, while in others it is statutory.

RSA formalized the process of safety reviews in many ways. Audit manuals:

1. distinguish between different audit stages. For example, Austroads (2002) suggests four different audit stages for road projects:
   - feasibility study;
   - preliminary design;
   - detailed design;
   - pre-opening.

   It also describes how the audit process can be applied to:
   - roadwork traffic schemes;
   - specific road user groups;
   - off-road land-use developments;
   - existing roads.

2. provide detailed checklists for each audit stage.

3. describe the auditors' required qualifications. Expertise and independence are seen as two essential qualities:
   - audits should be conducted by a small team of specialists having a solid and complementary expertise allowing them to evaluate all aspects that may contribute to accident occurrence: transportation and land-use planning, road design, traffic engineering (operation and maintenance), vehicle dynamics and human factors;
   - auditors must be independent from the team of designers who developed the project, freeing them from constraints imposed during the development phase and allowing them to examine the project with "fresh eyes".

Audits must rely on existing design standards but they must go beyond a simple verification of compliance with standards, which may be unsatisfactory in some circumstances:

> *"Applying standards and practices without considering prevailing circumstances is no substitute for judgment, and brings no assurance of an acceptable end product. Equally, designs prepared without referring to generally accepted standards and practices are not likely to serve the travelling public as intended. Designs based on a combination of sound professional judgment, applicable standards and current practices will generate the most effective highway…"*
>
> Professional Engineers of Ontario, 1998

Benefits of road project audits have been clearly demonstrated in recent studies. Typically, audits account for less than 0.5% of a project's total costs, but they produce significant returns in terms of accident savings and cost-effectiveness (Jordan, 2002).

Safety audits of road projects should therefore be included in the current practices of all road administrations.

Audit of existing roads

Audits of existing roads are aimed at detecting road network safety deficiencies without waiting for accident accumulations. This activity is often called by another name in order to differentiate it from design stage audits (e.g. road safety review, road safety assessment, etc.).

While there are still a number of road authorities that hesitate to conduct this type of audit because of the legal implications that might arise if the identified problems would not be solved rapidly, experience tends to show that this fear is unjustified. On the one hand, road traumas are quite obviously only one of the many health problems of a society and clearly, the annual budget that can be allocated to the improvement of road safety cannot suffice to solve at once every problem that may be identified. The main point is to be able to justify the established list of priorities. On the other hand, because they are duty-bound to care about public safety, road authorities are expected to use state-of-the-art methods to identify a road network's safety deficiencies, propose appropriate remedial actions, and then apply objective methods to prioritize actions. Road safety audits of existing roads can be of great assistance in detecting safety deficiencies.

Due to the scope of the task, these audits are often spread out over several years. After having completed several audits on similar road environments, auditors are likely to find repetitive patterns in the identified key issues. Examples are shown in Table 5-7. Such situations should trigger critical analyses of current practices of a road authority in order to reduce future occurrences of the same problems.

Checklists of ***Appendix 6-3*** can assist in making audits of existing roads.

Table 5-7 Example – Key issues in audits of existing roads

RURAL ROADS	URBAN ROADS
Roadside conditions (steep sideslopes, rigid obstacles, inadequate guardrails)	Management of traffic conflicts at intersections (all non priority manoeuvres, pedestrians and cyclists)
Road alignment	Signage (directional, street names)
Road signs (warning, direction)	Maintenance (road marking and lighting)
Maintenance (road signs, marking, road lighting, vegetation)	Parking management
Road accesses (density, location, geometric features)	Cluttered road environments
Mix of motorized and non motorized road users	Road surface conditions
Road surface conditions	

Inadequate maintenance (vegetation, guardails)

Breakdown of resources between proactive and reactive safety actions

The recent development of RSA procedures raises the issue of budget allocation between proactive actions (taken before accident occurrence) and reactive actions (taken after accident occurrence).

For road projects, it is generally easier to justify implementing the auditors' recommendations, the basic argument being that it is less costly to change a design plan than an existing road with unsafe features. However, even at this stage, it may be difficult to make a decision when the suggested modifications increase costs substantially. Part of the auditors' role is to take cost issues into consideration in their recommendations.

In the case of existing roads, safety investments at sites without accident problems may be difficult to justify when funding is inadequate for correcting high-accident locations. The decision and time of action should be based on the probability of accident occurrence, the expected accident severity, the treatment cost, its efficiency and the level of certainty with respect to this information. Obvious safety deficiencies that can cause serious injury accidents and that can be resolved at a reasonable cost should be corrected immediately. As the potential risk decreases and the treatment cost increases, actions will be incorporated into the planning of improvement projects or to regular maintenance activities.

Road deficiencies that are revealed by both safety audits and accident analyses should justify faster action. Methods for prioritizing recommendations from road safety audits have been recently proposed (e.g. Brodie and Koorey, 2000).

The relative importance of proactive actions is likely to increase over time as a network's blackspots become corrected and as safety knowledge develops.

5.4.2 IDENTIFICATION – A BROADER PERSPECTIVE

Most road authorities allocate a share of their operating budget to the improvement of high-accident locations and the correction of hazardous road elements. However, due to other requirements related to the development and operation of a road network, funding for such specific safety actions is generally quite limited. Nevertheless, most actions taken by a road authority have a safety impact, whether they are initiated for safety reasons or not. If these impacts were properly assessed, accidents could be avoided, often at little or no cost. The recent development of RSAs has marked a major improvement in that direction, but more can be accomplished.

The following paragraphs describe how decisions are currently made by most road administrations - ***decision-making process*** - and then propose general solutions for better incorporating safety concerns in current practices ***(How to broaden the safety perspective)***.

Decision-making process

Broadly stated, a road authority's mission is to satisfy the mobility needs of people and goods and to support socio-economic development, while ensuring that the safety and environmental impacts of the road network are minimized.

To accomplish this mission, the following tasks need to be completed:

- gather information;
- identify action needs;
- develop projects;
- assess anticipated impacts and select actions;
- implement selected actions and evaluate their consequences.

Gather information

In order to identify the most pressing action needs, a road authority uses various sources of information. First and most important, a reliable information system that accurately describes a road network's features must be established ***(Chapter 4)***. Other useful sources of information include:

- employees' knowledge, experience, and expertise;
- external knowledge (literature, experts);
- requests from road users, local population, police officers, etc.

Identify action needs

Based on this information, the performance of a road network is assessed in accordance with the various organizational objectives, such as mobility, road infrastructure quality, environment, safety, and so on. Several performance indicators have been developed to assist in this task (e.g. Table 5-8). Methods for assessing the safety performance of a road network have been described in details in ***Section 5.3***.

Develop projects

Based on the identified needs, various projects are then developed. They may consist of:

- actions aimed at maintaining the integrity of the existing network (road resurfacing, trimming of the vegetation, pavement marking, etc.);
- actions aimed at improving existing road features (installation of improved protection devices, change from a conventional intersection to a roundabout, etc.);
- development of new roads;
- changes to existing procedures/standards/practices: work-zone management procedures, geometric standards, maintenance practices, etc.;
- legal/financial incentives or deterrents (e.g. laws, funding, taxes).

Assess anticipated impacts and select actions

Most of these measures and actions have an impact on more than one performance indicator (Table 5-8). For example, a road resurfacing project that improves surface quality is likely to lead to speed increases, with secondary impacts on safety, mobility, and vehicle emissions. These various impacts should be formally assessed.

Table 5-8 Example – Performance indicators

OBJECTIVE	PERFORMANCE INDICATOR
MOBILITY	- travel time, speed, delay - number of trips (per road user type) - etc.
ROAD SURFACE CONDITION	- skid resistance - IRI - etc.
ENVIRONMENT	- vehicle emissions - noise - etc.
SAFETY	- accident frequency - accident rate - accident severity - etc.

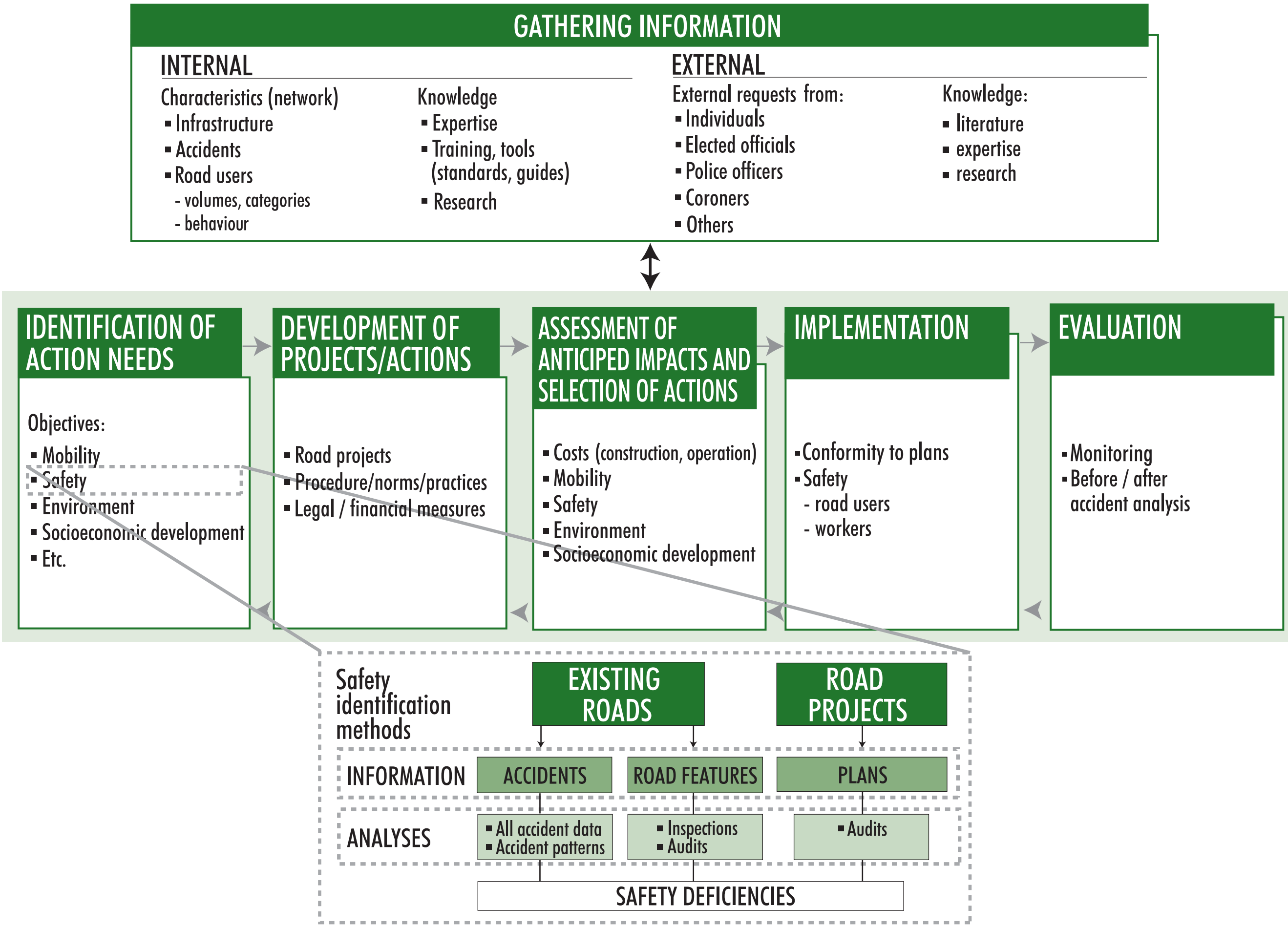
Implement and evaluate

During construction, appropriate monitoring is required to ensure that the implementation conforms to proposed plans and does not lead to the introduction of new road hazards.

Evaluations should also be conducted after a project's completion in order to ensure that anticipated benefits have been achieved and to ascertain that adverse effects have not been introduced into the system. Results of these evaluations will also contribute to improve the efficiency of future actions.

A schematic representation of this decision-making process is shown on Figure 5-9.

Figure 5-9 Decision-making process of a road authority



How to broaden the safety perspective

More safety assessments

As defined in ***Section 5.4.1***, a road safety audit is a formal assessment of the safety performance of a road project or an existing road conducted by a team of independent experts. There is a need to expand the scope of these safety assessments to include activities of a road authority that are not currently submitted to this type of evaluation but do have an impact on safety. These include:

- road projects that are not audited;
- procedures, programs and practices;
- road-related laws and regulations (e.g. load and size limits);
- incentives or deterrents (e.g. public transport funding).

Better use of available data, knowledge and technology

Accident data, which are expensive to collect, are often underused, particularly in light of recent technological advances that significantly enhance the range of analyses that can be conducted with reasonable effort. The organization of this data and the development of user-friendly programs that facilitate the extraction and analysis of this information should become a priority.

Simple query programs should be made available to decision-makers, allowing them to make more informed decisions. More sophisticated programs should be developed for safety analysts, in order to help them using recent analysis methods and techniques. And finally, easy access to existing databases should be provided to researchers, allowing them to extract a maximum of information from these systems.

Software that facilitates the use of knowledge that has been gathered on road safety - partly through the use of available databases - should also be developed. A major effort in that regard is the American *"Interactive Highway Safety Design Model (IHSDM)"* software, which is designed to help engineers take greater account of safety impacts when developing new road projects ***(http://www.tfhrc.gov/safety/ihsdm/ihsdm.htm)***.

Improved communication channels within road authorities

Engineers who develop new projects and safety experts often work in independent departments, with each having their own objectives and budgets. Designers typically believe that by following existing standards, they will necessarily develop safe projects, but experience shows that this is not necessarily the case. On the other hand, safety experts often work exclusively on the development of specific road safety programs (e.g. blackspot improvement program). The development of formal and informal communication channels between the various specialists in a transportation agency is needed: working groups, ad hoc meetings, control points, joint seminars and social events should all be organized.

5.5 CONCLUSION

This chapter has described several methods of identification of road safety deficiencies, making a distinction between reactive and proactive approaches.

Reactive identification

The main principles associated with the use of reactive (or accident-based) methods have been described in ***Section 5.3***. Simple criteria and more sophisticated ones have been described. This should fit the needs and possibilities of every road authority.

As it has been described in this chapter, the reactive identification is based on the principle of potential for improvement that can be expected from modifications made to existing road or traffic conditions. Notwithstanding the advantages of this identification strategy, it should be recognized that there are also other ways to detect deviant sites. For instance, it is possible to search for the worst sites of a road network, without considering its reference population, or search for sites with recent road safety deteriorations.

Section 5.3.2 has explained that a reactive identification may also be targeted at the detection of sites with an abnormal concentration of one or more accident types (with or without problems in terms of overall accident frequencies). This is, again, another way of looking at the identification task that may yield interesting results.

Explanations related to the reactive identification and the example of ***Appendix 5-2*** have been adapted to the case of blackspot detection. As described in the introduction, the correction of those sites is generally the first safety action taken by a road authority due to its high cost-effectiveness. However, it should be clear that a comprehensive identification of road safety deficiencies should extend beyond the identification of those sites and include a search for larger entities that may consist of:

- parts of a road network (e.g. an administrative region, a city, etc.);
- roads or long road segments;
- groups of sites, rather than individual sites (freeways, four-leg signalized intersections in urban areas, horizontal curves in rural areas, etc.).

Methods to identify such locations are quite varied; It could be:

- a comparison of the safety performance of different areas of a network (e.g. detection of administrative regions having more safety problems);
- a comparison of road categories or road entities, leading to the detection of unsafe types of entities (e.g. X-shaped intersections);
- accident pattern analyses conducted on large entities (e.g. high rate of pedestrian accidents in a municipality or high frequency of fixed-object accidents on rural roads);
- etc.

Identification criteria that have been described in ***Section 5.3*** may be used for these analyses. They will often lead to the development of specific safety programs aimed at the simultaneous correction of several sites having the same problem (mass action). Such programs will typically be included in a national ***road safety action plan*** (as would be a blackspot correction program or a safety belt usage program). Examples could include a roadside improvement program in rural areas or a program aimed at increasing the protection of pedestrian crossing manoeuvres in urban areas).

Proactive identification

Proactive identification methods, which are now largely centered on the application of road safety audit procedures (RSA), have been described in ***Section 5.4.1***. This is an activity that expanded significantly during the 1990's and a continuing trend is to be expected in the coming years.

But efforts should also be devoted to the development of a more comprehensive approach to road safety improvement. Accordingly, ***Section 5.4.2*** has described a global decision-making process of a road administration and made some suggestions for a better integration of safety concerns in the current practices of road authorities. To become more efficient in making strides toward safer roads, it is believed that profound organizational changes are required. The identification task should not be limited to the detection of safety deficiencies of a road network - either using proactive or reactive methods - but should also include, in a more positive manner, the search for safety opportunities.

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APPENDIX 5-1

Methodological aspects

REFERENCE POPULATION AND POTENTIAL FOR IMPROVEMENT

Several road features have an influence on accident risk. Main rural roads, which are designed and operated following higher standards than those for secondary rural roads, are usually safer in terms of accidents per vehicle-km (e.g. Table 5-A1).

Table 5-A1 Accident rates by road category (USA)

ROAD CATEGORY (RURAL)	FATAL ACCIDENTS PER 100 MVEH-KM	INJURY ACCIDENTS PER 100 MVEH-KM
INTERSTATE	0.63	13
ARTERIAL	1.31	35
COLLECTOR	1.81	59
LOCAL	2.26	109

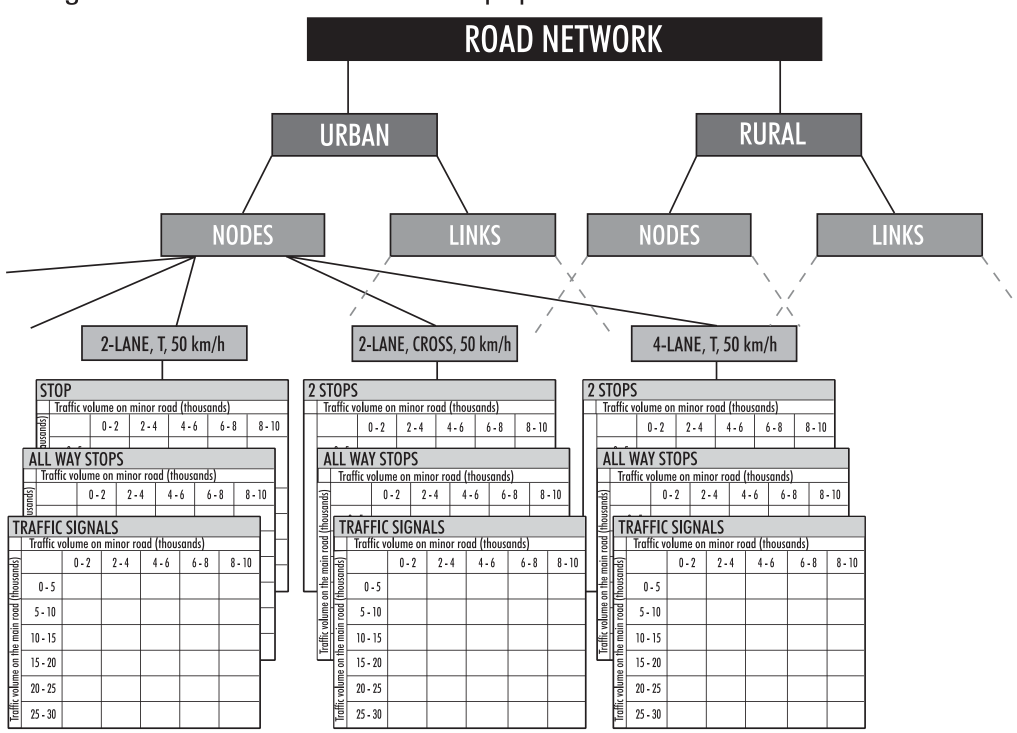
Source: Highway Safety Design and Operations Guide, Copyright 1997, by the American Association of State Highway and Transportation Officials, Washington, D.C. Used by permission.

On any given road, the ***safety level*** is not constant, either. For example, accident densities are generally lower on links than at nodes, due to differences in the number of traffic conflicts. At nodes, T intersections are generally safer than + intersections for the same reason, and so on.

Consequently, the potential for improvement depends to a large extent on the nature of the site under study and on the modifications that can be envisioned.

Distinct reference populations should therefore be defined to help determine what constitutes a representative safety level for a given type of site. Such populations are defined by taking into account the main road features having an impact on safety. For example, a reference population may be defined for two-lane + intersections in urban areas with stops on the minor legs, another population for T intersections on similar roads, and so on. Given the significance of traffic flows with respect to accidents, distinct reference populations should ideally be developed for different combinations of traffic flows. The establishment of reference populations requires a good knowledge of both accident contributing factors and available data that quickly limit the number of possible populations that can be defined (Figure 5-A1). In practice, the development of statistical multivariate models is often used to circumvent data limitations.

Figure 5-A1 Choice of reference populations



Potential for improvement – Example

As described in ***Section 5.2.1***, the difference in safety between the site and its reference population provides a value for the potential for improvement (P.I.)

$$P.I._j = IC_j - IC_{rp}$$

where:

$P.I._j$ = potential for improvement at site j
IC_j = value of the identification criterion at site j
IC_{rp} = average value of the identification criterion in the reference population

A numerical example, based on the accident rate criterion, illustrates the method.

Let us suppose that the average accident rates for three reference populations are as indicated in Table 5-A2.

Let us suppose also that a specific T intersection has an accident rate of 1.0 acc./Mveh-km.

Table 5-A2 Example – Accident rates at intersections

TYPE OF INTERSECTION	ACCIDENT RATE (acc./Mveh-km)
T, one stop, rural	0.8
+, two stops, rural	1.4
T and +, stop(s), rural	1.1

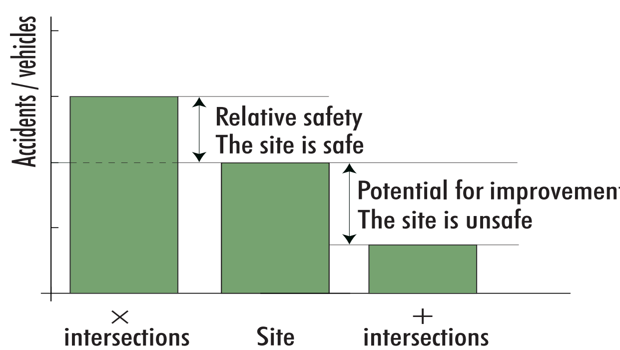
When this T intersection is compared with all intersections (T and + intersections grouped together), the potential for improvement is negative and the site is thus deemed to be safe (P.I. = 1.0 - 1.1 = - 0.1 acc./Mveh-km). However, when it is compared with T intersections, its potential for improvement becomes positive and it should be submitted to a ***safety diagnosis***, which is a more accurate conclusion in this case (P.I. = 1.0 - 0.8 = 0.2 acc./Mveh-km).

Limitations of the "potential for improvement" approach

Reliance on reference populations must not maintain unsafe conditions

To continue with the preceding example, let us assume that in the same rural environment, there are a certain number of X intersections and that the average accident rate at these intersections is 3.0 acc./Mveh-km. An intersection of this type with an accident rate of 2.5 acc./Mveh-km may be deemed safe in comparison with other X intersections. However, is it acceptable for users having to travel to such a high-risk location (compared to road users traveling elsewhere on the road network without crossing this type of intersection)?

Figure 5-A2 Relative safety at a site



Safety analysts must determine what constitute acceptable differences in safety between the various types of sites (or reference populations) that make up a network.

Potential for improvement when the reference population is modified

The estimated potential for improvement at a site may differ significantly when potential actions may change its reference population. Let us assume, for example, that 7,500 vehicles/day travel each day at a + intersection on a main rural road having an accident rate of 2.0 acc./Mveh-km. If compared to intersections having similar characteristics and an accident rate of 1.4 acc./Mveh-km (Table 5-A2), the potential for improvement is thus 0.6 acc./Mveh-km (or 1.8 acc./year). Let us also assume that the average accident rate at roundabouts in similar road environments is 0.5 acc./Mveh-km. If potential actions at this intersection include a conversion from a + intersection to a roundabout, the potential for improvement is then increased to 1.5 acc./Mveh-km or 4.1 accidents/year.

Potential strategies – Identification of road-related safety problems

For the foregoing reasons, it must be recognized that despite its advantages, an identification strategy based on estimating the potential for improvement does have certain limits (as any other identification strategy). On the one hand, it is quite useful in detecting **the worst sites of a reference population**. On the other hand, different complementary strategies aimed at identifying road safety deficiencies should also be considered, including:

- searching for a **network's worst sites** using any of the criteria described in ***5.3.1*** (e.g. ranking sites of a network in order of decreasing accident frequency without considering the reference population to which they belong);
- searching for **a network's worst types of sites**, i.e. detecting the reference populations having the worst safety performance;
- assessing the **safety deterioration at a site** between 2 observation periods. For this purpose, the Poisson test can be used.

[POISSON TEST]

RANDOM NATURE OF ACCIDENTS

A distinction needs to be made between two concepts:

accident frequency "**f**" and

long-term average accident frequency (or ***safety level*** "m"), which could be computed accurately only if all factors having an impact on accident occurrence remained constant over several years.

Safety decisions should be based on "m" estimates ($\hat{m}$) rather than on f values.

One of the main problems arising from the use of accident data to detect safety deficiencies has to do with the random nature of these events.

To make it easier to understand this concept and its consequences, let us use a die as an analogy. A toss of the die is also a random event, whose result depends on the number of sides of the die and the value of each side. On a standard six-sided die, the range of possible values is simple: [1, 2, 3, 4, 5, 6]. When a die is thrown many times, each side should come up an equivalent number of times and the resulting mean value of such throws is 3.5: (1 + 2 + 3+ 4 + 5 + 6) / 6 = 3.5. This value can be described as the die's "long-term average". When the die is thrown only a limited number of times, for example three times, the mean obtained may vary between extreme values of 1 and 6. If this result is used to estimate the die's long-term average, accuracy will vary greatly.

Similar variations also occur with accident frequencies. The number of accidents occurring at a site over a one-year period (f) can be compared to one throw of the die, while its long-term average accident frequency (m) can be compared to the die's long-term average. From a statistical standpoint, the throwing of the die is said to follow a uniform distribution, while accidents follow a Poisson distribution.

Poisson distribution:

$$p(f;m) = \frac{e^{-m} m^f}{f!}$$

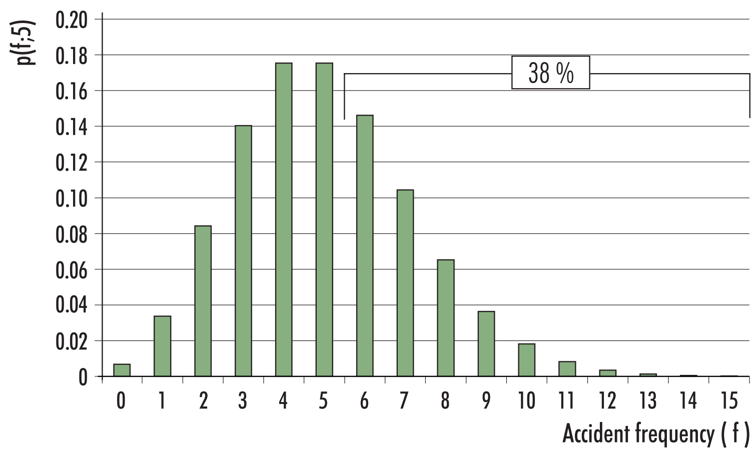
where:

$p(f;m)$	=	probability of observing f accidents given that the safety level of is m
f	=	accident frequency
m	=	safety level

This is a fundamental equation in road safety analysis. It can be used to calculate the probability of a given accident frequency (f) when the safety level (m) is known. For example, if a site's m value is 5 accidents/year, the probability of having exactly 1 accident/year is 3.4% while the probability of having 6 or more accidents is 38% (Figure 5-A3). The "Poisson test" calculator can be used to calculate this latter probability.

[POISSON TEST]

Figure 5-A3 Poisson distribution for m = 5



Each site of a road network has its own m value based on its set of characteristics (continuing the dice analogy, there would be several dice, each one with a distinct number of sides and values).

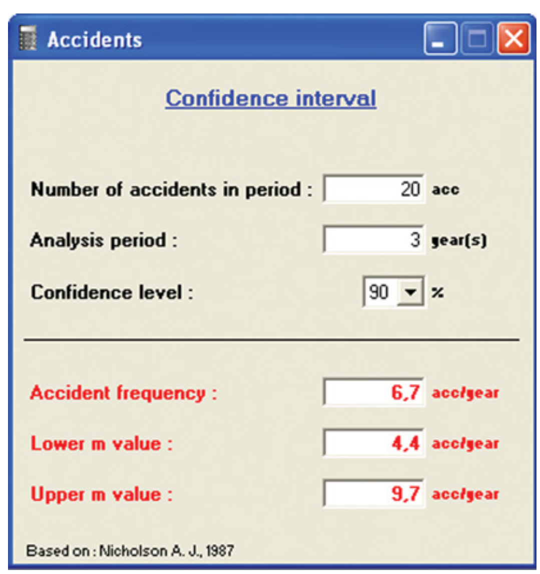
In practice, difficulties arise from the fact that the safety level (m) is unknown and that it must be estimated ($\hat{m}$) from the reported accident frequencies (f).

A calculator is provided to estimate the uncertainty of m based on an observed accident frequency (Nicholson, 1987). For example, if a total of 20 accidents have occurred at a site over a 3-year period and a 90% confidence interval is chosen, the true value of m ranges from 4.4 to 9.7 accidents/year (Figure 5-A4).

This estimate of m becomes more statistically reliable as the period increases but it may be less representative of the prevailing conditions if changes have occurred at the site during the period considered. To avoid this type of bias, relatively short ***accident periods*** are of often used.

[CONFIDENCE INTERVAL]

Figure 5-A4 Calculator - Accident confidence interval



ACCIDENT PERIOD

As mentioned above, the choice of an accident period may have a significant impact on the accuracy and reliability of safety estimates. Overly long periods may introduce biases in the analysis when current conditions differ from those prevailing when accidents occurred. Overly short periods reduce the number of accidents considered and the statistical accuracy. A compromise must be struck between these extremes.

In a landmark study, May (1964) attempted to ascertain the optimum period based on the analysis of accident data relating to 433 intersections over a 13-year period. After having compared the mean accident frequency for different periods to the mean accident frequency for the entire 13-year period, he concluded that prolonging the period beyond 3 years was of little use. Such a period is still often used at the identification stage.

Hauer (1996) recommends a review of this practice and an extension of the period when it can be verified that factors affecting accident occurrence and reporting have remained relatively stable. With today's technologies, a longer period can be used without significant increases in manpower.

In any case, accident periods should always be multiples of full years in order to avoid bias that may result from seasonal variations (e.g. rainy season, snow, holiday period, and so on).

REGRESSION TO THE MEAN

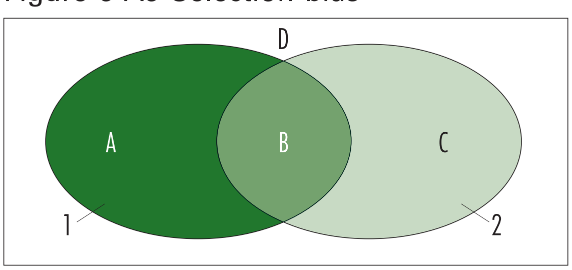
The regression to the mean phenomenon is common to a number of random events and consists of a general tendency for extreme values to return to median values. Sir Francis Galton, who noted that children of tall parents were usually shorter, and vice versa, was the first to identify regression to the mean in the 19th century. The phenomenon also applies to accidents. When the accident frequency is abnormally high during a certain period, it tends to decrease during the subsequent period and draw closer to the site's long-term average (and vice versa). See ***Section 8.3.2*** for details.

SELECTION BIAS

The ***random nature of accidents*** and the difficulty of extending ***accident periods*** as much as might be necessary to reach sufficient accuracy create two types of biases during the identification phase, i.e. normal sites may be detected as being unsafe and unsafe sites may not be detected.

Figure 5-A5 below, drawn from Hauer and Persaud (1984), illustrates the problem. The rectangle represents all the sites of a road network. Ellipsis 1 represents all of the unsafe sites (those with a high m value). It is solely at these sites that a treatment is warranted. Ellipsis 2 represents sites that were detected as being deviant during the identification phase (those with a high f value). Four types of situations can arise (domains A to D):

Figure 5-A5 Selection bias



A: unsafe sites undetected
B: unsafe sites detected as being hazardous
C: normal sites detected as being hazardous
D: normal sites undetected

The objective of the identification stage is to obtain the best possible superimposition of ellipses 1 and 2 and to limit areas A and C. Identification techniques that take into account the random nature of accidents are seen to reduce selection bias ***(Section 5.3.1)***.

ACCIDENT RATE – LINEAR HYPOTHESIS (based on Mahalel, 1986)

Accident rates are often used to compare the safety of two sites or road entities, but the result of this comparison is inaccurate when the relationship between traffic volume and accidents is not linear. The problem is described in the following paragraphs.

Note:

On graphs similar to those shown on Figure 5-A6 and 5-A7, the accident rate at a given traffic volume corresponds to the slope between the origin (0.0) and the point corresponding to this traffic volume on the line (or curve). Figure 5-A7 shows, in dotted lines, slopes (accident rates) at points A and B.

Case 1: Linear relationship between accident frequency and traffic flow (accident rate is constant)

Let us assume that on two different roads, the relationship between accident frequency and traffic flow is linear, as illustrated in Figure 5-A6. For identical traffic flows, accident frequencies on road 1 are always lower than accident frequencies on road 2. Road 1 is therefore safer.

In this linear case, accident rates are constant; they are always lower on read 1 than on road 2 (even when traffic flows on the two roads are different). In such a case the accident rate criterion can then be used to compare safety between two roads.

Case 2: Non-linear relationship between accident frequency and traffic flow (accident rate is not constant)

A different situation may arise when the relationship between accident frequency and traffic flow is non-linear, as illustrated in Figure 5-A7. Once again, accident frequencies on road 1 are always lower than accident frequencies on road 2 when traffic flows are the same. Road 1 is thus safer. The use of accident rates as a means of comparison may, however, lead to the opposite conclusions, depending on the traffic flows observed on each road. The following example provides an illustration.

Let us suppose that 2,000 vpd travel on road 1 and 8,000 vpd on road 2. The accident rate on road 1 (slope at point A on Figure 5-A7) is higher than the accident rate on road 2 (slope at point B). According to the accident rate criterion, road 1 is seen to be less safe than road 2, which is false.

Accident rates can only be used to compare the safety of two roads when relationships between traffic flows and accidents are approximately linear.

Figure 5-A6 Linear relationship between accidents and traffic flows

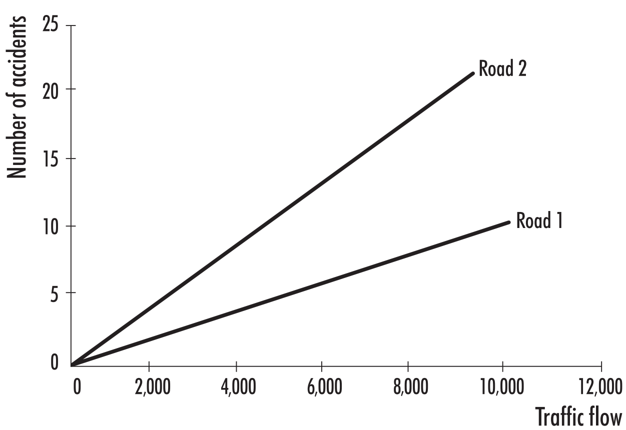
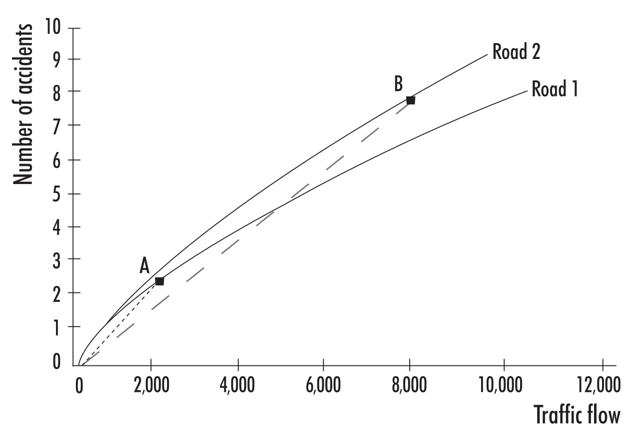


Figure 5-A7 Non-linear relationship between accidents and traffic flows



CRITICAL ACCIDENT RATE – LINEAR HYPOTHESIS

As is the case for accident rates, results obtained using the critical accident rate may also be biased when the relationship between traffic volume and accidents is not linear. To calculate the critical accident rate, the average accident rate (R_{rp}) is assumed to be constant, which supposes a linear relationship between accident frequency and traffic flow.

The problem is illustrated on Figure 5-A8 that shows average accident rate curves.

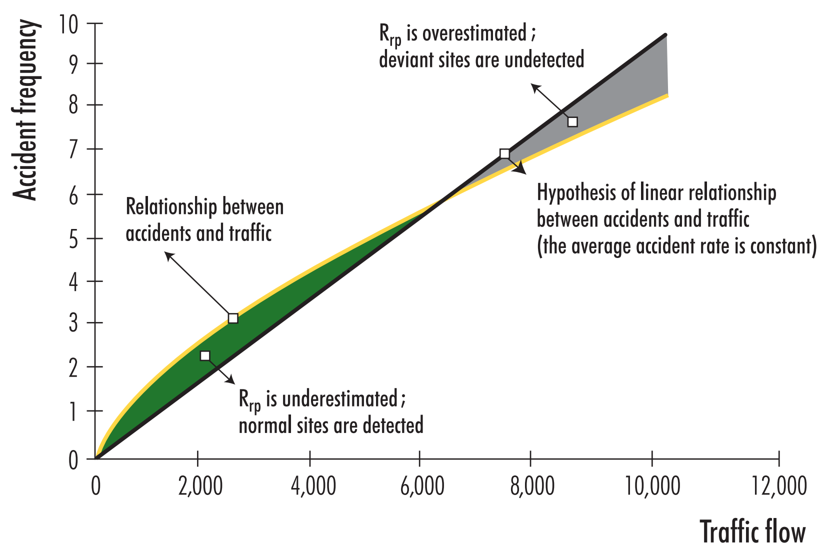
- The black line assumes a linear relationship between traffic flows and accidents, i.e. the hypothesis underlying the calculation of critical rates.
- Let us assume that the yellow curve illustrates the exact relationship between accidents and traffic flows for this type of road.

Two cases can be distinguished:

- In the green zone, the average accident rate (R_{rp}) is underestimated, reducing the value of the critical rate. As a consequence, safe sites may be detected as being hazardous.
- In the grey zone, the average accident rate (R_{rp})is overestimated and deviant sites may not be detected.

As is the case for the accident rate, the critical accident rate should only be used when the relationship between traffic flows and accidents is approximately linear.

Figure 5-A8 Critical accident rate - Linear hypothesis



Appendix 5-2

Example

TABLE 5-A3 EXAMPLE – ACCIDENT DATA (01/01/98 TO 31/12/00)																								
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
		ACCIDENT FREQUENCY					SURFACE				ACCIDENT TYPE													
Section number	Q (AADT)	Total	Fatal	Serious	Minor	PDO	Dry	Wet	Icy	Other	parallel lanes, turning	lane change	intersection (adjacent approaches)	hit permanent obstruction	off road, on straight	off road, on straight, hit object	out of control on road, on straight	off road, on curve	off road, on curve, hit object	out of control on road, on curve	hit animal on road	rear-end	opposing turns	head-on
1	6,050	9	1	1	3	4	5	3	1		2		2					1				2		2
2	800	1			1		1						1											
3	8,500	7		2		5	5	2					1						3		3			
4	4,500	5		1	1	3	3	2									1	1	1	2				
5	4,500	6				6	6											1	3			2		
6	6,800	7			1	6	1	3	2	1	2		2		2									1
7	1,000	2			1	1		1		1		1	1											
8	2,200	3			1	2	1	2			1				1									1
9	2,500	0																						
10	5,400	14	1		3	10	10	2		2	1		5			2					1	2		3
11	4,200	6				6	2	2	1	1			2		2		2							
12	7,400	9		1	3	5	4	4		1		2	1								2		3	1
13	1,900	3		2	1	1	1	1						2										1
14	1,400	1				1	1									1								
15	4,000	6		1	2	3	4	1		1			2									2		2
16	8,000	7	1		2	4	2	2		3								1				3	2	1
17	2,500	3		1		2		1	2								1		1			1		
18	1,500	2				2	2						1		1									
19	4,150	0																						
20	5,700	7			3	4	6	1			1	1	2	2										1
21	4,700	5		1	2	2	3	1	1			1										2		2
22	5,400	4				4	1	3					2			2								
23	3,400	5		1	1	3	3	1	1					1						2		2		
24	3,700	2				2	2						1									1		
25	4,000	4			2	2	2	2							1			1	1					1
26	3,200	3			3	3						1										2		
27	4,400	5		1	2	2	1		4				2									2	1	
28	4,500	1				1	1				1													
29	4,300	4	1			3	3	1					1									3		
30	3,600	5			1	4	1	1	3				1		1	1	1					1		
31	3,700	0																						
32	7,500	6				6	3	2	1				1			1					1	1		2
33	1,300	3		1	1	1	2	1						1		1								1
34	3,150	0																						
35	1,700	4				4	2		1	1							2					2		
36	5,700	8				8	4	3	1		1	1	2									2	2	
37	6,500	5				5	3	1		1				1	2	1					1			
38	2,500	3				3	3								1	2								
39	800	2				2	1	1											1	1				
40	4,200	4			2	2	4								1	1				1		1		
41	7,950	7		1	1	5	2	3	2		1	1	1				1	1		1				1
42	1,950	2				2		1		1														1
43	4,500	4				4	3	1			1	1	1	1										
44	3,800	3			2	1	2		1						1							2		
45	6,900	12		1	4	7	5	7			2		2		1							3	3	1
46	2,600	4				4	3	1							1					1	1	1		
47	7,100	8			2	6	5	1	1	1	1		2									3	2	
48	7,900	9			2	7	7	1	1		3											3	2	1
49	5,400	5	1	1		3	3	2				1			1	1						2		
50	3,800	4				4	2		1	1								1			1	2		
51	7,500	7			1	6	2	3	1	1		2						1	1		1	1	1	
52	8,500	10		1	3	6	8	2			2	2											4	2
53	4,000	3				3	3					1								1		1		
54	5,600	5			2	3	2	1	1	1		1										1	2	1
55	3,600	4			1	3	2	2				2								1		1		
	TOTAL	**258**	**5**	**15**	**52**	**186**	**145**	**69**	**30**	**14**	**19**	**19**	**36**	**8**	**16**	**13**	**8**	**8**	**11**	**10**	**11**	**51**	**22**	**26**

TABLE 5-A4 EXAMPLE – RESULTS												
1	2	3	4	5	6	7	8	9	10	11	12	13
Section number	Q (AADT)	Accident frequency	Accident rate	Critical rate	EPDO index	$\overline{\text{EPDO}}$ index	RSI	$\overline{\text{RSI}}$	f_p	P.I. (model)	f_{EB}	P.I. (EB method)
1	6,050	9	2.72	2.89	33.5	3.72	1,634,100	181,567	6.07	2.93	6.72	0.65
2	800	1	2.28	5.27	3.5	3.50	173,200	173,200	1.31	-0.31	2.96	164
3	8,500	7	1.50	2.72	24	3.43	1,070,800	152,971	7.84	-0.84	5.78	-2.07
4	4,500	5	2.03	3.07	16	3.20	735,500	147,100	4.85	0.15	4.84	-0.01
5	4,500	6	2.43	3.07	6	1.00	1,054,400	175,733	4.85	1.15	5.31	0.46
6	6,800	7	1.88	2.83	9.5	1.36	1,189,400	169,914	6.63	0.37	5.78	-0.85
7	1,000	2	3.65	4.81	4.5	2.25	306,000	153,000	1.56	0.44	3.43	1.87
8	2,200	3	2.49	3.67	5.5	1.83	592,300	197,433	2.82	0.18	3.90	1.07
9	2,500	0	0.00	3.54	0	0.00	0	0	3.11	-3.11	2.49	-0.62
10	5,400	14	4.73	2.95	30	2.14	2,707,500	193,393	5.57	8.43	9.06	3.50
11	4,200	6	2.61	3.11	6	1.00	870,000	145,000	1.40	1.40	5.31	0.70
12	7,400	9	2.22	2.78	25	2.78	1,445,200	160,578	7.06	1.94	6.72	-0.35
13	1,900	3	2.88	3.84	8	2.67	668,400	222,800	2.53	0.47	3.90	1.37
14	1,400	1	1.30	4.24	1	1.00	206,600	206,600	2.01	-1.01	2.96	0.95
15	4,000	6	2.74	3.15	19.5	3.25	1,249,000	208,167	4.44	1.56	3.51	0.87
16	8,000	7	1.60	2.75	20.5	2.93	1,183,800	169,114	7.49	-0.49	5.78	-1.72
17	2,500	3	2.19	3.54	11.5	3.83	445,100	148,367	3.11	-0.11	3.90	0.79
18	1,500	2	2.43	4.14	2	1.00	319,300	159,650	2.11	-0.11	3.43	1.31
19	4,150	0	0.00	3.12	0	0.00	0	0	4.56	-4.56	2.49	-2.07
20	5,700	7	2.24	2.92	14.5	2.07	1,252,200	178,886	5.80	1.20	5.78	-0.02
21	4,700	5	1.94	3.04	18.5	3.70	1,035,400	207,080	5.01	-0.01	4.84	-0.18
22	5,400	4	1.35	2.95	4	1.00	759,600	189,900	5.57	-1.57	4.37	-1.20
23	3,400	5	2.68	3.27	16	3.20	607,000	121,400	3.92	1.08	4.84	0.91
24	3,700	2	0.99	3.20	2	1.00	282,900	141,450	4.18	-2.18	3.43	-0.76
25	4,000	4	1.83	3.15	9	2.25	883,300	220,825	4.44	-0.44	4.37	-0.07
26	3,200	3	1.71	3.32	3	1.00	352,200	117,400	3.75	0.75	3.90	0.15
27	4,400	5	2.07	3.08	18.5	3.70	734,400	146,880	4.77	0.23	4.84	0.07
28	4,500	1	0.41	3.07	1	1.00	104,600	104,600	4.85	3.85	2.96	-1.89
29	4,300	4	1.70	3.10	12.5	3.13	502,300	125,575	4.69	-0.69	4.37	-0.32
30	3,600	5	2.54	3.22	7.5	1.50	751,300	150,260	4.10	0.90	4.84	0.74
31	3,700	0	0.00	3.20	0	0.00	0	0	4.18	4.18	2.49	-1.70
32	7,500	6	1.46	2.78	6	1.00	1,252,200	208,700	7.14	1.14	5.31	-1.83
33	1,300	3	4.21	4.36	14	4.67	711,600	237,200	1.90	1.10	3.90	2.00
34	3,151	0	0.00	3.33	0	0.00	0	0	3.70	3.70	2.49	-1.22
35	1,700	4	4.29	3.98	4	1.00	450,800	112,700	2.32	1.68	4.37	2.04
36	5,700	8	2.56	2.92	8	1.00	1,140,400	142,550	5.80	2.20	6.25	0.45
37	6,500	5	1.40	2.85	5	1.00	741,700	148,340	6.40	-1.40	4.84	-1.57
38	2,500	3	2.19	3.54	3	1.00	559,300	186,433	3.11	-0.11	3.90	0.79
39	800	2	4.56	5.27	2	1.00	331,800	165,900	1.31	0.69	3.43	2.11
40	4,200	4	1.74	3.11	9	2.25	574,500	143,625	4.60	-0.60	4.37	-0.24
41	7,950	7	1.61	2.75	18	2.57	1,155,900	165,129	7.46	-0.46	5.78	-1.68
42	1,950	2	1.87	3.81	2	1.00	474,400	237,200	2.58	-0.58	3.43	0.85
43	4,500	4	1.62	3.07	4	1.00	574,000	143,500	4.85	-0.85	4.37	-0.48
44	3,800	3	1.44	3.18	8	2.67	365,500	121,833	4.27	-1.27	3.90	-0.37
45	6,900	12	3.17	2.82	30.5	2.54	1,878,200	156,517	6.70	5.30	8.12	1.42
46	2,600	4	2.81	3.50	4	1.00	447,400	111,850	3.20	0.80	4.37	1.16
47	7,100	8	2.06	2.80	13	1.63	1,117,300	139,663	6.85	1.15	6.25	-0.60
48	7,900	9	2.08	2.75	14	1.56	1,321,700	146,856	7.42	1.58	6.72	-0.71
49	5,400	5	1.69	2.95	22	4.40	704,900	140,980	5.57	-0.57	4.84	-0.73
50	3,800	4	1.92	3.18	4	1.00	474,800	118,700	4.27	-0.27	4.37	0.10
51	7,500	7	1.70	2.78	9.5	1.36	1,019,000	145,571	7.14	-0.14	5.78	-1.36
52	8,500	10	2.15	2.72	26	2.60	1,832,400	183,240	7.84	21.6	7.19	-0.66
53	400	3	1.37	3.15	3	1.00	354,600	118,200	4.44	-1.44	3.90	-0.54
54	5,600	5	1.63	2.93	10	2.00	921,300	184,260	5.72	-0.72	4.84	-0.89
55	3,600	4	2.03	3.22	6.5	1.63	487,400	121,850	4.10	-0.10	4.37	0.27

CHAPTER 6
Diagnosis

Carl Bélanger

CHAPTER 6

Diagnosis

LIST OF FIGURES

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INTRODUCTION

This chapter describes how to conduct a road safety diagnosis, i.e. how to:

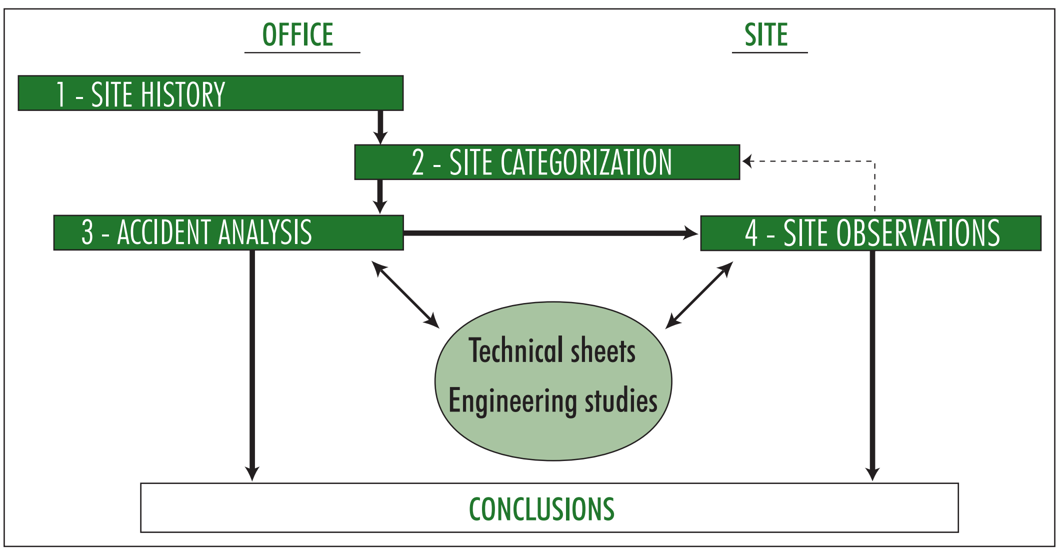
- identify the nature of safety deficiencies;
- search for factors contributing to these deficiencies;
- determine if modifications to existing or proposed road characteristics could efficiently improve safety.

As shown in Figure 6-1, the diagnosis is described as a four step process:

1) verification of the information already available (site history);
2) determination of the site category;
3) accident analysis;
4) site observations.

When conducting a diagnosis, analysts may have to consult technical references in order to better understand whether a road component can contribute to a given safety problem or could improve the situation. Part Three ***(technical sheets)*** of this manual describes the relationship between several road features and safety (horizontal alignment, vertical alignment, intersection, etc.). Some technical data may also need to be collected at the site in order to make progress in the diagnosis. Part Four ***(technical studies)*** of the manual explains how to conduct various technical studies: spot speed, traffic count, etc.

Figure 6-1 Diagnostic process

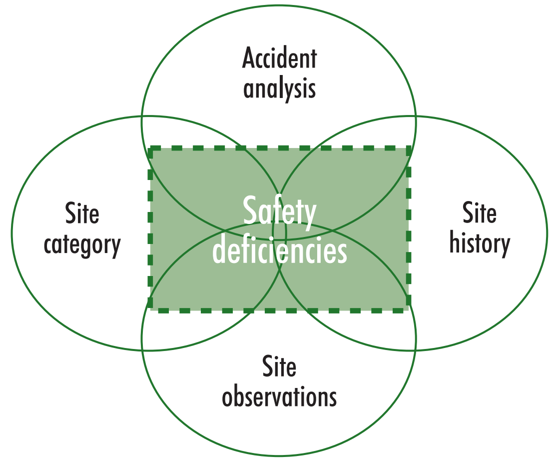


This process is best suited to the analysis of blackspots, generally the first action taken by road authorities to reduce accidents, but methods and tools that are proposed in the chapter can also be used to conduct:

- safety diagnoses at sites that are larger than blackspots and have an abnormal accident history;
- safety diagnoses of specific road features (e.g. horizontal alignment, surface conditions, etc.);
- safety reviews, when accident data are not available.

Results obtained at each of these four steps may be closely related. For example, a safety deficiency at an horizontal curve is likely to be detected during both the accident analysis step (large proportion of single-vehicle accidents) and the site observation step (isolated sharp curve). In other cases, the conclusions of each step will be complementary. For example, the accident analysis may detect a cluster of nighttime collisions, which will focus the analyst's attention on problems that may not have been detected by a daytime field survey. It is therefore highly recommended to complete all the steps of the diagnostic process, even when a solution seems to have been found at the beginning of the analysis (Figure 6-2).

Figure 6-2 Detection of safety deficiencies



Given that each site has its own combination of road characteristics, road users and vehicles, the list of potential safety problems and relevant solutions is quite long. When conducting a safety diagnosis, the analyst should verify the following points (see ***Appendix 6-1*** for details):

- the differences between the site features and established standards or practices;
- the complexity of the driving task and the compliance with drivers' expectancies;
- the coherence of the road environment.

Sometimes, desirable actions may extend beyond road engineering work. As shown in ***Table 2.3***, the range of measures that may be implemented to improve safety is quite wide. It should be clear that the realization of a safety diagnosis requires knowledge not only in road engineering, but also outside this field (human factors, vehicle engineering, statistics, etc.). The analyst has to determine whether the most appropriate treatment is related to the road or to other components of the ***safety system***.

The analysis of complex cases for which there is no obvious solution requires the contribution of a multidisciplinary team of experts who together are more likely to develop a good understanding of the problems encountered and to propose appropriate solutions ***(detailed accident analysis)***. Accordingly, it is important to ensure that efficient coordination structures and communication channels are developed between the main groups playing an active role in road safety, in order to allow constructive interdisciplinary exchanges leading to the implementation of optimal solutions ***(Chapter 2)***.

From the standpoint of road safety engineering, it is also important to keep in mind that problems may originate at different stages of development and operation of a road network: planning of the transportation system, road designing, construction, operation and maintenance (some examples are listed on the next page).

The ability to make a good safety diagnosis is therefore highly related to the experience and "sound engineering judgment" of the analyst who, after having conducted several of these studies, will know how to recognize situations that increase the accident risk. Obviously, this is a knowledge that cannot be learned only from textbooks but the process described in this chapter should help those with less experience in gaining a better understanding of the underlying principles and logic of their work.

Origins of safety problems

Safety problems may result from decisions made at various stages in the development and operation of a road network: planning, design, construction, operation and maintenance. When making a diagnosis, analysts should therefore verify whether the observed problems are caused by errors made at any of these stages. Effective and lasting solutions can often be found only by going right back to the origin of a problem.

Table 6-1 Examples – Measures having an impact on safety

STAGE	EXAMPLES
PLANNING	Concerted actions among land-use planners and transportation planners may help reduce road trips and their associated risk. The transfer of car and truck trips to safer modes (public transportation, rail and maritime transport) improves safety. The development of a sound road hierarchy system can help lead to the desirable separation of incompatible road users (as a general principle, avoid situations where road users having large mass or speed differentials share the same road).
DESIGN	On roads with a mobility function, safety increases with the level of geometric standards. On roads with an access function, design features must encourage all road users to adopt slower speeds that are compatible with frequent entering and exiting manoeuvres at access points. Design criteria must take into account the safety requirements of all road users, with particular attention to the needs of pedestrians and cyclists, who are more vulnerable to injury. Human error, which is often cited as the main cause of road accidents, may result from inadequate design features that increase the likelihood of driver error or inadequate behaviour (e.g. excessive speed, drowsiness).
CONSTRUCTION	Various construction errors may have an adverse impact on safety, such as an irregular curve radius, the use of rapid-wearing surface aggregates, the incorrect installation of a safety guardrail, etc. During roadwork, adequate measures should also be taken to ensure the safety of road users and workers. Road accidents at work zones are often a problem.
OPERATION MAINTENANCE	Over the years, various road and traffic characteristics may change, with adverse safety impacts, such as the development of new access points on a mobility road, the deterioration of existing equipment, the addition of visual obstructions, etc.

The detection of these various types of problems requires a broad range of knowledge. With their training and experience, transportation engineers, who most often conduct safety diagnoses, can generally detect several types of problems related to road design, construction, operation or maintenance. They may, however, have more difficulty in detecting problems resulting from planning errors or from inadequate considerations of road users' capabilities and limitations. *Appendix 6-1* provides some basic information on these two topics and illustrates some frequent problems.

Diagnostic tools proposed in this manual :

Chapter 6 Main text	describes each step of the process shown in ***Figure 6-1***.
Additional notes *(Appendix 6-1)*	provides a more detailed description of some important concepts that need to be taken into account when conducting a safety diagnosis.
Accident tables *(Appendix 6-2)*	lists the main possible contributing factors and potential solutions regarding various accident types.
Detailed checklists *(Appendix 6-3)*	describes, in a checklist format, the various steps of a safety diagnosis.
Technical Sheets	describes the relationship between specific road components and safety (horizontal alignment, vertical alignment, road-surface condition, etc.).
Technical studies	explains how to conduct technical studies whose results may be required when conducting a safety diagnosis (spot speed, traffic count, etc.).

6.1 SITE HISTORY

Different types of information may be available about the site under study even before initiating the diagnosis:

- existing databases (accidents, geometric characteristics, road sign inventory, traffic volumes, etc.);
- photos and videos;
- results of technical studies (spot speeds, sight distances, etc.);
- previous reports (on safety, maintenance, etc.);
- employees' knowledge;
- external requests and complaints;
- etc.

All this information should be gathered and analyzed at the beginning of the diagnosis in order to:

- be informed of problems identified in the past and actions taken;
- avoid duplication of effort - if no major change has occurred at the site, some technical studies may not have to be repeated.

6.2 SITE CATEGORIZATION

What constitutes a hazardous road feature or dangerous road user behaviour is strongly influenced by the road environment in which it is observed. For example, the risk associated with the same sharp curve radius may be very high on a rural road but very low in a residential area since the curve acts as a speed regulator. Conversely, the risk associated with a speed of 100 km/h may be low on a rural road with generous geometric features but extremely high in a residential area. What constitutes a "normal" proportion of a given type of accident is also highly dependant on the category of site being considered ***(Accident comparative tables)***.

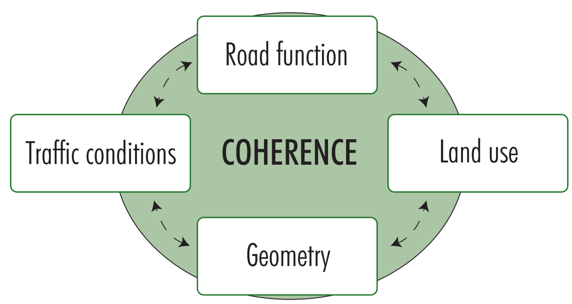
The site category must therefore be established at the beginning of the diagnosis since it will be used throughout the search for problems and solutions. For the purpose of a safety study, the site category is not only defined by the road class to which it belongs in the road classification system, it also takes into account some of the main site features that have an impact on road safety (e.g. T but + intersection, stops or traffic signals, etc.).

How to make use of the site categorization in a safety diagnosis

1) Determine the site category;
2) During the accident analysis ***(step 6.3)***, select a ***reference population*** (based on the site category) that will be used to detect abnormal accident patterns by comparing accident characteristics at the site with those of similar sites;
3) During the site investigation ***(step 6.4)***, refer to the site category to verify compliance with existing standards and to assess the overall ***coherence*** of the road environment. The site category also serves to verify the presence of problems that are frequently observed at sites having similar characteristics;
4) Finally, use the site category to propose remedial actions that are well suited to the road environment considered.

Checklists provided in *Appendix 6-3* incorporate these various tasks.

Are existing road categories appropriate?

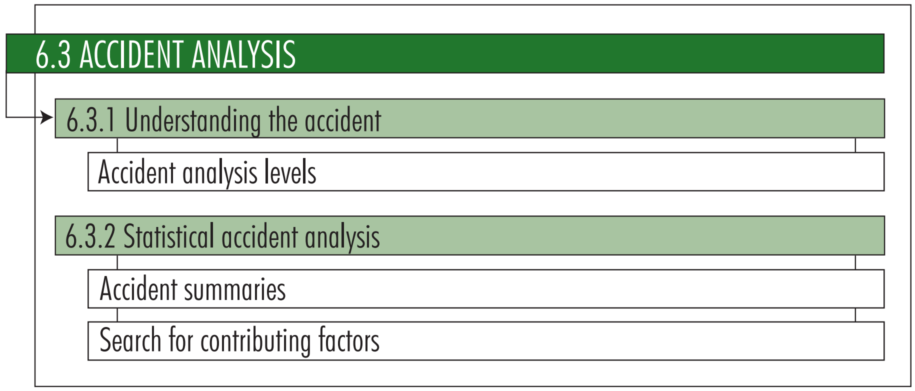


The recommended features of each recognized road category are described in a country's design standards. Road environments created when applying these standards should satisfy both mobility and safety objectives. However, recent research and development have shown that in many instances, a road may comply with the requirements of its category without being sufficiently coherent to allow safe traffic operation. If this is the case, a review of the road classification system may very well be needed (see ***Appendix 6-1*** for more details).

Adequate actions also need to be taken to ensure that roads that were safe at the time of their construction remain safe over time (e.g. access-control regulations, integration of transportation planning and land-use planning).

While these topics clearly extend beyond the scope of this chapter, they are nevertheless essential components of a transportation system that has the necessary features to minimize current and future road safety problems ***(Appendix 6-1)***.

6.3 ACCIDENT ANALYSIS



The analysis of the available accident data is a fundamental step of a safety diagnosis as it helps in gaining a better understanding of problems that have been experienced by road users travelling at the site. As a result, analysts can propose solutions that are well suited to encountered problems and will help in reducing the occurrence of similar accidents in the future.

The accident analysis should be initiated prior to the site visit as it may influence observations that need to be made at the site. In some cases, analysts will also have to bring additional equipment, to verify the relevance of potential accident factors (radar gun to measure operating speeds, rods and measuring wheel to determine available sight distance, etc.). Accident tables should be brought to the site ***(Appendix 6-2)***.

6.3.1 UNDERSTANDING THE ACCIDENT

To properly diagnose safety problems, an analyst must first have a good understanding of the accident mechanisms:

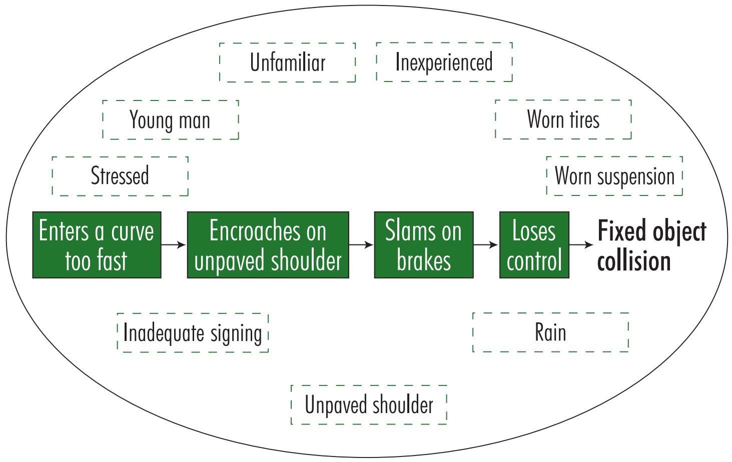
- a road accident is the end result of a sequence of events occurring under specific circumstances (rather than the “cause” of a single factor);
- each event and each circumstance are linked to one of the three basic components of the safety system - human, road environment, vehicle ***(Chapter 3)***;
- each event is strongly influenced by the result of preceding actions and circumstances of these actions.

The following example illustrates a hypothetical accident sequence:

> *An 18-year-old man who had his driving licence for six months was going for a job interview in an unfamiliar area. He was late, tense and speeding. It was raining. His vehicle's suspension and tires were worn. At the approach to a sharp curve after a long, straight section, he did not see the warning sign, which is deficient under prevailing standards, and entered the curve too fast. He encroached on the shoulder, which was unpaved, slammed on the brakes, lost control and collided with a tree by the side of the road.*

Analysts must seek to understand such chains of events and circumstances leading up to each accident in order to propose measures that may break these sequences (Figure 6-3). Where there is not enough information to reconstruct the course of each accident in detail, simplified analysis methods must be used.

Figure 6-3 Accident chain of events and circumstances



Accident analysis levels

Different types of analysis levels can be recognized based on the number of accidents considered.

The micro level

Where a single accident is analyzed (see ***detailed analysis***).

The intermediate level

All accidents having occurred at a same location with a poor safety record are analyzed to find solutions that will reduce their future occurrence. As mentioned in the introduction, the diagnosis process described in this chapter is best suited to this level of analysis.

The macro level

A larger set of accident data is considered. It may be the set of all accidents on a road network, all accidents involving a specific type of road user (pedestrians, heavy vehicles), or all accidents on a given road category. Results of macro-analyses conducted on road categories may yield useful information when conducting a safety diagnosis at a specific site, by providing insight into problems that are likely to be encountered ***(problems at similar sites)***. Such analyses are also conducted when developing a country's ***road safety action plan*** and establishing a country's action priorities.

Different analysis levels can also be identified, based on the level of information used in the diagnosis:

Detailed analysis

In several countries, detailed accident analyses are conducted after a serious accident, in order to accurately reconstruct its chain of events and circumstances.

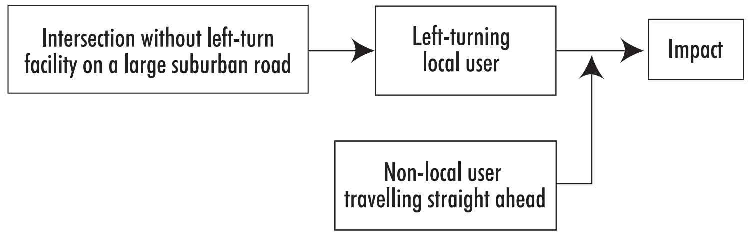
The analysis often begins at the scene of the accident before the vehicles are removed, allowing for the collection of volatile information such as participant and eyewitness versions, weather and surface conditions, tire marks, etc.

Detailed analyses require the participation of experts from a number of disciplines: transportation engineers, mechanical engineers, human-factor specialists, police officers, doctors, etc. Recommendations made at the end of these investigations often extend beyond the framework of the accident itself to prevent other events liable to occur under similar circumstances. Due to the high cost of the method, this type of analysis is only applied in a limited number of cases.

Accident scenarios

These types of studies are usually conducted after the accident evidence has been erased from the site. Analysts rely mainly on the information contained in accident reports to determine partial sequences of events and circumstances that are common to a number of accidents (Figure 6-4). Most accident reports contain not only coded information (see ***statistical accident analysis***), but also sketches and narratives that may be quite useful in the determination of accident scenarios.

Figure 6-4 Example – Accident scenario

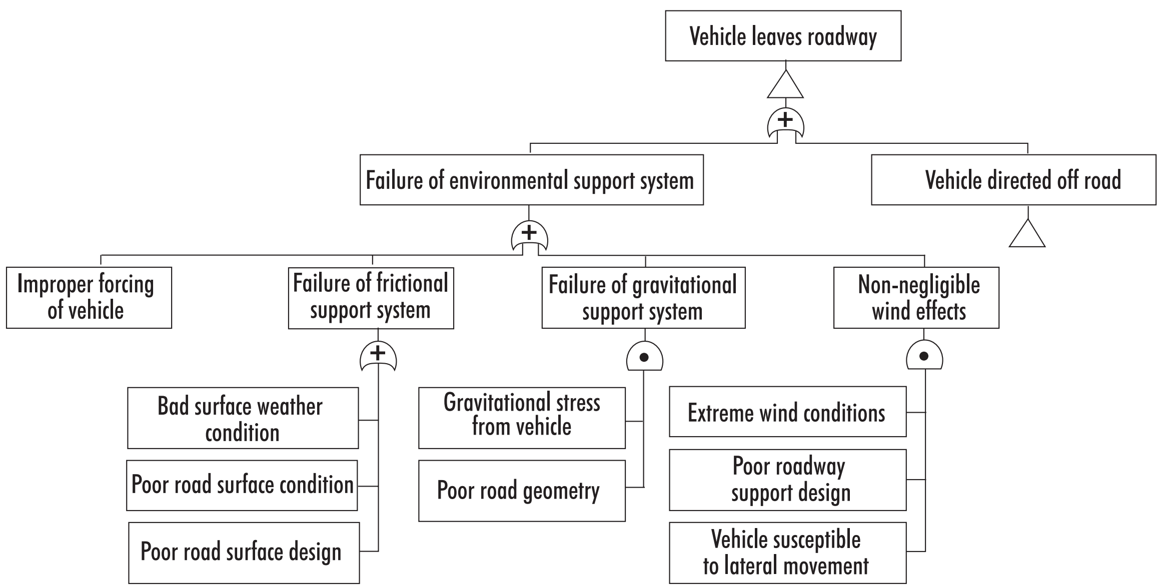


Source: Fleury et al., 1990

This information is then used to propose solutions that will avoid the repetition of similar chains of events. The work is generally completed by small multidisciplinary teams or by road engineering specialists.

Fault trees offer a convenient way of grouping different scenarios of the same accident type in a single diagram (Joshua and Garber, 1992; Kuzminski et al., 1995). Each tree path represents a possible accident scenario (Figure 6-5).

Figure 6-5 Fault tree – Vehicle leaves roadway



Source: Kuzminski et al., 1995

Statistical analysis

This level involves a purely statistical analysis. Here again, the diagnosis covers a series of accidents but the available data may not be sufficient to develop accident scenarios. Accident reports are analyzed to see if one or more factors are abnormally repeated. This information is then used to advance the diagnosis.

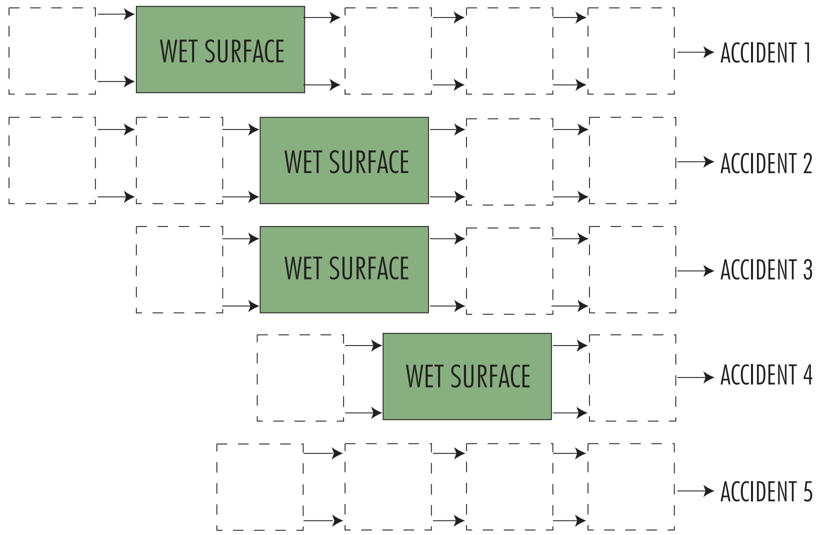
Figure 6-6 illustrates the method. The chain of events in each accident cannot be reproduced but the "wet surface" factor is common to four of the five accidents that have occurred at the same site.

The analysis will seek to understand the causes of this repetition.

The level of detail of a safety diagnosis depends on the available information. In most cases, the analysis takes place between the accident scenarios and statistical analysis levels: some scenarios or quasi scenarios can be developed and a complete statistical analysis is conducted.

The tools presented in the next section describe how to conduct a statistical accident analysis.

Figure 6-6 Example – Repetition of the same contributing factor



6.3.2 STATISTICAL ACCIDENT ANALYSIS

Typically, accident reports contain several elements of information that may highlight potential road deficiencies (Table 6-2).

Table 6-2 Typical accident report information that may highlight road deficiencies

COLLISION INVOLVING	ACCIDENT TYPE	MANOEUVRE	SEVERITY
- pedestrian, cyclist - passenger car - heavy vehicle, bus - train - animal - etc.	- right-angle - rear-end - head-on - sideswipe - single vehicle - etc.	- crossing - turning - passing - parking - etc.	- fatal - severe injury - light injury - PDO
WEATHER CONDITION	**SURFACE CONDITION**	**TIME**	**ROAD FEATURE**
- clear - cloudy - rain - mist - snow	- dry - wet - other (sand, mud, ice, snow) - holes, ruts	- time of day - day of week - month - year	- intersection - horizontal curve - vertical grade - etc.
RIGHT-OF-WAY RULES	**HUMAN FACTORS**	**DRIVER**	**OTHERS**
- none - yield - stop - traffic signals	- fatigue - inattention - alcohol - etc.	- home address - age - driving experience - etc.	- roadworks - statutory holiday - etc.

By combining information from the accident report, the analyst may sometimes obtain results that are similar to quasi-scenarios: heavy vehicle on grade; right-angle collision at intersection at rush hour, etc.

Additional information contained in the accident report may also reveal problems that require actions on other components of the HEV system: impaired driving, young drivers, overloaded vehicles, mechanical defects, etc. In such cases, the appropriate authorities should be informed of the existence of the problem.

Procedure – Statistical accident analysis

Steps of a statistical accident analysis are as follows:

1) Preparation of accident summaries

Various accident summaries can be prepared to help identify abnormal accident patterns. In the following pages, three types of summaries are described:

Collision diagrams
Summary tables
Comparative tables

2) Search for contributing factors

Once deviant accident patterns have been identified, the analyst will seek to understand their causes (contributing factors) in order to determine whether road engineering actions could efficiently prevent similar accidents in the future. The first part of the ***Accident tables*** in Appendix 6-2 provides practical assistance in this task. Separate tables have been developed for nodes and links and for the most frequent accident types.

3) Search for solutions

For each accident contributing factor, there are generally several actions that can be envisioned to improve the situation. The second part of the ***Accident tables*** in Appendix 6-2 lists the most common treatments and also provides links to relevant ***Technical Sheets*** (in Part 3), that contain supplemental information.

Accident summaries

Collision diagrams

This diagram displays all accidents that have occurred at a same site (Figure 6-7). It shows:

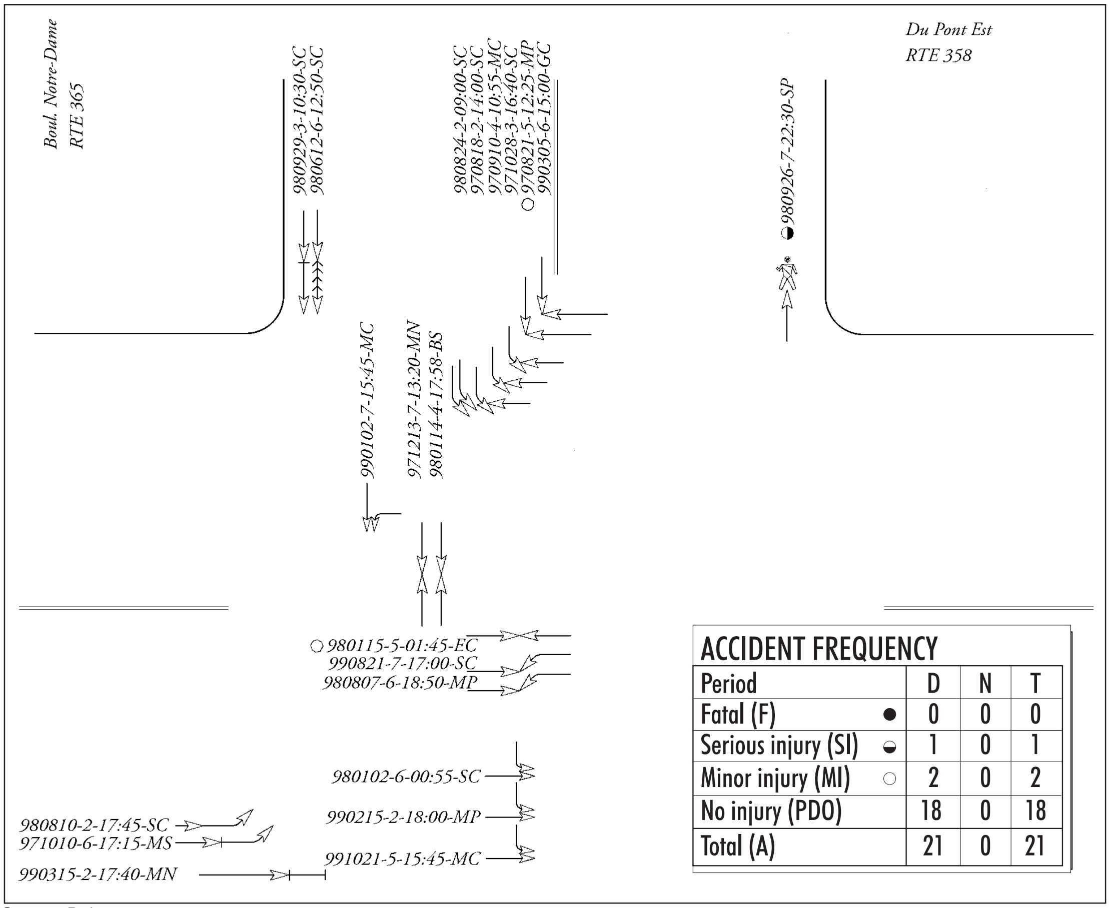
- the exact location of each accident;
- the travel direction of each vehicle;
- the manoeuvres of each vehicle (straight ahead, turning, loss of control);
- the type of collision (right angle, rear-end, etc.).

It may also include additional information such as the accident severity, the date, the day of week, the time, the surface condition, etc.

The collision diagram makes it easier to identify repetitive accident patterns and their concentration in certain travel directions.

Several commercial programs are now available to speed up the preparation of these diagrams.

Figure 6-7 Collision diagram



Source: Bélanger, 2002

Accident summary tables

These table display on a single page several characteristics of a group of accidents, facilitating the detection of repetitive factors. For instance, Table 6-3 shows clearly that several of the 12 accidents reported at this site occurred during weekends, information that will guide the search for problems and solutions. If accident data are computerized, the preparation of such summary tables can be easily automated. Deviant accident factors may then be brought automatically to the analyst's attention, based on pre-established threshold values (see ***accident comparative tables***).

Table 6-3 Example – Accident summary table

	ACCIDENT NUMBER											
	1	2	3	4	5	6	7	8	9	10	11	12
YEAR	00	99	00	98	99	99	00	98	00	99	98	98
MONTH	02	03	07	04	01	04	04	12	05	04	09	10
DAY OF WEEK	SUN	FRI	MON	SUN	TUE	SAT	SAT	TUE	MON	FRI	SUN	SAT
TIME	1615	0210	1240	1750	1520	1125	1430	2200	1825	0910	0500	0940
SEVERITY (● : fatal ○ : injury)		●				○				○		
ACCIDENT TYPE												
SURFACE CONDITION (D: dry W: wet)	D	D	W	W	W	D	W	D	D	W	D	W
LIGHTING	NIGHT	DAY	DAY	NIGHT	DAY	DAY	DAY	NIGHT	DAY	DAY	DAY	NIGHT

Accident comparative tables

What constitutes an abnormal proportion of accidents depends greatly on the site category being analyzed. For instance, average proportions of rear-end collisions or right-angle collisions at an intersection will depend on whether the right-of-way is managed by stop signs or traffic signals; the proportion of run-off the road accidents is higher on horizontal curves than on straight alignments, etc.

Therefore, comparing accident patterns at the site under study with accident patterns at sites having similar characteristics ***(reference population)*** will help provide a more accurate estimate of the anticipated improvement potential. For example, Table 6-4 shows that in this dataset, a 40% proportion of rear-end collisions is below average at an intersection with traffic signals, but above average at an intersection with stop signs.

Table 6-4 Example – Accident proportions at 4-leg intersections

		
TRAFFIC SIGNAL	45%	30%
STOPS	32%	48%

Note: Accidents involving only one vehicle and accidents with unknown patterns are not included.

Source: Ministère des Transports du Québec.

However, it is first necessary to ensure that the geometric and traffic characteristics of the ***reference population*** are adequate; otherwise, this comparison might simply lead to the maintaining of unsafe conditions. ***Appendix 5-1*** discusses this problem in greater detail.

Various statistical tests can be used for this comparison and ***Section 5.2.1*** describes how to calculate binomial proportions to this end. Table 6-5 shows the results of this calculation for the variable "vehicle type". In this example, the high proportion of accidents involving a heavy vehicle requires more in-depth investigation.

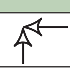
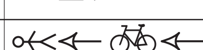
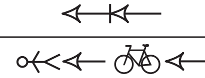
Table 6-5 Example – Accident comparative table

VEHICLE TYPE	SITE[a] NUMBER	SITE[a] PERCENTAGE	REFERENCE FAMILY[b] PERCENTAGE	DEVIANCE PROBABILITY (%)
PASSENGER VEHICLES	33	80	90	2
HEAVY VEHICLES	7	17	7	98
MOTORCYCLES/MOPEDS	1	2	1	66
BICYCLES	0	0	2	N/A
OTHERS	0	0	0	N/A

[a] Site under study: + intersection with stops on minor legs in a urban area.
[b] Reference family: 145 similar intersections.

Search for contributing factors

Accident tables of ***Appendix 6-2*** help in finding which factors have contributed to the following accident patterns:

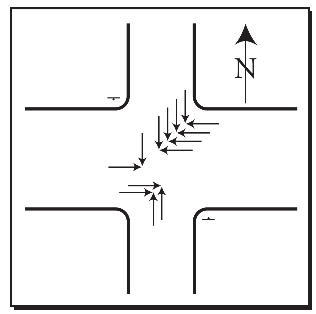
INTERSECTION		SECTION		GENERAL
RIGHT ANGLE		SINGLE VEHICLE		NIGHT
REAR-END		REAR END		WET SURFACE
OPPOSITE TURN		HEAD-ON		
PEDESTRIAN / CYCLIST		PEDESTRIAN / CYCLIST		

These tables are divided into two parts:

ELEMENT	EXPLANATIONS
1) POSSIBLE FACTORS	
contributing factors	List of main factors that may have contributed to the type of accident considered.
other accident types	List of other accident types that may be associated with a contributing factor.
observations, measures, calculations	Main observations, measures or calculations that can help to confirm or reject the relevance of a contributing factor.
2) POSSIBLE ACTIONS	
contributing factors	As above.
possible actions	Main types of remedial actions that may be considered for a given contributing factor.
references	Link to relevant technical sheets and technical studies in Part 3 and Part 4 of the manual.

From easy sites to difficult sites

The level of complexity of safety diagnoses varies according to the case under study. Adapting the concept of "easy sites and difficult sites" (Department Of Transport London, 1986), the following types of cases can be identified:

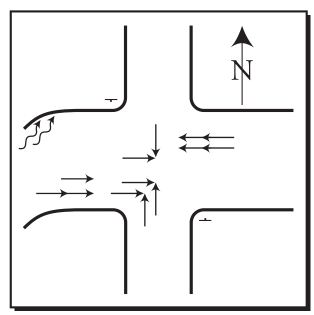


Easy site, simple pattern

Easy sites - simple accident pattern(s)

Sites where one or more abnormal accident patterns - right angle, run-off-road, etc. - are detected.

Accident tables of ***Appendix 6-2*** can be used when seeking to identify the most likely contributing factors and potential remedial measures.

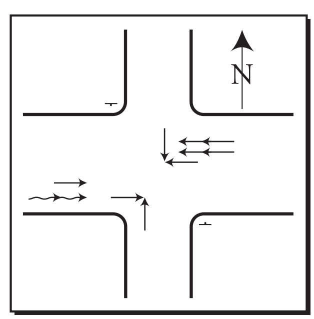


Easy site, multiple patterns

Easy sites - multiple patterns

Sites where potential road deficiencies can be detected by the superposition of more than one accident pattern. For instance, a horizontal curve on an approach to an intersection, which contributes to loss-of-control, rear-end, right-angle and wet-surface accidents.

In practice, this category covers a number of cases since the same deficiency often contributes to more than one accident pattern. The example given in ***Appendix 6-4*** belongs to this category.



Difficult site

Difficult sites

Sites where the accident analysis does not clearly identify the nature of the problem. Various factors may explain this situation:

- poor quality or insufficient quantity of accident data ***(Chapter 4)***;
- the site has several deficiencies;
- accidents are not primarily related to road deficiencies;
- analysts do not have sufficient knowledge.

Easy sites, for which low-cost treatment can be found, should be treated first.

6.4 SITE OBSERVATIONS

The site visit is also an essential component of a safety diagnosis in which the analyst verifies the actual site characteristics and observes how it operates. The analyst can then better understand the nature of the safety problems and verify the applicability of solutions that have been envisioned at the office. While at the site, the analyst can:

- complete the accident analysis that has been initiated in step 6-3 (finalize the determination of possible contributing factors and potential solutions);
- identify hazardous conditions that might not have been detected during the accident analysis.

If the accident analysis did not lead to a satisfactory understanding of the problems, ***traffic conflict techniques*** may be used to make progress in the safety diagnosis.

The following elements need to be observed at the site:

- road and roadside characteristics;
- traffic conditions (road users' categories, traffic volumes, delays, etc.);
- road users' behaviour (speed, compliance with road regulations, etc.).

These observations will help to identify situations that increase accident risk and can be improved by road-engineering actions. It may consist of:

- differences between site features and established standards or practices;
- improper consideration of drivers' capabilities and limitations;
    - driving task;
    - expectancies.
- incoherence of the road environment.

As mentioned in introduction, these elements are described in more details in ***Appendix 6-1***.

During the site visit, the analyst should also verify if problems that are often encountered at similar sites are found at this site. Experienced analysts intuitively use the knowledge they have accumulated in previous safety diagnoses to focus their attention on the most likely sources of problems (this might in itself become a limitation if it prevents them from seeing the real origin of the problem).

In that respect, it should be noted that several countries have developed guides describing safety problems encountered on the main road categories of their network (e.g. Centre d'études des Transports urbains et Service d'études techniques des routes et autoroutes, 1992; American association of state highway and transportation officials, 1997; Department of transport, 2001). Such guides may provide useful information at the diagnostic stage and it would be a desirable initiative for any country to develop its own similar guide.

Also, one will often find, after having completed several ***safety reviews*** on the same road category, that there are similarities in the nature of the encountered problems. Again, this knowledge should be used at the diagnosis stage ***(frequent problems, safety principles)***.

As a result, the number and diversity of observations that need to be made at a site is considerable. Sometimes, problems may be easy to diagnose - a missing stop sign, the presence of pedestrians on a freeway, a hidden intersection - but in other circumstances, the diagnosis may be much more complex and require the contribution of a multidisciplinary team of experts.

In trying to provide assistance for safety diagnoses, the main difficulty is to efficiently target the attention of less experienced analysts on the most important safety issues without asking too many questions that are irrelevant to the case under study.

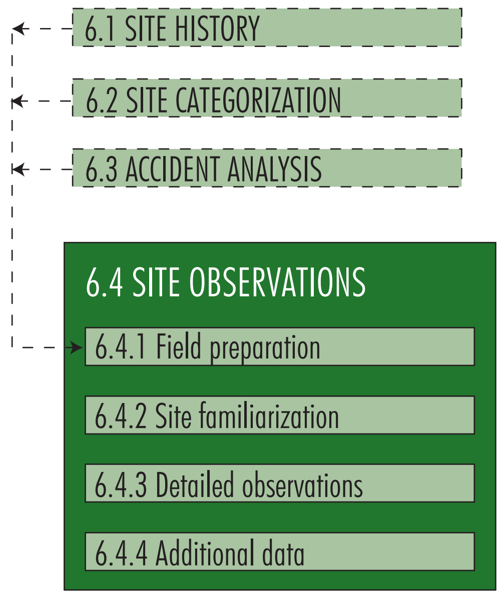
Procedure – Site observations

The observation procedure proposed in this chapter relies on four tasks: field preparation, site familiarization, detailed observation and additional data collection (Figure 6-8). These tasks are described in the following pages.

With experience, analysts will learn to develop shortcuts that will improve the efficiency of their observations. The site-familiarization step will always be conducted as described, but detailed observations are likely to become progressively more informal.

The important point is to ensure that the main sources of problems and possible solutions are adequately considered during the diagnosis.

Figure 6-8 Procedure – Site observations



Notes:

- detailed observation checklists have been prepared to assist analysts in this task; they are included in ***Appendix 6-3***;
- a practical example is presented in ***Appendix 6-4***;
- the ***Appendix 6-1*** describes in more detail several concepts that need to be taken into consideration during a safety diagnosis: road-related problems and solutions, road categorization, road coherence, driving task and drivers' expectancies;
- site observations should be made when problems are most likely to be observed (rush hour, night, weekend, wet pavement, etc.);
- observation methods should never jeopardize the safety of road users and observers.

Debris on the road - The retaining wall is too short

Frequent problems	

In **rural areas**:
• inappropriate geometric characteristics for operating speeds: insufficient sight distances, narrow lanes and shoulders, unprotected rigid obstacles on roadsides, etc. Between 33% and 50% of all fatalities occur in run-off-road accidents;
• difficult transitions between two adjacent road segments having different characteristics, which may surprise drivers and cause errors - a sharp curve after a long straight section, an unexpected lane drop, etc.;
• uncontrolled development of frontage access, which increases speed differentials and traffic conflicts between users.
	In **urban areas**:
	• inadequate management of conflicting manoeuvres at intersections and accesses (motorized-motorized, motorized-non-motorized). Typically, around 50% of all accidents occur at intersections;
	• inadequate protection of non-motorized users. If low speed cannot be maintained, motorized and non-motorized road users must be separated[1]:
	  • in space (exclusive lanes or paths, grade-separated crosswalks);
	  • in time (traffic signals with exclusive phases for non-motorized users).
	• driving task overload, which may be linked to the number or complexity of the information that needs to be processed or to the number of actions that need to be completed at a site.

Safety principles	
At intersections: • minimize the number of conflict points; • give precedence to major movements through alignment, delineation and traffic control; • separate conflicts in space or time; • control the angle of conflict; • define and minimize conflict areas; • define vehicle paths; • ensure adequate sight distances; • control approach speeds using alignment, lane width, traffic control or speed limits; • provide clear indications of right-of-way requirements; • minimize roadside hazards; • provide for all potential vehicular and non-vehicular traffic likely to use the intersection; • simplify the driving task; • minimize road-user delay.	**On links:** • ensure appropriate and consistent standards of horizontal and vertical alignments; • develop roadway cross-sections to suit road function and traffic volumes; • delineate roadway and vehicle paths; • ensure appropriate standards for access control from abutting land use; • ensure that the roadside environment is clear or forgiving.

Source: Ogden, 1996

[1] Fleury (1998) defines two opposing principles, **integration** and **segregation** of motorized and non-motorized road users:

Integration is only possible when traffic volumes are light and speeds can be kept sufficiently low (through an appropriate selection of road layouts and geometric features). Under such conditions, accident and trauma risks can be kept to a minimum.

Separation should be applied elsewhere in order to limit potential conflicts.

6.4.1 FIELD PREPARATION

The analyst must bring to the site the following items:

- accident tables ***(Appendix 6-2)***;
- diagnostic checklists ***(Appendix 6-3)***;
- film camera and video camera with sufficient recording media and batteries;
- measuring tape and measuring wheel;
- paper, pencils, ruler, and eraser;
- cell phone.

When available, the following should also be brought to the site:

- road drawings (geometric design, signing, marking, lighting, etc.). Several road administrations now have computerized databases containing most of this information. If these data can be linked to a geographic information system (GIS), a scaled road drawing can be easily prepared and brought to the site. Only the differences with existing conditions will then be noted, facilitating preparation of the ***condition diagram***;
- reports of previous studies (to verify whether problems identified in the past have been corrected as recommended);
- conclusions of the ***accident analysis***.

It may also be helpful to provide the following items (particularly if the site is far from the office):

- sighting and target rods ***(sight distance study)***;
- radar gun ***(spot speed study)***;
- stop watch ***(delay***, ***travel time***, traffic-signal timing);
- tally sheets or mechanical or electronic counter ***(traffic count)***;
- tape recorder;
- level (superelevation).

For the analysts' safety, also provide:

- safety helmet, vest and boots;
- rotating beacon and other required road signalling equipment;
- police assistance (when necessary).

6.4.2 SITE FAMILIARIZATION

The main objectives of the site familiarization are to detect obvious problems and to understand the main difficulties encountered by drivers at the analyzed site. Upon arrival, the analyst drives through the site at the same speed as other drivers and in all permitted directions. The distance to be covered depends on the type of road environment and the nature of the suspected problems. In urban areas, a distance of a few hundred meters in each direction is usually sufficient. In rural areas, the distance to be covered may be much longer and extend up to several kilometers when the problem may be related to a violation of ***drivers' expectancies***. The analyst must also complete pedestrian manoeuvres.

Various types of problems can be detected during the site familiarization:

- hazardous road or roadside characteristics:
  restricted sight distance, inadequate signing, hazardous roadside conditions, etc.
- hazardous traffic conditions:
  severe traffic conflicts, high speed differentials, excessive delays etc.
- risky behaviour:
  poor compliance with traffic, rules, excessive speeds, tailgating, etc.
- expectancy violations or inappropriate driving task requirement.
  inadequate transition zone, multi-branch intersection, etc.
- obvious coherence problem:
  commercial stand on freeway shoulder, non-local traffic on residential street, etc.
- insufficient maintenance;
  faded markings, worn road signs, overgrown vegetation, etc.

Figure 6-9 Example – Obvious problems to be detected during the site familiarization

Hazardous roadside barrier near traffic lanes on rural freeway

Hazardous road use on suburban freeway

6.4.3 DETAILED OBSERVATIONS

At this stage, the analyst:

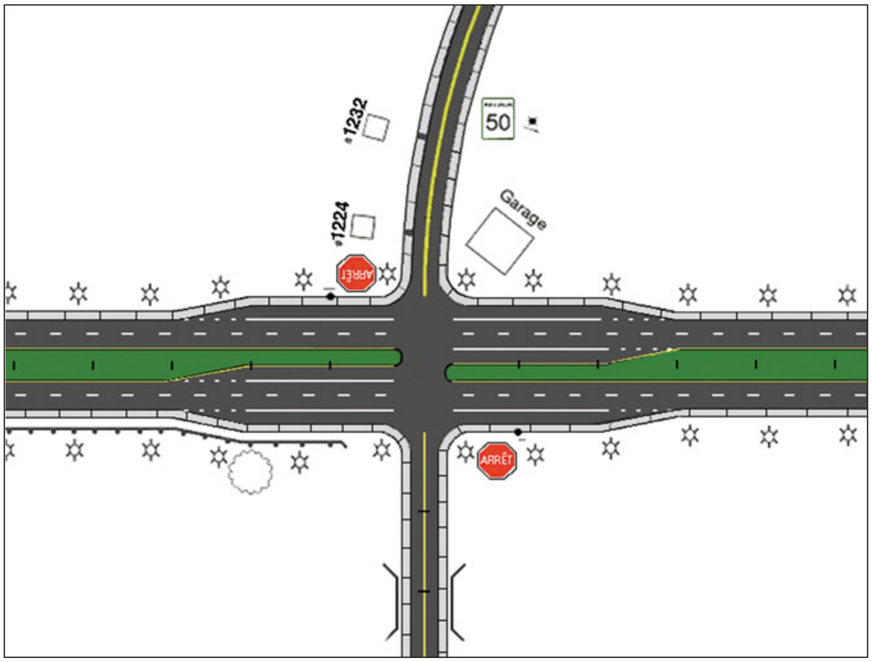
1. makes observations related to problems that have been found in the previous steps of the diagnosis, i.e.:
   - verifies whether problems that have been identified in the past at this site have been successfully treated ***(site history)***;
   - completes the determination of possible accident contributing factors and potential solutions ***(accident analysis)***;
   - analyzes problems that have been detected during the site familiarization.
2. checks whether problems that are frequently encountered at similar sites are also found at this site ***(problems at similar sites)***;
3. observes traffic conditions. Excessive delays and travel times may cause road-user frustration, leading to risky behaviour, such as short gap acceptance, tailgating or illegal passing manoeuvres. If these problems are observed or suspected, a more detailed analysis of the traffic conditions should be conducted. This will always include a ***traffic count*** and a ***capacity analysis*** and, in some instances, ***additional technical studies*** may also be required.

   The analyst should also ensure that no category of road user has an unacceptable level of risk. Frequent problems include:
   - hazardous left-turn manoeuvres on high-speed roads (insufficient protection);
   - high speed differentials (between road users at the same location or for the same road user between two road segments);
   - high mass differentials (inappropriate mixes of road users sharing the road);
   - severe traffic conflicts;
   - encroachments (e.g. during turning manoeuvres of heavy vehicles at intersection);
   - inadequate consideration of the needs of specific categories of road users (e.g. audible crossing signals for blind people, longer crossing times for elderly persons, etc.).
4. makes detailed observations of the features of the road environment:
   - surrounding land use
   - speed (posted, operating)
   - horizontal alignment
   - vertical alignment
   - sight distance
   - cross-section
   - road surface conditions
   - road surface markings
   - roadside conditions
   - accesses and crossings
   - road signs
   - road lighting
   - intersection features (type, control, layout)

Analysts should verify that each of these features follows relevant standards or practices and assess the associated risk when deviations are observed.

A condition diagram is generally prepared in order to present, on a single sheet, a graphic summary of the main physical characteristics of the site under study (e.g. ***Figure 6-10***). Notes should be made directly on this diagram to highlight identified safety deficiencies. Placed beside the collision diagram, the condition diagram will often help in revealing features that may explain a specific accident problem.

Figure 6-10 Example - Condition diagram



Source: Bélanger, 2002

5. assess drivers' workload and expectancy violation. If needed, a more detailed analysis of the driving task should be conducted.
6. check whether road safety problems may be linked to inappropriate road user behaviour and determine if such behaviour could be efficiently prevented by changing some road features; when the problem would be better solved by other types of actions (e.g. education, enforcement), contacts should be made with the agencies responsible to ensure that they are well aware of the problem.
7. check whether the safety problems may be related to inadequate maintenance. Frequent deficiencies include worn road signs, faded road marking, overgrown vegetation, distressed road surface, damaged road safety equipment (e.g. guardrails) and broken road light or traffic signal.

6.4.4 ADDITIONAL DATA COLLECTION

While at the site, the analyst should take pictures and record a video of the prevailing conditions for future references (particularly if the site is far from the office). Based on the conclusions reached during the diagnosis, additional technical studies may also need to be conducted at the site to validate specific problem assumptions. Some of these studies will be conducted directly by the analyst during the site visit while others, that require more time, equipment or manpower, will be planned at a different time.

Photos and videos

Photos should be taken at regular intervals (e.g. 100m), in each direction of travel. The camera should be at a position that is close to that of a driver's eyes of a passenger car, to ensure that photos are representative of the conditions seen while driving. When the vehicle is stopped at the stop line of each minor leg, pictures are taken from the driver's seat (toward the left side, straight ahead and toward the right side). When driving through the site (site familiarization step), it may also be useful to record a video of the prevailing conditions. Comments could be included with the recording for future reference. Photos or videos of noteworthy features should also be taken: hazardous geometric characteristics, hazardous manoeuvres or behaviour, brake marks, etc.

Technical studies

Technical studies that are most often required during a safety diagnosis are:

Traffic count

A traffic count should be conducted at each location where traffic operation problems have been detected or suspected (long delays, line-ups, excessive travel times, etc.). A traffic count may also be needed to check whether some road features are warranted (a traffic signal, a turning lane, etc.). Counts should include the morning and the evening peak periods of a representative day (unless problems are clearly linked to a different time). The collected data often need to be expanded to provide estimates of the average annual daily traffic (AADT), which is used to make various road engineering decisions. Information on the different road user categories and manoeuvres also needs to be collected. Part 4 of the manual explains how to conduct a ***traffic count***.

Capacity analysis

The analyst should verify whether the capacity is adequate (overall capacity at the site, sharing of this capacity among road users).

on road sections: check whether the number, assigning and features of each traffic lane are appropriate, including passing lanes (width, length, end treatment);

at intersections: check whether the actual traffic control device is well suited to the prevailing traffic conditions (stops on minor legs, all-way stop, traffic signal, etc.), determine at signalized intersections if the number and length of each phase is appropriate, and ensure that the necessary channelization is provided to reduce delays and traffic conflicts.

Specialized procedures and related software are available to conduct these analyses.

Delay, ***travel time*** and gap acceptance studies may also be needed to ascertain capacity problems. At traffic signals, the timing of each phase must be known, including each change interval (be aware that in many cases, different timings are programmed at the same traffic signal).

Traffic conflicts

A traffic conflict is a situation where one or more road users have to take evasive action (braking, accelerating, swerving or a combination of these manoeuvres) in order to avoid an accident. The observation of traffic conflicts, using formal procedures, is a useful diagnosis tool, particularly at intersections and when accident data do not provide sufficient information to understand why accidents do occur. Part 4 of the manual describes the main issues related to the conduct of a ***traffic conflict study***.

Speed

Driving too fast for conditions increases both the accident risk and their severity. Substantial speed differentials between two adjacent road segments (e.g. sharp horizontal curve, work area) or between different categories of road users (e.g. tractor on a high-speed road) is another risk factor that should be detected during a safety diagnosis. A ***spot speed study*** may be required to determine the speed distribution at a site and Part 4 explains how to conduct this type of study.

Sight distance

At any point on a road, the available sight distance must be sufficient to allow a driver travelling at a reasonable speed to safely bring the vehicle to a complete stop. When road conditions are complex or unexpected, longer sight distances may be required. At intersections, the available sight distance must also be sufficient to allow each non-priority manoeuvre to be completed safely. When site observations reveal sight distance restrictions, field measurements should be made. Part 3 of the manual contains a ***sight distance technical sheet*** describing in more detail the various sight distance requirements and Part 4 explains how to conduct a ***sight distance study***.

Driving task analysis

When site observations reveal a complex situation (e.g. cluttered visual environment, difficult manoeuvre) or an unexpected situation (e.g. unusual road intersection or traffic pattern, first sharp curve after a long straight segment), a detailed analysis of the driving task may be required. ***Appendix 6-1*** discusses the important concepts of ***drivers' expectancies*** and ***driving task workload***. A technical sheet is provided in Part 3 of the manual to describe ***Human factors*** that need to be considered during a safety diagnosis.

Checklists

Checklists are provided to assist the analyst in completing the various steps of a safety diagnosis (see ***Appendix 6-3***).

The "Detailed observation" part of these checklists contains questions related to the main occurrences of the various types of problems described in this chapter. For example, the analyst is asked to verify if the speed reduction at the approach to a curve is excessive in order to detect expectancy violations (and he is provided with quantitative guidelines to make his decision). He is also asked to check for encroachments at the site, which may be a symptom of a lack of coherence between the site geometric features and its road user categories. Etc.

These lists are general - only links and nodes have been separated - and consequently some questions may not be relevant to a given site. Different checklists should preferably be developed for each type of site (or feature) that may be analyzed in a country. This would increase the proportion of relevant questions.

With experience, analysts will quickly determine which points require attention. Some will then continue to answer all questions of those checklists in order to obtain a complete report on a site's safety performance, while others will use only those parts dealing with features they found hazardous during the previous steps of their analysis.

To avoid multiple cross-referencing between the various sections of these checklists, some elements have been repeated a few times (e.g. road surface conditions and sight distance). By doing so, each section of these checklists becomes self-contained.

All questions have been formulated to yield a positive answer when there is no problem. In this manner, one can rapidly find all detected site deficiencies by browsing the "No" column of filled checklists.

Technical sheets have also been developed for several elements of these checklists: horizontal alignment, vertical alignment, surface condition, etc. ***(Part 3)***. These sheets describe in detail the relationship between the element considered and safety and can be used as a reference. Additional technical sheets should be added in future editions of the manual.

Naturally, checklists will never replace the expertise and judgment acquired by experienced analysts and consequently, they should not be seen for more than what they are: a tool that may be of assistance to avoid overlooking important elements and to ensure that observations are made systematically.

6.5 CONCLUSION

This chapter has described how to conduct a safety diagnosis on existing roads. It has proposed an analytical process using four main sources of information:

site history
site categorization
accident analyses
site observations

A variety of practical tools are provided throughout the manual to assist in making those diagnoses: accident tables ***(Appendix 6-2)***, detailed checklists ***(Appendix 6-3)***, technical sheets ***(Part 3)*** and technical studies ***(Part 4)***.

The diagnostic process that has been described is best suited to blackspot analysis, but it can also be used for other types of safety diagnoses. For example, the content of the ***site categorization*** and ***site observation sections*** can be helpful in conducting safety reviews (or audits) of existing roads. Even at this level, however, accident data should be used, if available. As is the case with any other type of diagnosis, best results can be expected when making optimal use of all pertinent information.

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APPENDIX 6-1

Additional notes

ROAD-RELATED PROBLEMS AND SOLUTIONS

Road engineering actions that may be taken to improve road safety consist of changes to one of the following elements:

- geometric characteristics (alignment, cross-section, roadside conditions, etc.);
- traffic management (right-of-way rules, manoeuvring restrictions, etc.);
- information for road users (traffic signs, marking, etc.).

Such actions may solve various types of problems that need to be identified during a safety diagnosis:

- **Differences between the site features and established standards or practices**

  The analysts should verify whether a site's features are in compliance with existing standards and practices that have been adopted to satisfy mobility and safety needs. When deviations are found, they must determine whether these can cause safety problems and assess the associated risk. Immediate actions will be necessary when the accident risk (or its severity) is high. Those differences may be related to:

  - geometric standards: restricted sight distance, insufficient curve radius, etc.;
  - road sign standards (and other visual or audible aids such as marking, delineation, etc.);
  - traffic conditions: severe traffic conflicts, excessive delays, insufficient passing opportunities, etc.;
  - maintenance.

  One must go beyond the verification of individual standards in order to determine whether some combinations of elements that individually follow those standards, may be hazardous. It could be for example, the combination of a minimum horizontal curve radius with a maximum grade percentage.

- **Improper consideration of drivers' capabilities and limitations (human factors)**

  One should also verify whether the existing road features appropriately take into account drivers' capabilities and limitations. The focus here is the human-road interface of the ***road safety*** system and the main elements that need to be considered are the complexity of the ***driving task*** and the ***drivers' expectancies***.

- **Incoherence of the road environment**

  The analyst should verify if the actual combination of features at the site (road function, geometric characteristics, traffic characteristics and adjacent land use) is sufficiently homogeneous to ensure safe traffic operations ***(road coherence)***.

When looking at the site from these three different points of view (deviations from established standards, human factors and incoherence of the road environment), similar conclusions will often be reached. This is surely a desirable situation as one would hope that the application of existing standards will lead to the implementation of road environments that meet drivers' expectations and properly account for their capabilities and limitations. However, one will often find situations where this basic safety requirement is not satisfied. This is partly because road standards cannot take into account all the possible combinations of features that increase the accident risk and also because knowledge evolves necessarily at a faster pace than standards. It is therefore recommended that a site be analyzed from these three different points of view.

The following pages describe in more detail the important concepts of ***driving task***, ***driver's expectancies*** and ***road coherence***.

ROAD CATEGORIZATION

Road design manuals define the different road categories that road planners and designers can select when developing new roads and they also describe their respective features: main traffic function, design speed, geometric features, traffic volumes, etc. Compliance with these features should lead to the implementation of road environments that are conducive to safe traffic operation. As basic as this requirement may seem, it should be recognized that it is not always the case in practice. With barely a century of experience in developing road networks to satisfy an always-growing transportation demand, errors have been made and lessons have been learned the hard way.

Recent research and development have shown that profound modifications of well-accepted road classification systems may very well be needed in order to make roads inherently safer. In many instances, road users cannot distinguish between the various road categories of a network and they cannot determine what constitutes a reasonable speed on these roads. It should therefore not be a surprise to observe risky behaviour.

Such modifications, which are central to the Dutch "sustainable safety" approach, led in that country to significant changes in both the number of road categories and their features. Research and development made in Sweden, England and France also provide useful information in this field. Countries that are at an early stage of motorization should try to benefit from this knowledge and develop road classification systems that avoid some of the past errors.

The next paragraphs describe the principles of the functional classification, which is the system most often used by road authorities to categorize the roads of a network. But no matter the classification system in use, one should verify, when conducting a safety diagnosis, whether a site's features are sufficiently coherent to maintain the accident risk at an acceptable level. If not, one should try and determine the origin of the problem: it might be that some features that are recommended in the classification system are inadequate, that the recommended road features have not been applied or that road features were originally adequate but have since degraded. If the problem is related to deficiencies of the classification system, it should obviously be reviewed in order to avoid the future construction of unsafe roads. While this exercise clearly extends beyond the diagnostic task and the analyst's mandate, it is nonetheless essential in view of "sustainable safety".

Some of the most frequent coherence problems related to a road function and its attributes are discussed.

Functional classification

A functional classification differentiates two opposing traffic functions: mobility, the aim of which is to permit relatively fast movements over distances that may be long, and access, which enables exchanges between roads or streets and adjacent lands or properties. An intermediate road function (collectors or distributors) must necessarily be provided in order to limit access points on arteries or traffic volumes on access roads. A basic functional classification therefore consists of three types of roads, as shown in Figure 6-A1.

The distinctive features of urban and rural areas also need to be recognized, whether in terms of traffic volumes and traffic conflicts, trip purposes and lengths, road user types (motorized/non-motorized), network density, land use and even accident characteristics. Rural and urban roads should therefore have distinct and coherent sets of features.

Figure 6-A1 Functional classification

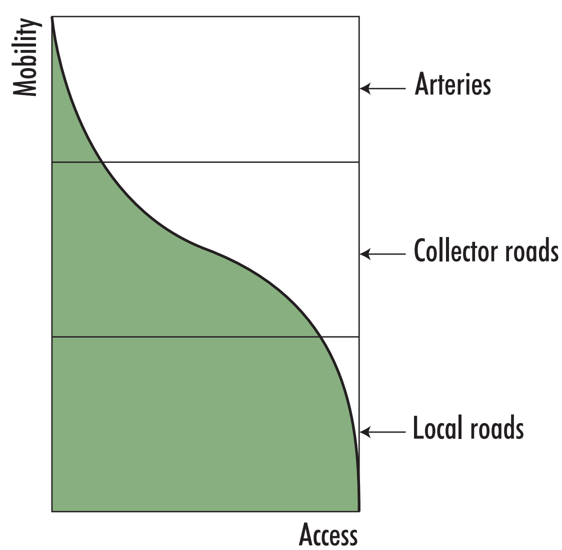


Table 6-A1 describes the general features of these basic road categories; in practice, each of them is in turn subdivided into different sub-categories, the details of which vary from one country to another. This breakdown is necessary to take into account the diversity of road environments that may adequately satisfy the same traffic function. For example, no one will be surprised if the geometric characteristics of a rural artery carrying 20,000 vpd in a flat region - most likely a freeway - are higher than those of a rural artery in a mountainous region with 3,000 vpd.

Table 6-A1 Functional classification – Road characteristics

	RURAL - ARTERY	URBAN - ARTERY
ROAD FUNCTION	Mobility Link between cities (national level)	Mobility
GEOMETRIC CHARACTERISTICS	High design standards (generous alignment, wide cross-section, possibility of a median strip, clear roadsides)	High design standards (generous alignment, possibility of multiple lane roads and median strip)
TRAFFIC CONDITIONS	High traffic flows High speeds Motorized users only	High traffic flows Relatively high speeds Motorized users only (no pedestrians or cyclists on the road; where necessary, provide distinct paths for these users) Possibility of bus bays
INTERSECTIONS AND ACCESSES	On freeways, no intersection or access (entries and exits at interchanges only) On arteries, no private access (only well-spaced intersections)	On freeways, no intersections or access (entries and exits at interchanges only) On arteries, no private access (only well-spaced intersections that may be signal-controlled) No roadside parking
	RURAL-COLLECTOR ROAD	URBAN-COLLECTOR ROAD
ROAD FUNCTION	Link between medium-sized towns (regional level)	Link between separate urban districts
GEOMETRIC CHARACTERISTICS	Intermediate design standards	Intermediate design standards
TRAFFIC CONDITIONS	Moderate speeds and traffic flows Respective proportions of through and local traffic vary according to the importance of the collector road	Moderate speeds and traffic flows Respective proportions of through and local traffic vary according to the importance of the collector road Pedestrians and other non-motorized users travel in separate paths (sidewalk or other ways) Buses may stop on the road
INTERSECTIONS AND ACCESSES	Closer spacing between intersections Private accesses are controlled but not prohibited	Closer spacing between intersections Private accesses are controlled but not prohibited Roadside parking is forbidden on main collectors but it may be allowed on smaller collectors
	RURAL-LOCAL ROAD	URBAN-RESIDENTIAL STREET
ROAD FUNCTION	Access to adjacent land	Access to adjacent properties
GEOMETRIC CHARACTERISTICS	Design standards adapted to lower speeds 2-lane, sometimes 1-lane roads	Design standards that encourage low speeds (narrow lanes, cul-de-sacs, loops, etc.)
TRAFFIC CONDITIONS	Low speeds and traffic flows Local users and delivery vehicles Non-motorized users may be present	Low speeds and traffic flows Local users and delivery vehicles Non-motorized users are generally present in high proportions and share the road with motorized users
INTERSECTIONS AND ACCESSES	The number of intersections and accesses is not controlled but their geometric characteristics must be safe	The number of intersections and accesses is not controlled but their geometric characteristics must be safe Street parking is allowed

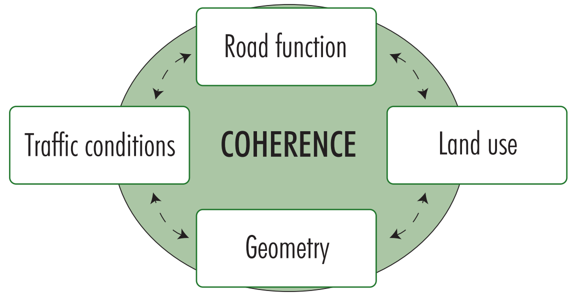
COHERENCE OF THE ROAD ENVIRONMENT

A driver adopts a speed that balances his needs for safety and mobility by processing information transmitted by the road and its surroundings. When the message he receives is ambiguous, hesitations, unsafe behavior and driving errors may occur. Conversely, when the road environment is coherent, more appropriate and homogeneous driving behaviour may be expected.

For a road environment to be coherent, all of its components must be harmoniously fitted together:

- road function
  mobility, distribution, access;
- traffic conditions
  road user types, traffic volumes, etc;
- geometry
  alignment, cross-section, etc.;
- land use
  residential, commercial, agricultural, etc.

Figure 6-A2 Coherence of the road environment



Some basic principles need to be satisfied to ensure coherence:

- avoid mixing functions on the same road (mono-functional roads);
- avoid combining features that send road users contradictory messages (some examples are shown in Figure 6-A5);
- avoid high speed differentials and high mass differentials;
- take into account the needs of all road users (particularly those of non-motorized road users).

The mono-functionality principle is discussed in more detail in the following paragraphs.

Avoid the mix of traffic functions on the same road

Low accident rates observed on freeways serving only a mobility function and in access roads that have been adequately planned and designed to exclude non-local traffic clearly demonstrate the safety benefits that may be achieved from the separation of these two opposite traffic functions. Conversely, safety problems are often encountered on roads with a mix of mobility and access functions. The following problems are frequently encountered and should be detected during a safety diagnosis:

1) **Arterial roads with a large number of roadside accesses;** this situation is often a result of inadequate access control mechanisms such as:

   - the expansion of small communities along rural arteries, which creates conflicts between fast through traffic and slower local road users who enter and exit the road. The problem is amplified when those conflicts occur between motorized vehicles and non-motorized road users (pedestrians, cyclists, etc.). Clear separations need to be maintained between urban and rural areas.

   - the development of commercial facilities along arterial roads that again create unsafe combinations of road users (fast and slow, heavy and light). To deal with these situations, the *Road safety good practice guide* (Department for Transport, 2001) recommends the following measures:

     - separate the mobility, distribution and access functions (where the available width is insufficient to separate functions, the mobility function must be downgraded);

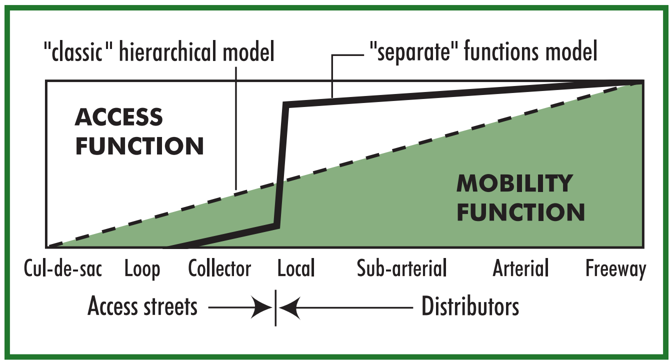
- raise the priority given to pedestrians and cyclists and give them specific space, such as bicycle lanes and wider sidewalks;
- use gateways to emphasize the transition from one type of road to another;
- reduce the difficulties of certain manoeuvres and prevent unsafe manoeuvres;
- use narrow lanes and channelization (cyclists should be taken into account).

2) Access roads with significant volumes of non-local road users; this is often a result of errors made at either the planning or design stage (e.g. street network allowing short-cuts through residential areas). A large array of "traffic-calming" measures are now available to reduce traffic volumes or speeds when necessary (road closures, horizontal or vertical deviations, etc.).

Example – Traffic-calming measures

3) Collectors, with an unsafe mix of mobility and access functions. According to Brindle (1989), a direct consequence of a classic system of functional classification is to create a large number of mixed function roads, which are a major challenge in terms of road safety. Based on British experiences, he instead recommends a clear-cut separation between access roads and mobility roads (Figure 6-A3). While collectors are necessary to ensure the integrity of both mobility and access roads, it is without doubt the road category that is more difficult to define and for which it is harder to maintain safe traffic conditions.

Figure 6-A3 Road classification models



Source: Brindle, 1989

For urban environments, Gunnarsson (1999) proposes an interesting classification approach. He defines five distinct "spaces".

F : free foot space

F/C : integrated foot space

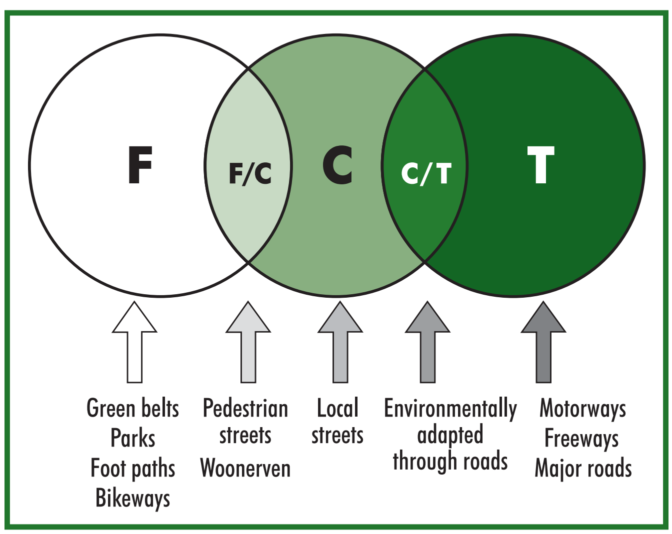
C : traffic-calming space

C/T : integrated calming and motor transport space

T : motor transport space

To each of these spaces corresponds a set of road categories that are conducive to safe traffic operations (Figure 6-A4).

Figure 6-A4 Traffic spaces and relevant roads



Source: Gunnarsson, 1999

Figure 6-A5 Examples - Coherence problems

Excessive road width, leading to excessive speeds

Inadequate road and roadside features for the mobility function and traffic volumes

Hazardous mix of motorized and non-motorized road users (urban area)

Hazardous mix of motorized and non-motorized road users (rural area)

Hazardous drainage structure on a main rural highway (errant vehicle are directed on a vertical concrete structure)

Incoherence between posted speed and development level

DRIVING TASK - WORKLOAD

The driving task is often represented as being comprised of three subtasks: control, guidance and navigation *(Chapter 3)*. To accomplish these tasks, a driver must:

- process various road related information: horizontal and vertical alignment, lane and shoulder width, channelization, traffic signs, etc.;
- take into consideration prevailing traffic rules (mandatory stop, turning prohibition, etc.) and interact with other road users, who may slow down or stop, merge, pass a slower vehicle, etc.;
- take into account his vehicle characteristics: dimensions, acceleration and deceleration performance, stability, etc.

Part of his attention may also be diverted by the presence of stimuli that are not relevant to the driving task, such as eye-catching advertisements, panoramic view or roadside activity. The number of possible distractions is quite large, particularly in urban areas.

The quantity of information that is contained in the road environment clearly exceeds the human processing capabilities at usual driving speeds[2].

And yet drivers succeed most of the time not only in driving without making serious errors but also in keeping some of their attention for other activities: changing radio station, talking, drinking, planning weekend activities, etc.

This can in large part be attributed to the repetitive use of sound practices in both road design and traffic operations, which lead to the development of automatisms that greatly facilitate the driving task:

- the same information (and sequence of information) is always used when the same road conditions are encountered (e.g. always the same set of messages at the approach to the same type of intersection);
- the complexity of each message is controlled (e.g. avoiding long texts on direction signs by using pictorial messages);
- important messages are repeated, increasing the probability of their detection;
- the amount of critical information at a same location is limited (e.g. spreading the information out over space);
- the information that is critical to the driving task is made more obvious than the rest of the information contained in the road environment (e.g. a stop sign needs to be more conspicuous than a nearby advertising sign, especially when the stopping requirement is not necessarily obvious to drivers);
- the number of elements that increase the complexity of the driving task is reduced as speed increases (e.g. intersections and turning manoeuvres are not allowed on freeways).

When these principles are not satisfied, drivers may quickly become unable to cope with the situation. At first, they will stop all activities that are not essential to the driving task and when this is not sufficient, driving errors may occur. A common characteristic of many high accident locations is that they place large or unusual demands on driver’s information-processing capabilities.

[2] In this respect, the human brain can be seen as a single-channel processor that can treat only a fixed number of bits of information at a time. When the amount or complexity of the information that has to be treated exceeds the capacity of the processor and when the treatment period cannot be extended without excessive risk (by reducing speed), some information cannot be processed.

According to Lunenfeld and Alexander (1990), factors to be considered when calculating the information load are:

- land use
- access control
- traffic volumes
- speed
- task/manoeuvre
- hazard (quantity and visibility)
- hazard visibility
- sight distance
- expectancy violations
- clutter
- competition
- complexity

A model has recently been developed to estimate the information load imposed on drivers approaching a group of road signs on a freeway. According to this model, a driver's attention is divided into two main sources: the information search demand and the driving task demand (Figure 6-A6).

Reaction times

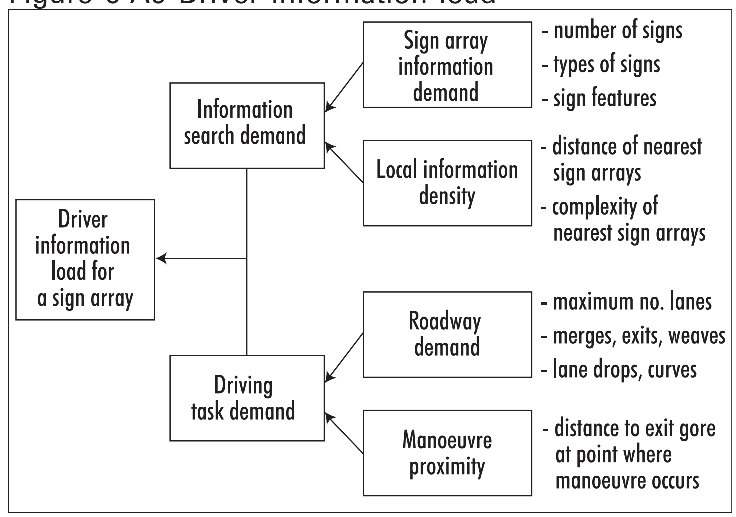
Figure 6-A6 shows how the reaction time increases with the quantity of information that needs to be processed. It can be seen that reaction times widely used in traffic engineering practices (1 second in urban areas, 2.0 - 2.5 seconds in rural areas) correspond to very simple situations.

Drowsiness or inattention

A driver's attention lessens if there is too little stimulation. He then allocates a greater share of his processing capabilities to other thoughts and actions and by doing so, becomes less conscious of the road environment. In such a case, the driver might not be in a position to cope with a road situation requiring a sudden increase in his attention and errors may occur. Drowsiness may also be a problem, especially at night and in rural environments.

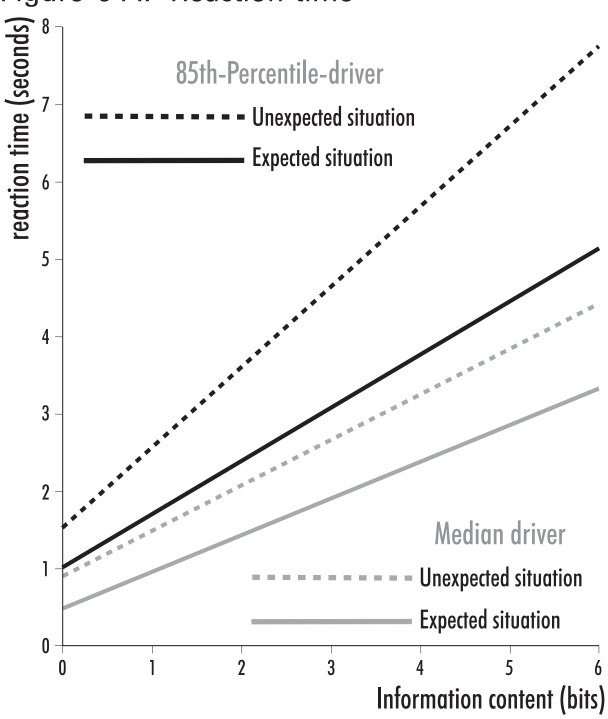
Excessive informational content at a decision point

Figure 6-A6 Driver information load



Source: National Cooperative Highway Research Program, 2003

Figure 6-A7 Reaction time



Source: A Policy on Geometric Design of Highways and Streets, Copyright 2001, by the American Association of State Highway and Transportation Officials, Washington, D.C. Used by permission.
1 bit = one decision (e.g. turning left/right, fast/slow, etc.)

DRIVERS' EXPECTANCIES

Expectancy is described as "*a driver's readiness to respond to situations, events, and information in predictable and successful ways*" (Lunenfield and Alexander, 1990). Expectations are strongly influenced by experience. When they face unexpected situations, drivers are more likely to make errors and the probability of accidents increases. According to the same authors:

- *the more predictable the roadway features, the less likely will be the chance of errors;*
- *expectations are associated with all aspects of the driving task; configurations, geometrics, traffic operations and traffic management rules that are counter to and/ or violate expectancies lead to longer reaction time, confusion, inappropriate response, and driver error;*
- *drivers tend to anticipate upcoming situations and events that are common to the road they are travelling;*
- *drivers, in the absence of counter evidence, assume that they will only have to react to standard situations;*
- *drivers experience problems in transition areas and locations with inconsistent design or operation;*

Different expectation levels can be recognized (Lunenfeld and Alexander, 1990; Ogden, 1996):

1. **Long-term expectations:**

   Acquired throughout a driver's life and common to a large proportion of the population. For instance, stop signs always have the same shape, colour, size and are always located at the same place at an intersection, freeway exits are always on the same side of the road, red always follows yellow at traffic lights, etc.

2. **Short-term expectations:**

   Acquired during a trip. For instance, a driver who has been travelling for several kilometers along a major rural road with the right-of-way can be surprised by the presence of a mandatory stop if nothing else has changed in the road environment.

   Therefore, major discontinuities should be avoided along a route; they may be related changes in:

   - geometric characteristics:

     alignment (first sharp curve or steep hill), divided/undivided road, lane or shoulder width, lane drop, surface characteristics, roadside conditions, lighting conditions, etc.;
   - signing and marking practices;
   - traffic characteristics (volumes, types of road users, manoeuvres);
   - land use;
   - roadwork areas.

   When such changes cannot be avoided, drivers should be adequately warned of the upcoming situations by appropriate treatment at the transition zone.

3. **Event-related expectations:**

   Drivers expect that what has never happened will not happen. For instance, a driver who regularly goes through a railroad crossing without seeing a train expects there will never be a train at that location.

Figure 6-A8 Examples – Violations of drivers' expectancies

Unexpected traffic signals on high-speed artery (brake marks indicate that some road users do not expect to have to stop).

Unexpected T intersection at hill bottom on a rural road (brake marks).

Unexpected road layout: the main road seems to go straight ahead but veers to right (possible traffic conflict).

Unusual crossing layout and mandatory STOP require excessive road signing.

Stop sign hidden by a parked vehicle. Drivers unfamiliar with the area may not realize that they have to stop.

Unsafe combination of vertical and horizontal alignments. Drivers do not see the horizontal curve beyond the vertical crest.

APPENDIX 6-2

Accident tables

CONTRIBUTING FACTORS

INTERSECTION - REAR-END

FACTORS	OTHER ACCIDENT TYPES	OBSERVATIONS/MEASURES/CALCULATIONS
Capacity	Head-on with turning vehicle	Are turning volumes heavy? Are through lanes blocked by turning vehicles? Is the intersection capacity adequate? - calculate capacity, levels of service; - check available gaps, ***delays***, vehicle queues; - are accidents occurring at rush hours? At traffic signals Is the signal timing adequate (length of each phase, necessity of an exclusive turning phase)? Is there an unusual signal sequence that may confuse drivers?
Protection Turning manoeuvres	Head-on with turning vehicle	Are vehicles completing non-priority turning manoeuvres separated from through vehicles?
Surface condition	Wet-surface accidents Single-vehicle accidents	Is skid resistance adequate? - surface polishing, bleeding, contamination. Check for hazardous manoeuvres that may be related to surface deficiencies (potholes, waves, other deformations, water accumulation).
Drivers' behaviour	Right-angle collisions, Head-on with turning vehicles	Check for excessive speed, tailgating, short gap acceptance, aggressive driving behaviour.
Sight distance	Right angle collisions Single vehicle accidents	Are available sight distances sufficient to allow safe braking and manoeuvering at intersection? - observe/measure available sight distances and compare with required sight distances (for all permitted and non-priority manoeuvres); - check sight distances at possible ends of vehicle queues.
Unexpected intersection	Right-angle collisions Single-vehicle accidents	Is the intersection conspicuous? Is the presence of the intersection coherent in the road environment? - check for excessive speeds, late braking, brake marks.
Road access	Access-related accidents	Are accidents related to manoeuvres at access points near the intersection? Is the presence of the access expected (visibility, road category)? Is access geometry adequate (width, channelization, additional lane)?
Road lighting	Nightime accidents	Are accidents occurring at night? Check for the presence and condition of the road lighting system (at night)
Presence of pedestrians or cyclists	Collisions with pedestrians or cyclists	Are crossing pedestrians/cyclists clearly visible? - check for pedestrian/cyclist sight obstructions (parked or stopped vehicles, stands, etc.); - check for pedestrian/cyclist compliance with traffic rules; - check for related traffic conflicts.
Weather conditions	Accidents under adverse conditions (rain, fog, etc.)	Plan the site visit when adverse conditions are likely to be observed.

Possible actions

CONTRIBUTING FACTORS

INTERSECTION - HEAD-ON WITH TURNING VEHICLE

FACTORS	OTHER ACCIDENT TYPES	OBSERVATIONS/MEASURES/CALCULATIONS
Capacity	Rear-end collisions	Are turning volumes heavy? Are through lanes blocked by turning vehicles? Is the intersection capacity adequate? - calculate capacity, levels of service; - check available gaps, delays, vehicle queues; - are accidents occurring at rush hours? At traffic signals Is the signal timing adequate (length of each phase, necessity of an exclusive turning phase)? Is there an unusual signal sequence that may confuse drivers?
Protection Turning manoeuvres	Rear-end collisions	Are vehicles completing non-priority turning manoeuvres separated from through vehicles? Are turning drivers hurrying their manoeuvres to avoid approaching vehicles from behind?
Drivers' behaviour	Rear-end collisions Right-angle collisions	Check for short gap acceptance, red light running or excessive speed Speed May turning drivers have difficulties in estimating the speed of opposing vehicles?
Sight distance	Right-angle collisions Single-vehicle accidents	Are available sight distances sufficient to allow safe turning manoeuvres? - observe/measure available sight distances and compare with required turning sight distances. At traffic signals - check visibility of signal heads.
Road access	Access-related collisions	Are accidents related to manoeuvres at access points near the intersection? Is the presence of the access expected (based on road category)? Is access geometry adequate (width, channelization, additional lane)?

Possible actions

CONTRIBUTING FACTORS

INTERSECTION - RIGHT-ANGLE

FACTORS	OTHER ACCIDENT TYPES	OBSERVATIONS/MEASURES/CALCULATIONS
Capacity	Rear-end collisions	Is the intersection capacity adequate? - calculate capacity, levels of service; - check available gaps, delays, vehicles queues; - are accidents occurring at rush hours? At traffic signals Are phase length adequate (including yellow and all red)? Is there an unusual signal sequence that may confuse drivers?
Sight distance	Rear-end collisions Single-vehicle accidents	Are available sight distances sufficient to allow safe manoeuvres? - observe/measure available sight distances and compare with required sight distances. At traffic signals - check visibility of signal heads.
Drivers' behaviour	Rear-end collisions Head-on with turning vehicle	Check for short gap acceptance, red light running or excessive speed.
Road signs		Do road signs conform with standards (sequence, size, location, height)? Is the stop sign clearly visible? - check for obstruction by parked or stopped vehicles, trees, stands etc.
Marking		Is the stop line clearly visible? Are vehicles stopped position safe?
Road width		Are manoeuvering difficulties increased by excessive lane or roadway width?
Turning radii		Excessive radii Check for the presence of wide turning radii that encourage incomplete stopping manoeuvres and excessive turning speeds. Insufficient radii Check for the presence of insufficient turning radii that force heavy vehicles to encroach in adjacent lanes.
Unexpected intersection	Rear-end collisions Single-vehicle accidents	Is the presence of the intersection likely to surprise drivers unfamiliar with the area? - visibility and conspicuity of intersection, coherence of the intersection in the road environment, first mandatory stop after several kilometers, end of high-speed facility; - check for excessive speeds, late braking, brake marks.
Weather conditions	Accidents under adverse conditions (rain, fog, etc.)	Plan the site visit when adverse conditions are likely to be observed.

Possible actions

CONTRIBUTING FACTORS

INTERSECTION - PEDESTRIAN/CYCLIST

FACTORS	OTHER ACCIDENT TYPES	OBSERVATIONS/MEASURES/CALCULATIONS
Insufficient protection		Do existing facilities provide adequate protection for pedestrians? - crossing characteristics (location, width, median refuge material, road signs, markings); - check pedestrian crossing times, delays, available crossing gaps. Traffic signals - Is a traffic signal with an exclusive pedestrian phase required? - Are pedestrian phases of adequate lengths? Have safety needs of all pedestrian categories been properly considered? - baby carriages, children, elderly people, disabled persons, wheelchairs (e.g. low curbs, gentle slopes, handrails, etc.).
Sight distance		Are pedestrians and cyclists clearly visible when crossing? - sight obstructions may be permanent (e.g. vertical curve, building), temporary (e.g. parked vehicle) or seasonal (e.g. vegetation, snow). Traffic signals Are pedestrian signal heads clearly visible to pedestrians (e.g. hidden by a stopped bus)?
Behaviour		Speed Are vehicle speeds compatible with pedestrian safety (based on crossing times, available sight distances)? Drivers of motorized vehicles Are drivers yielding to pedestrians and cyclists? Are drivers complying with traffic regulations (mandatory stops, red lights)? Pedestrians/cyclists Are pedestrians/cyclists crossing at designated locations? Are pedestrians/cyclists crossing at designated times (traffic signals)?
Road lighting	Nighttime accidents	Are pedestrian or cyclist accidents occurring at night? Check the presence and condition of the road lighting system (at night) Are pedestrian and cyclist facilities adequate for night usage (if required)?

Possible actions

CONTRIBUTING FACTORS

SECTION - SINGLE-VEHICLE

FACTORS	OTHER ACCIDENT TYPES	OBSERVATIONS/MEASURES/CALCULATIONS
Horizontal alignment	Head-on collisions Wet-surface accidents	Is the horizontal curve clearly visible? Are significant speed reductions required when approaching the curve? ***[speed differentials]*** Are warning signs and devices adapted to road conditions (e.g. first sharp curve)? Check for late braking, brake marks, encroachments.
Vertical alignment	Accidents involving trucks Rear-end collision	Are grade characteristics obvious (e.g, compound grade)? Check for potential sources of traffic conflicts, particularly at hill bottom. Are warning signs and devices adapted to grade conditions? Is brake overheating possibility low? ***[grade analysis]*** Is safety equipment adapted to hill features and traffic conditions (check brake area, arrester bed)? Do features of truck lanes allow safe traffic operation? (alignment, lane length, taper features) Are truck downhill speeds safe?
Cross-section	Head-on collisions Sideswipe collisions	Is the general aspect of the road cross-section adequate for the road category and traffic conditions (e.g. too narrow lanes for heavy vehicles)? Are channelization features safe (curb height, alignment, end treatment). Is transition adequate at cross section change (divided/undivided, lane drop)? Are rumble strips provided if required? Check for encroachments, lane/shoulder drop-off.
Surface condition	Wet-surface accidents Rear-end collisions	Is skid resistance adequate? - surface polishing, bleeding, contamination; Check for hazardous manoeuvres that may be related to avoidance manoeuvres of surface deficiencies (potholes, waves, other deformations, water accumulation).
Roadside conditions		Are roadsides free of features that may increase the severity of losses of control (e.g. steep side slopes, rigid obstacles, inadequate end treatment of structures).
Sight distance		Are available sight distances sufficient to allow safe stopping manoeuvres? - observe/measure available sight distances and compare with required stopping sight distances; ***[braking distance (curve)]*** - check for visual obstructions on interior side of curves. Check for sources of traffic conflicts or road hazards where sight is restricted (intersection, crossing, access, narrow structure, etc.).
Road access	Access-related collisions	Are accidents related to manoeuvres at accesses? Is the presence of access expected (visibility, road category)? Is access geometry adequate (width, channelization, merging/diverging lane)?
Speed	Head-on collisions	Are operating speeds compatible with safe traffic operation (based on road characteristics).
Road lighting	Nighttime accidents	Check the frequency of night accidents. Check the presence and condition of the road lighting system (at night).
Animals	Accidents with animals	Check the frequency of accidents with an animal.
Weather conditions	Accidents under adverse weather conditions (rain, fog, etc.)	Plan the site visit when adverse conditions are likely to be observed.
Combination of features		Is there a combination of features that may increase the accident risk or its severity (horizontal curve, hill, intersection, access, narrow bridge, etc.).

Possible actions

CONTRIBUTING FACTORS

SECTION - REAR-END

FACTORS	OTHER ACCIDENT TYPES	OBSERVATIONS/MEASURES/CALCULATIONS
Capacity		Is the capacity adequate? - calculate capacity, levels of service; - travel times, platoons; - are accidents occurring at peak hours? Turning movements Are through lanes blocked by turning vehicles?
Unexpected congestion	Multi-vehicle accidents	Plan the site visit when congestion is likely to be observed.
Road access	Access-related accidents	Are accidents related to manoeuvres at accesses? Is the presence of access expected (visibility, road category)? Is access geometry adequate (width, channelization, merging/diverging lane)?
Sight distance		Are available sight distances sufficient to allow safe stopping manoeuvres? - observe/measure available sight distances and compare with required stopping sight distances. ***[braking distance (curve)]*** Check for sources of traffic conflicts or road hazards where sight is restricted (intersection, crossing, access, narrow structure, etc.).
Drivers' behaviour	Single-vehicle accidents	Check for excessive speeds, tailgating, hazardous passing manoeuvres.
Surface condition	Wet-surface accident Rear-end collisions	Is skid resistance adequate? - surface polishing, bleeding, contamination.
Weather Conditions	Accidents under adverse conditions (rain, fog, etc.)	Plan the site visit when adverse conditions are likely to be observed.

Possible actions

CONTRIBUTING FACTORS

SECTION - HEAD-ON

FACTORS	OTHER ACCIDENT TYPES	OBSERVATIONS/MEASURES/CALCULATIONS
Capacity	Single-vehicle accidents	Is the capacity adequate? - calculate capacity, levels of service; - travel times, platoons; - are accidents occurring at rush hours? Passing opportunities Check whether passing opportunities are sufficient based on road category and traffic conditions (opposing direction gaps, passing lane).
Marking	Sideswipe collisions	Is the center line clearly marked? Does marking clearly prohibit passing if hazardous? Is the marking clearly visible under all conditions (night, rain, sunset or sunrise, winter).
Cross-section	Head-on collisions Sideswipe collisions	Is the general aspect of the cross-section adequate for the road category and the traffic conditions (e.g. too-narrow lanes for heavy vehicles)? Are channelization features safe (curb height, alignment, end treatment)? Are rumble strips provided if required? Is transition adequate at cross-section changes (divided/undivided, lane drop)? - check for encroachments, lane/shoulder drop-off. Climbing lane - Are features of auxiliary lanes allowing safe traffic operation (length, taper)?
Surface condition	Sideswipe collisions	Check for hazardous manoeuvres that may be related to surface deficiencies (potholes, waves, water accumulation, etc.).
Drivers' behaviour		Check for hazardous passing manoeuvres.
Weather conditions	Accidents under adverse conditions (rain, fog, etc.)	Plan the site visit when adverse conditions are likely to be observed.

Possible actions

CONTRIBUTING FACTORS

SECTION - PEDESTRIAN/CYCLIST

FACTORS	OTHER ACCIDENT TYPES	OBSERVATIONS/MEASURES/CALCULATIONS
Insufficient protection		Are existing facilities providing adequate protection for pedestrians and cyclists? - on high-speed roads, pedestrians/cyclists should be clearly separated from motorized traffic. Have safety needs of all pedestrian categories been properly considered (baby carriages, children, elderly people, disabled persons, wheelchairs)?
Coherence		Is the continuity of pedestrian/cyclist facilities provided along their routes? Are pedestrian/cyclist crossings located at the right place (based on their itineraries)? (see also ***Intersection - Pedestrian/cyclist***)
Illegal use of pedestrian facilities		Have adequate measures been taken to avoid illegal use of pedestrian or cyclist facilities (parked vehicles, stands, other obstacles)?
Behaviour		Are pedestrians using their facilities?
Visibility		Are pedestrians/cyclists clearly visible?
Road lighting	Nighttime accidents	Check the frequency of night accidents. Check the presence and condition of the road lighting system (at night). Are pedestrian and cyclist facilities adequate for night usage (if required)?

Possible actions

CONTRIBUTING FACTORS

GENERAL - NIGHT*

FACTORS	OTHER ACCIDENT TYPES	OBSERVATIONS/MEASURES/CALCULATIONS
Road lighting		Check for the presence and condition of the road lighting system.
Road sign Marking		Are signs and marking retro-reflectivity adequate at night?
Behaviour		Check for excessive speeds, compliance with traffic rules.

* The site visit should be conducted at night.

Possible actions

CONTRIBUTING FACTORS

GENERAL - WET SURFACE

FACTORS	OTHER ACCIDENT TYPES	OBSERVATIONS/MEASURES/CALCULATIONS
Surface condition	Rear-end collisions	Is skid resistance adequate? - surface polishing, bleeding, contamination.
Excessive speed	Rear-end collisions Single-vehicle accidents	Are operating speeds compatible with safe traffic operation (based on road characteristics and traffic conditions)?

Possible actions

POSSIBLE ACTIONS

INTERSECTION - REAR-END

FACTORS	POSSIBLE ACTIONS	REFERENCES[a]
Capacity	Add turning lane and channelization. Prohibit turning manoeuvres. Change signal timing (exclusive turning lane).	*Intersections*
Protection Turning manoeuvres	Add turning lane, channelization. Pave shoulders. Prohibit turning manoeuvres.	
Surface condition	Proceed to superficial surface treatments (grooving, sand blasting, etc). Resurface. Improve drainage conditions. Correct structural deficiencies. Add warning sign (temporary measure).	*Road surface condition* *Friction*
Drivers' behaviour	Increase visibility of stop signs/signal heads/intersection. Install advance-warning signs. Implement traffic-calming measures. Increase drivers' education and police enforcement. Install surveillance cameras.	*Spot speed*
Sight distance	Install warning signs/devices. Remove sight obstructions. Separate turning vehicles in exclusive lanes. Prohibit turning manoeuvres.	*Sight distance* *Sight distance*
Unexpected intersection	Increase intersection conspicuity through: - road signs, channelization, road lighting, landscaping; - elimination of competing information (street parking, stands, advertising, etc.). Re-design intersection (e.g. roundabout). Close/relocate intersection.	*Intersections* *Human factors*
Road access	Improve access geometry. Prohibit some access-related manoeuvres (median barrier, traffic island). Close/relocate access.	
Road lighting	Install or improve road lighting.	
Presence of pedestrians or cyclists	Improve pedestrian/cyclist visibility (crossing, parking prohibition, etc.). Separate pedestrians/cyclists and motorized traffic (traffic signal, exclusive phase, grade-separated crossing).	*Traffic count* *Traffic conflicts*
Weather conditions	Improve maintenance. Install warning signs (e.g. wind gusts, fog).	

[a] In blue: technical sheet, in green: technical study

Contributing factors

POSSIBLE ACTIONS

INTERSECTION - HEAD-ON WITH TURNING VEHICLE

FACTORS	POSSIBLE ACTIONS	REFERENCES[a]
Capacity	Add turning lane and channelization. Install all-way stops. Install traffic signals, add an exclusive turning phase. Prohibit turning manoeuvres. Change intersection into roundabout.	***Intersections***
Protection Turning manoeuvres	Add turning lane and channelization. Pave shoulders. Prohibit turning manoeuvres.	***Intersections***
Drivers' behaviour	Install traffic signal with exclusive turning phases, increase the duration of change intervals (yellow, all red). Implement traffic-calming measures. Increase drivers' education. Increase police enforcement. Install surveillance cameras.	***Spot speed***
Sight distance	Remove sight obstructions. Prohibit turning manoeuvres. Modify right-of-way rules (all-way stops, exclusive turning phases).	***Sight distance*** ***Sight distance***
Road access	Improve access visibility. Improve access geometry (width, channelization, merging/diverging lane). Prohibit some access-related manoeuvres (median barrier, traffic islands). Close/relocate access.	

[a] In blue: technical sheet, in green: engineering study

Contributing factors

POSSIBLE ACTIONS

INTERSECTION - RIGHT-ANGLE

FACTORS	POSSIBLE ACTIONS	REFERENCES[a]
Capacity	Install all-way stops. Install traffic signals, change timing. Add channelization (median refuge). Prohibit some manoeuvres. Change intersection into roundabout.	***Intersections***
Sight distance	Install warning signs/devices. Remove sight obstructions (trees, parking spaces near the intersection, etc.). Prohibit turning manoeuvres. Modify right-of-way rules (all-way-stops, signal phasing). Improve signal lenses visibility (location, angle, visors, etc.).	***Sight distance*** ***Sight distance***
Drivers' behaviour	Install advance-warning signs. Install traffic signals. Increase visibility of stop signs/signal lenses. Implement traffic-calming measures. Increase drivers' education. Increase police enforcement. Install surveillance cameras.	***Spot speed***
Road signs	Improve road signs.	
Marking	Improve marking (e.g. stop lines).	
Excessive road width	Reduce lane/road width (median refuge, other islands, marking). Install traffic signals, change timing.	
Turning radii	Modify turning radii (channelize, improve marking). Modify lane widths.	
Unexpected intersection	Increase intersection conspicuity: - road signs, channelization, road lighting, landscaping; - elimination of competing information (street parking, stand, advertising, etc.). Re-design intersection (e.g. roundabout). Close/relocate intersection.	

[a] In blue: technical sheet, in green: engineering study

Contributing factors

POSSIBLE ACTIONS

INTERSECTION - PEDESTRIAN/CYCLIST

FACTORS	POSSIBLE ACTIONS	REFERENCES[a]
Insufficient protection	Add or improve crossing facilities, their location or their signing. Install traffic signals with an exclusive pedestrian phase. Provide grade-separated crossing. Provide adequate protection for particular pedestrian needs. (e.g. audible traffic signal for blind people).	
Sight distance	Install warning signs/devices. Remove sight obstructions (e.g. relocate street parking). Relocate crossing. Change right-of-way rules. Improve signal lens visibility.	***Sight distance*** ***Sight distance***
Speed and other behaviour	Improve road signs. Increase separation between pedestrians/cyclists and motorized road users (exclusive phase, median refuge, grade-separated crossings barriers to guide pedestrians to designated crossings). Implement traffic-calming measures. Increase drivers' education. Increase police enforcement. Install speed cameras.	***Spot speed***
Road lighting	Install or improve road lighting.	

[a] In blue: technical sheet, in green: engineering study

Contributing factors

POSSIBLE ACTIONS

SECTION - SINGLE-VEHICLE

FACTORS	POSSIBLE ACTIONS	REFERENCES[a]
Horizontal alignment	Improve warning signs/devices (marking, delineation). Improve geometry (superelevation, shoulders, skid resistance, roadside conditions, curve radius).	***Horizontal alignment***
Vertical alignment	Improve warning signs/devices. Provide safety equipment (check brake area, arrester bed). Improve geometry (cross-section, roadside conditions, grade).	***Vertical alignment***
Cross section	Widen lane or shoulder width. Improve shoulder condition. Install channelization. Provide rumble strips.	
Surface condition	Proceed to superficial surface treatment (grooving, sand blasting, etc). Resurface. Improve drainage conditions. Correct structural deficiencies. Add warning sign (temporary measure).	***Road surface condition*** ***Friction test***
Roadside conditions	Improve roadside conditions (removal, displacement, protection or fragilization of fixed objects; side-slopes smoothing).	
Sight distance	Install warning signs/devices. Improve sight distance. Eliminate traffic conflict possibilities where sight is restricted.	***Sight distance*** ***Sight distance***
Road access	Improve access geometry. Prohibit some access-related manoeuvres (median barrier, traffic island). Close/relocate access.	
Speed	Improve visibility of speed limit signs. Implement traffic-calming measures. Increase drivers' education. Increase police enforcement. Install surveillance cameras.	***Spot speed***
Road lighting	Install or improve the road lighting system.	
Animals	Install warning signs. Install fences, grade-separated crossings.	
Weather conditions	Improve maintenance. Install warning signs (e.g. fog).	

[a] In blue: technical sheet, in green: engineering study

POSSIBLE ACTIONS

SECTION - REAR-END

FACTORS	POSSIBLE ACTIONS	REFERENCES[a]
Capacity	Add lane, channelization. Prohibit turning manoeuvres (median barrier). Promote alternative route or transportation solution (e.g. transit).	*Travel time*
Unexpected congestion	Install active warning signs/devices. Reduce congestion (through geometric improvements or traffic management). Increase police surveillance.	
Road access	Improve access geometry (merging/diverging lane). Prohibit some access-related manoeuvres (median barrier, traffic islands). Close/relocate accesses.	
Sight distance	Install warning signs/devices. Improve sight distance. Prohibit turning manoeuvres where sight is restricted.	*Sight distance* *Sight distance*
Drivers' behaviour	Increase visibility of speed-limit signs. Implement traffic-calming measures. Increase drivers' education. Increase police enforcement. Install surveillance cameras.	*Spot speed*
Surface condition	Proceed to superficial surface treatment (grooving, sand blasting, etc). Resurface. Improve drainage conditions. Correct structural deficiencies. Add warning sign (temporary measure).	*Road surface condition* *Friction*
Weather conditions	Improve maintenance. Install warning signs (e.g. fog).	

[a] In blue: technical sheet, in green: engineering study

Contributing factors

POSSIBLE ACTIONS

SECTION - HEAD-ON

FACTORS	POSSIBLE ACTIONS	REFERENCES[a]
Capacity	Add a traffic lane (or passing lane). Prohibit passing manoeuvres (marking, median barrier). Improve road signs (distance to the next passing lane). Promote alternative routes or transportation solution (e.g. transit).	***Horizontal alignment*** ***Vertical alignment***
Marking	Improve marking.	
Cross-section	Widen lanes or shoulders. Improve shoulder condition. Add channelization. Provide rumble strips.	
Surface condition	Proceed to superficial surface treatment (grooving, sandblasting, etc.) Resurface. Improve drainage conditions. Correct surface deficiencies. Add warning sign (temporary measure).	***Road surface condition*** ***Friction***
Drivers' behaviour	Improve road signs. Increase drivers' education. Increase police enforcement. Install surveillance cameras.	***Spot speed***
Weather conditions	Improve maintenance. Install warning signs (e.g. fog).	

[a] In blue: technical sheet, in green: engineering study

Contributing factors

POSSIBLE ACTIONS

SECTION - PEDESTRIAN/CYCLIST

FACTORS	POSSIBLE ACTIONS
Insufficient protection	Provide footways, bicycle paths. Increase lateral offset of pedestrian/cyclist facilities. Install physical barriers between motorized and non motorized traffic. Implement traffic-calming measures. At crossings: see ***Intersections - pedestrians/cyclists***.
Coherence	Ensure continuity of pedestrian/cyclist facilities along their itineraries. Relocate crossings based on pedestrian (cyclist routes).
Illegal use of pedestrian facilities	Add parking prohibition signs. Provide barriers between pedestrians/cyclists and motorized vehicles. Modify traffic regulations. Increase police enforcement.
Behaviour	Increase driver/pedestrian/cyclist education. Increase police enforcement.
Pedestrian cyclist visibility	Remove sight obstructions (e.g. parking along the road). Install warning signs/devices.
Road lighting	Install or improve road lighting.

Contributing factors

POSSIBLE ACTIONS

GENERAL - NIGHT

FACTORS	POSSIBLE ACTIONS
Road lighting	Install or improve road lighting.
Road signs Marking	Improve road signs/markings.
Behaviour	Increase drivers' education. Increase police enforcement.

Contributing factors

POSSIBLE ACTIONS

WET SURFACE

FACTORS	POSSIBLE ACTIONS	REFERENCES[a]
Surface condition	Proceed to superficial surface treatments (grooving, sand blasting, etc). Resurface. Improve drainage conditions. Correct structural deficiencies. Add warning sign (temporary measure).	***Road surface condition*** ***Friction***
Excessive speed	Improve visibility of speed limit signs. Implement traffic-calming measures. Increase drivers' education and police enforcement. Install red-light camera.	***Spot speed***

[a] In blue: technical sheet, in green: engineering study

Contributing factors

APPENDIX 6-3

Checklists

Safety diagnosis CHECKLISTS

Municipality: ______________________________

Location: ______________________________

Date: ______________________________

Analyst: ______________________________

Analysis objectives: ______________________________

____

____

____

____

Step 1 - SITE HISTORY

Check for availability of the following information:

ELEMENT	OK	COMMENTS
Data		
Accident	❑	
Traffic	❑	
Geometry	❑	
Conclusions of previous studies (safety, sight distance, spot speed, skid resistance, etc.)	❑	
Maintenance reports	❑	
Photos/videos	❑	
Employees' knowledge	❑	
Requests/complaints/discussions (road users, local residents local government officials)	❑	
Others	❑	

Conclusions:

Step 2 - SITE CATEGORIZATION

Road category: ______________________________

Step 3 - ACCIDENT ANALYSIS

TASK	OK	COMMENTS
Select accident period and retrieve data from _____________ to _____________	❏	
Select the reference population *(Appendix 5.1)*	❏	
Prepare accident summaries *(Section 6.3.2)* Collision diagram Summary tables Comparative tables	 ❏ ❏ ❏	
Calculate safety indicators *(Section 5.3.1)*	❏	
Determine abnormal accident patterns *(Section 5.3.2)*	❏	
Search for accident factors *(Appendix 6-2)* (to be completed at the site)	❏	

Conclusions:

IMPORTANT

Bring relevant accident tables to the site

Step 4 - SITE OBSERVATIONS – PREPARATION

Gather the following items:

ITEM	OK
In all studies:	
Camera (film or memory, batteries)	❏
Video recorder and sufficient recording medium	❏
Measuring tape and measuring wheel	❏
Notebook, pencils, eraser, rule	❏
Cell phone	❏
Existing drawings	❏
Conclusions from previous studies	❏
Diagnostic checklists	❏
Accident tables	❏
According to study requirements:	
Sighting rod and target rods ***(sight distance study)***	❏
Radar or laser gun ***(spot speed study)***	❏
Stop watch (***delay***, ***travel time***, ***traffic count***, traffic signal timing)	❏
Tally sheets or mechanical or electronic counter ***(traffic count)***	❏
Level (superelevation)	❏
Tape recorder	❏
For the analysts' safety:	
Safety helmet, jacket and boots	❏
Flashing lights and other signalling equipment	❏
Police assistance (where necessary)	❏

IMPORTANT

The site visit must be scheduled at a time when the detected problems are most likely to be observed.

Step 4 - SITE OBSERVATIONS – FAMILIARIZATION

TASKS	OK	COMMENTS
Travel through the site in all directions and note obvious problems: - road characteristics; - traffic operation; - road user behaviour.	 ❏ ❏ ❏	
Verify the overall coherence of the road environment based on:	❏	

Road category

	main	minor
artery	❏	❏
collector road	❏	❏
local road	❏	❏

Section ❏
Intersection ❏

Type	
T	❏
+	❏
Y	❏
X	❏
>4	❏
roundabout	❏

Number of lanes (road)

	main	minor
1 lane	❏	❏
2 lanes	❏	❏
multi-lane	❏	❏

Area

rural	❏
urban	❏

Traffic control

none	❏
yield	❏
stops (minor)	❏
multiple stops	❏
traffic signals	❏

Road type

	main	minor
undivided	❏	❏
divided	❏	❏
freeway	❏	❏

Speed limit

Main ______ km / h

Minor ______ km / h

Is the posted speed coherent with the road function, road characteristics, road use and land use?

yes	no
❏	❏

Traffic

	Volume
motorized	______
passenger	______
2-wheel	______
bus	______
heavy vehicle	______
others	______
non-motorized	
pedestrian	______
cyclist	______
others	______

Adjacent land use

residential	❏
commercial	❏
industrial	❏
agricultural	❏
forestry	❏
others	❏

____

TASKS	OK	COMMENTS
Check for obvious human factor problems: (***drivers' expectancies***, ***driving task***)		
Features that drivers may find surprising (violation of expectancies) unusual or unexpected change in alignment, cross-section, road surface, signing, marking, traffic, land use Check violations of: - short-term expectancies (acquired during the trip); - long term expectancies (acquired during a driver's life) - event related expectancies (rare events)	❏	
Overload possibilities - Too many stimuli - Information too complex	❏	
Drowsiness or inattention possibilities	❏	

Step 4 - SITE OBSERVATIONS – SITE HISTORY

TASK	OK	
Check whether problems detected in past studies have been successfully treated.	❏	

Conclusions:

STEP 4 - SITE OBSERVATIONS – PROBLEMS AT SIMILAR SITES

TASK	OK	
Check whether problems that are frequently observed at similar sites are present at this site (*based on results of previous studies at similar sites, available guides, etc.*).	❏	

Conclusions:

Step 4 - SITE OBSERVATIONS – ACCIDENT FACTORS

TASK	OK	
Complete the accident analysis that has been initiated in step 3 by verifying, for each deviant accident pattern, the potential contributive factors and possible actions (based on Tables in ***Appendix 6-2***).	❏	

Conclusions:

Step 4 - DETAILED OBSERVATIONS – ROAD SECTIONS

ROAD SECTIONS		YES	NO	COMMENTS
TRAFFIC OPERATIONS				
General	Have site observations been completed without any hazardous traffic conditions being seen? - vehicle platoons - excessive travel times (on mobility roads) - tailgating - hazardous passing manoeuvres - significant speed differentials - significant mass differentials - important speed differentials - important mass differentials (If needed, conduct a ***traffic count***, a ***travel time study*** or a capacity analysis)			
Speed	Are operating speeds adequate for road conditions? (if needed, conduct a ***spot speed study***).			
Traffic conflict	Have site observations been completed without seeing any obvious traffic conflict problem (related to road accesses, parkings, etc.)?			

Conclusions:

See also :

Pedestrians/cyclists

Step 4 - DETAILED OBSERVATIONS – ROAD SECTIONS

HORIZONTAL ALIGNMENT		YES	NO	COMMENTS
TRAFFIC OPERATIONS				
Speed	Are observed speeds in curve safe? - compare with posted speed and design speed. Is the speed reduction required in the approach to the curve compatible with safe traffic operations? - calculate ***speed differentials*** between the curve and its adjacent segments; - skidding (or skid marks).			
Braking	Are braking manoeuvres safely performed? - late braking, brake marks.			
Encroachment	Have site observations been completed without seeing hazardous encroachment?			
ROAD CHARACTERISTICS				
Curve radius	Is the curve radius adequate for the road category and traffic conditions? - compare with recommended standards; - avoid sharp curves on arteries. Is the risk of overturning low? - calculate ***overturning speed*** and ***skidding speed***.			
Lane width	Are lane widths sufficient for safe traffic operation?***[road width]***			
Shoulder	Do shoulders allow the safe recovery of errant vehicles? - lane/shoulder drop off, shoulder width, surface material, stability, erosion, obstacles (trees, etc.).			
Surface condition	Is the skid resistance adequate? - surface polishing, bleeding, contamination; - ***friction tests*** (if needed). Is the evenness adequate? - potholes, waves, rutting, etc. Is the road surface free of water (or traces thereof)? Is the road surface free of loose material (sand, rocks, leaves, etc.)?			
Superelevation	Is the superelevation adequate? - height, transition between tangent and curve; - drainage condition in transition zone.			
Roadside condition	In the required clearance zone, are roadsides free of features that may increase accident severity? - steep side slopes; - rigid obstacles (trees, poles, rocks, etc); - inadequate end treatment of road equipment (bridge, barrier, drainage structure, etc.).			

STEP 4 - DETAILED OBSERVATIONS – ROAD SECTIONS

HORIZONTAL ALIGNMENT (continued)		YES	NO	COMMENTS
ROAD CHARACTERISTICS				
Roadside condition (continued)	Are safety barriers in good condition? Is roadside equipment free of damage that may have been caused by errant vehicles? Are roadsides free of features or activities that may overly distract drivers (commercial signs, stands, etc.)?			
Sight distance	Is the road alignment obvious? - check for features that may create confusion as to the road alignment (minor road in the continuity of the road tangent, pole or tree line at angle with the road alignment, horizontal curve after a crest vertical curve, etc.). Are the available sight distances sufficient to allow safe stopping manoeuvres (throughout the curve)? ***[braking distance (curve)]*** - compare available sight distances with required stopping distances. Are roadsides on curve interior free of features that may impede visibility? - beware of seasonal or temporary sources of sight obstruction that may not be present during the site visit (parked vehicles, vegetation, etc.); - check for sources of traffic conflicts or road hazards where sight is restricted (intersection, crossing, driveway, narrow structure, etc).			
Passing	Is passing clearly prohibited if unsafe (marking, median barrier)? - compare available sight distances with required passing distances. Have site observations been completed without seeing any hazardous passing manoeuvre? Are there sufficient passing opportunities on the road, based on road category and traffic conditions?			
Warning sign/device	Do warning signs/devices comply with standards? - missing or superfluous equipment, size, location (height and lateral offset), message simplicity. Is the warning level well-suited to the situation? - advisory speed sign if required. Are the visibility and conspicuity of warning signs and devices adequate? Are warning signs/devices in good condition? - worn, broken, unclean, non-retro-reflective. Are sign supports adequately shielded or made frangible if required?			
Combination of features	Is the horizontal curve free of additional features that may increase accident severity? - combination of horizontal and vertical alignment, intersection, crossing, narrow bridge, etc.			

Step 4 - DETAILED OBSERVATIONS – ROAD SECTIONS

VERTICAL ALIGNMENT - DOWNHILL		YES	NO	COMMENTS
TRAFFIC OPERATIONS				
Speed	Are truck downhill speeds safe? Are speed differentials between cars and trucks compatible with safe traffic operations?			
Braking Platoon	If braking manoeuvres are required, are they safely completed (at intersection, access)? - late braking, brake marks, traffic conflicts. Are vehicles platoons unlikely to form? - based on grade features and traffic conditions.			
ROAD CHARACTERISTICS				
Grade percentage and length	Are grade percentages and lengths unlikely to cause safety problems? - compare with recommended standards; - calculate the truck brake temperature. ***[grade analysis]*** Are drivers likely to expect the grade features? - beware of first steep grade, compound grades.			
Warning signs/device	Do warning signs/devices comply with standards? - missing or superfluous devices, size, location, height and lateral offset, message simplicity. Is the warning level well-suited to the situation? - advance warnings if required. Are the visibility and conspicuity of signs/devices adequate? Are warning signs/devices in good condition? - worn, broken, unclean, non retro-reflective.			
Safety facility check brake area arrested bed	Are the required safety facilities available at the site? - brake check area, arrester bed, others. Are features of the safety facilities adequate? - location, alignment, geometry, material, etc. Are the safety facilities well maintained?			
Surface condition	Is the skid resistance adequate? - surface polishing, bleeding, contamination; - ***friction tests*** (if needed). Is road surface's evenness adequate? - potholes, waves, rutting, etc. Is the road surface free of loose material (sand, rocks, leaves, etc.)?			
Drainage	Are drainage facilities adapted to rainfall conditions? - water accumulation, erosion. Are drainage structures safe for all road users (including two-wheelers)? - avoid deep and opened drainage structures close to traffic lanes.			

Step 4 - DETAILED OBSERVATIONS – ROAD SECTIONS

VERTICAL ALIGNMENT - DOWNHILL (continued)		YES	NO	COMMENTS
ROAD CHARACTERISTICS				
Passing	Is passing clearly prohibited if unsafe (marking, median barrier)? - compare available sight distances with required passing distances. Have site observations been completed without seeing hazardous passing manoeuvres? Are passing opportunities sufficient on the road, based on road category and traffic conditions?			
Combination of features	Is the hill free of additional features that increase accident risk or severity, particularly if located at hill bottom (intersection, narrow bridge, etc.)?			

VERTICAL ALIGNMENT - UPHILL		YES	NO	COMMENTS
TRAFFIC OPERATIONS				
Speed differential	Are speed differentials between cars and trucks compatible with safe traffic operations? - calculate ***heavy-vehicle speed profile***.			
Platoon	Are vehicle platoons unlikely to form? - based on grade features and traffic conditions.			
ROAD CHARACTERISTICS				
Passing	Without climbing lane Is passing clearly prohibited if unsafe (marking, median barrier)? - compare available sight distances with required passing distances. Have site observations been completed without seeing hazardous passing manoeuvres? Are passing opportunities sufficient on the road, based on road category and traffic conditions? Climbing lane Is a climbing lane available if required? - based on design standards and ***truck speed profiles***. Are climbing lane features safe? - alignment, lane length, taper (length, location, sight distance).			

Step 4 - DETAILED OBSERVATIONS – ROAD SECTIONS

VERTICAL ALIGNMENT - CURVES		YES	NO	COMMENTS
TRAFFIC OPERATIONS				
Hazardous manoeuvre	Have site observations been completed without seeing any hazardous manoeuvres at crest vertical curve? - hazardous passing manoeuvres, late braking, brake marks, avoidance manoeuvres, etc.			
ROAD CHARACTERISTICS				
Sight distance	Are sight distances sufficient to allow safe stopping manoeuvres (throughout the curve)? - compare available sight distances with required stopping distances; ***[braking distance (curve)]*** - check for road hazards or sources of traffic conflicts where sight is restricted (intersection, crossing, driveway, end of climbing lane, etc.).			
Passing	Is passing clearly prohibited if unsafe (marking, median barrier)?			
	- compare available sight distances with required passing distances. - have site observations been completed without seeing hazardous passing manoeuvres? Are passing opportunities sufficient on the road, based on the road category and traffic conditions? Climbing lane Is the climbing lane ending safe? - taper length and location (sight distance).			
Drainage (sag curve)	Is drainage capacity adapted to rainfall conditions? - water accumulation, erosion. Are drainage structures safe for all road users (including two-wheelers)? Avoid deep and opened drainage structures close to traffic lanes.			

Step 4 - DETAILED OBSERVATIONS – ROAD SECTIONS

SIGHT DISTANCE		YES	NO	COMMENTS
TRAFFIC OPERATIONS				
Speed	Are operating speeds safe based on available sight distance?			
Hazardous manoeuvre	Have site observations been completed without seeing any hazardous manoeuvres that may be related to sight restrictions? - late braking, brake marks, avoidance manoeuvres, etc.			
ROAD CHARACTERISTICS				
Stopping sight distance	Are sight distances sufficient to allow safe stopping manoeuvres (throughout the site)? - compare available sight distances with required stopping distances; ***[braking distance (curve)]*** - beware of seasonal or temporary sight obstructions that may not be present during the site visit (parked vehicle, crops, etc.); - check for sources of traffic conflicts or road hazards where sight is restricted; (intersection, crossing, driveway, narrow structure, etc.).			
Passing sight distance	Is passing clearly prohibited if unsafe (marking, median barrier)? - compare available sight distances with required passing distances. Have site observations been completed without seeing hazardous passing manoeuvres? Are passing opportunities sufficient on the road, based on road category and traffic conditions?			
Intersection sight distance	Is the intersection obvious to all road users? Are available sight distances sufficient to allow safe completion of all permitted manoeuvres? - compare available sight distances with manoeuvring sight distances; - check for visual obstructions at each intersection corner (horizontal curve, grade, building, stand, bridge, landscaping, pole, etc.). Beware of seasonal or temporary sight obstructions that may not be present during the site visit (parked vehicles, stopped bus, vegetation, etc.).			
Decision sight distance	Is the site free of any unusual, unexpected or complex situation that requires longer sight distances? - first mandatory stop on a main road, unusual road layout or traffic rule, etc.			

Step 4 - DETAILED OBSERVATIONS – ROAD SECTIONS

CROSS-SECTION		YES	NO	COMMENTS
TRAFFIC OPERATIONS				
Encroachment	Have site observations been completed without seeing any hazardous encroachment?			
ROAD CHARACTERISTICS				
General	Is the general aspect of the road section adequate given the road category and traffic conditions? - avoid narrow lanes on truck roads and wide roads in residential areas. Have the needs of more vulnerable road users been adequately considered? - see ***pedestrians/cyclists***. Are cross-section features consistent along the road? - if not, are drivers adequately warned of the transition? (warnings signs, taper features, marking).			
Number of lanes	Is the number of lanes adequate, based on road category and traffic conditions? - too many lanes (excessive speeds) or too few lanes (capacity problem). Is each traffic lane clearly delimited by markings and/or channelization?			
Lane width	Are lane widths adequate for road category and traffic conditions? - too narrow or too wide. Is the site free of hazardous lane width change? - e.g. sudden narrowing at bridge.			
Auxiliary lane	Are features of auxiliary lanes safe? - alignment, length, traffic management; - taper (length, location, sight distance).			
Shoulder	Do shoulders allow safe recovery of errant vehicles? - lane/shoulder drop off, shoulder width, surface material, stability, erosion, obstacles (trees, etc.).			
Channelization (median separation, traffic island, etc.)	Does the existing channelization help improve the safety of road users? - clear delineation of each travel path; - reduction in traffic conflicts (separation of opposing, crossing, turning manoeuvres). Are channelization features safe for all road users (motorized and non-motorized)? - alignment, height of curbs, end treatment, etc.			

Step 4 - DETAILED OBSERVATIONS – ROAD SECTIONS

CROSS-SECTION (continued)		YES	NO	COMMENTS
Drainage	Do crown and cross slope allow adequate water runoff? Is drainage capacity adapted to rainfall conditions? - water accumulation, road erosion. Are drainage structures safe for all road users, including two-wheelers? - avoid deep and open drainage structures close to traffic lanes.			
Parking	Are parking facilities compatible with safe traffic operations? - avoid parking manoeuvres on high-speed roads; - check that parking does not impede visibility of crossing pedestrians and vehicles.			

ROAD SURFACE CONDITION		YES	NO	COMMENTS
TRAFFIC OPERATIONS				
Hazardous manoeuvre	Have site observations been completed without seeing any hazardous manoeuvres that may be related to road surface deficiencies? - skidding (or skid marks), traffic conflict, unsafe lateral position.			
ROAD CHARACTERISTICS				
Skid resistance	Is the road surface's skid resistance adequate, particularly at locations where friction requirement is high, such as in horizontal curves, in downhill grades and at intersections? - surface polishing, bleeding, contamination; - friction tests (if needed).			
Evenness	Is the road surface's evenness adequate? - potholes, waves, rutting, etc.			

ROAD SURFACE MARKING		YES	NO	COMMENTS
TRAFFIC OPERATIONS				
Travelling path	Are paths followed by road users safe?			
ROAD CHARACTERISTICS				
General	Does the marking comply with standards? - centerline, edgeline, laneline, audible marking/rumble strips; - crossings (pedestrians, cyclists, animals, trains, other); - marking width, length, color, location, alignment.			

Step 4 - DETAILED OBSERVATIONS – ROAD SECTIONS

ROAD SURFACE MARKING (continued)		YES	NO	COMMENTS
ROAD CHARACTERISTICS				
General (continued)	Is the location of each lane and travelling path clearly delimited by marking and channelization? - avoid wide roads with inadequate marking that create confusion as to the number of travel lanes and location of each of them. Is the marking clearly visible under all conditions? - night, sunrise and sunset, rain, winter, etc. Has possible confusion been avoided? - between permanent and temporary markings; - between old and new markings.			

ROADSIDE		YES	NO	COMMENTS
ROAD CHARACTERISTICS				
General	In the required clearance zone, are roadsides free of features that may increase the severity of losses of control? - steep side slopes; - rigid obstacles (trees, poles, rocks, etc.); - inadequate end treatment of rigid structures (bridges, guardrails, drainage structures, etc.). Are guardrails in good condition? Is roadside equipment free of damage that may have been caused by errant vehicles? Are roadsides free of features or activities that may distract drivers (commercial signs, stands, etc.)?			

ACCESS		YES	NO	COMMENTS
TRAFFIC OPERATIONS				
Traffic conflict	Have site observations been completed without seeing any traffic conflict related to the presence of road accesses?			
ROAD CHARACTERISTICS				
Density and type	Are access density and type compatible with safe traffic operations (based on road category and traffic conditions)? - keep the number of accesses low on mobility roads.			
Location and geometry	Are the locations and geometry of road accesses safe? - avoid accesses where driving workload is high (in the vicinity of intersections, curves, etc.); - avoid too-narrow or too-wide accesses; - if necessary, provide channelization to minimize traffic conflicts (splitter island, median separation, entrance or exit lane, etc.).			

Step 4 - DETAILED OBSERVATIONS – ROAD SECTIONS

ACCESS (continued)		YES	NO	COMMENTS
Sight distance	Is sight distance adequate at each road access? - road users entering or leaving accesses must be clearly visible to through traffic (and vice versa); - beware of seasonal or temporary sight obstructions (e.g. street parking). Check for competing information.			

ROAD SIGNS		YES	NO	COMMENTS
TRAFFIC OPERATIONS				
Compliance	Are drivers complying with road sign rules? - stop, speed, red light, etc.			
Driver error	Have site observations been completed without seeing any driver error or hazardous behaviour that may result from inadequate signing? - late braking, hesitation, etc.			
ROAD CHARACTERISTICS				
General	Do existing road signs comply with standards? - missing or superfluous sign, material, size, location (height and lateral offset), message simplicity. Are warning and guidance messages adapted to the road context? Is the site free of information overload (road signs and others)? Are messages and traffic rules associated with road signs coherent along the road and on the road network? Are sign supports adequately shielded or made frangible if required?			
Visibility Conspicuity	Are sign visibility and conspicuity adequate? - beware of temporary or seasonal obstructions (parked vehicles, vegetation, etc.); - check for primacy of road signs over competing information (contrast, adjacent distractions). Are road signs clearly visible under all conditions? - night, sun glare, winter (snow).			
Maintenance	Are road signs in good condition? - worn, broken, unclean, non-retro-reflective.			

LIGHTING		YES	NO	COMMENTS
ROAD CHARACTERISTICS				
General	Does the road lighting equipment comply with standards? Is the site free of hazardous lighting conditions at all times? - sunrise or sunset, winter, fog; - headlamp glare. If not, have appropriate measures been taken to reduce the associated risk?			
Maintenance	Are road lights functioning properly?			
Protection	Are road poles adequately shielded or made frangible if required?			

Step 4 - DETAILED OBSERVATIONS – ROAD SECTIONS

PEDESTRIANS/CYCLISTS		YES	NO	COMMENTS
TRAFFIC OPERATIONS				
Traffic conflict	Have site observations been completed without seeing any traffic conflicts or hazardous manoeuvres involving pedestrians/cyclists?			
ROAD CHARACTERISTICS				
General	Is the level of protection provided to pedestrians/cyclists appropriate for the road category and traffic conditions? - if high speeds, high volumes or heavy vehicles are involved: - pedestrians and cyclists should be separated from motorized vehicles (different paths); - crossings and turning manoeuvres should be separated in time (exclusive phases) or space (grade separated crossings).			
Foot or bicycle path	Are the required pedestrian/cyclist facilities provided (based on existing norms)? Is the continuity of pedestrian/cyclist facilities ensured along their itineraries? Are the widths of foot/bicycle paths adequate for traffic volumes? Have adequate measures been taken to avoid illegal use of pedestrian and cyclist facilities? - parked vehicles, stands, other obstacles. Are pedestrian/cyclist facilities adequate for night use? Is drainage capacity adequate? - water accumulation, erosion; - drainage structures that are hazardous to bicyclists. <u>Crossings</u> Are pedestrian or cyclist crossings provided if needed? Does their location suit the needs of these road users? Do pedestrian/bicycle crossings comply with standards? - type, width, signing. Have safety fences been installed where necessary to guide pedestrians to crossings? Are sight distances adequate? - drivers must clearly see pedestrians and cyclists (and vice versa); - beware of temporary or seasonal obstructions.			
Road signs	Are road signs warning drivers of the presence of pedestrians or cyclists? - near school, playground, etc.			
Special road user	Have the needs of all pedestrian categories been properly addressed? - baby carriages, children, elderly people, disabled persons, wheelchairs (e.g. low curbs, gentle slopes, handrails, etc.).			

Step 4 - DETAILED OBSERVATIONS – ROAD SECTIONS

TRUCKS		YES	NO	COMMENTS
TRAFFIC OPERATIONS				
Traffic conflict	Have site observations been completed without seeing any traffic conflicts or hazardous manoeuvres involving trucks?			
Speed differential	Are speed differentials between cars and trucks compatible with safe traffic operations (downhill or uphill)? *[grade analysis]*			
Platoon	Are vehicle platoons unlikely to form behind trucks (downhill or uphill)?			
ROAD CHARACTERISTICS				
General	Is the presence of trucks coherent with road category and traffic conditions?			
Lane width	Are lane widths adequate for truck dimensions? *[road width]*			
Horizontal and vertical alignment	Are the features of the horizontal alignment adequate to prevent the risk of truck overturning? *[skidding speed]* *[overturning speed]*			
	Are the features of the vertical alignment adequate to prevent the risk of brake overheating or excessive speed differentials (downhill and uphill)? *[grade analysis]* If not, are the required safety facilities available? - brake check area, arrester bed; - climbing lane.			
Vertical clearance	Is there adequate vertical clearance or proper signage of height restriction?			
Sight distance	Are available sight distances adequate for trucks to stop and complete all permitted manoeuvres safely? - beware of situations where the truck driver's higher position cannot compensate for the increased stopping and manoeuvering distances (e.g. vertical structures).			

ANIMALS		YES	NO	COMMENTS
ROAD CHARACTERISTICS				
Road equipment	Are fencing and crossings provided where necessary?			
Warning sign	Is signing adequate (cattle crossing, wild-animal warning, etc.)?			

Step 4 - DETAILED OBSERVATIONS – INTERSECTIONS

INTERSECTIONS		YES	NO	COMMENTS
TRAFFIC OPERATIONS				
General	Have site observations been completed without seeing any hazardous traffic conditions? - excessive delays (motorized, non-motorized); - queues of vehicles; - hazardous manoeuvres (short gap acceptance); - poor compliance with traffic regulations (incomplete stop, red light running, no yield to pedestrians); - if needed, conduct a ***traffic count***, ***delay study***, capacity analysis.			
Traffic control device	Is the traffic control device appropriate for traffic conditions? - (none, yield, stop on minor legs, all-way stops, traffic signals); - is the timing of traffic signals appropriate (number and length of each phase, including clearance intervals)?			
Traffic pattern	Is the intersection free of unusual traffic patterns that may surprise drivers (e.g. change of main road direction)?			
Travel path	Are travel paths easy to identify?			
Speed	Are operating speeds adequate for road conditions? - if needed, conduct a ***spot speed study***.			
Traffic conflict	Have site observations been completed without seeing any obvious traffic conflict problem (motorized - motorized, motorized - non-motorized) - if needed, conduct a ***traffic conflict study***.			

See also:
Pedestrians/cyclists
Trucks

Step 4 - DETAILED OBSERVATIONS – INTERSECTIONS

INTERSECTIONS (continued)		YES	NO	COMMENTS
ROAD CHARACTERISTICS				
Type of intersection	Is the presence of this type of intersection (e.g. T, +, roundabout): - coherent with the road environment? - allowed by existing norms. Is the density of intersections suited to the road category and traffic conditions?			
Layout	Are intersection characteristics adequate for the road category and traffic conditions? - excessive intersection areas; - insufficient turning radii (encroachments of large vehicles); - unusual or complex intersection layouts (more than 4 legs, skewed, offset).			
Sight distance	Is the intersection obvious to all road users? Are available sight distances sufficient to allow safe stopping manoeuvres (throughout the intersection)? - compare available sight distances with required stopping distances; ***[braking distance (curve)]*** - check sight distances at possible end of vehicle queues. Are available sight distances sufficient to allow safe completion of all permitted manoeuvres? - compare available sight distances with manoeuvring distances; - check for visual obstructions at each intersection corner (horizontal curve, building, stand, bridge, landscaping, pole, etc.); - beware of seasonal or temporary sight obstructions that may not be present during the site visit (parked vehicles, stopped bus, seasonal vegetation, etc.).			
Horizontal and vertical alignment	Is the intersection free of horizontal curve or grade that may reduce visibility and increase manoeuvring difficulties?			
Lane	Is the number of lanes adequate for the road category and traffic conditions? - too many or too few lanes. Have turning lanes been provided if required? Are turning lane characteristics safe? - advance warning of turning lane; - sufficient length to avoid blockage of through lanes; - tapers (length, alignment). Is the continuity of each lane provided before and after the intersection? Are lane widths adequate? - too narrow or too wide. Is each traffic lane clearly delimited (marking and/or channelization)?			
Channelization	Does the existing channelization improve the safety of all road users? - clear delineation of each travel path (e.g. traffic island to separate conflicting manoeuvres, median refuge, etc.). Are the channelization features safe for all road users? - channelization alignment, height of curbs, end treatments, etc.			

Step 4 - DETAILED OBSERVATIONS – INTERSECTIONS

INTERSECTIONS (continued)		YES	NO	COMMENTS
Drainage	Is drainage capacity adapted to rainfall conditions? - water accumulation, road erosion. Are drainage structures safe for all road users, including two-wheelers? - avoid deep and open drainage structures close to traffic lanes.			
Surface condition	Is skid resistance adequate? - surface polishing, bleeding, contamination; - ***friction tests*** (if needed). Is surface evenness adequate? - potholes, waves, rutting, etc. Is the road surface free of water (or traces thereof)? Is the road surface free of loose material (sand, rocks, leaves, etc.)?			
Roadsides	In the required clearance zone, are roadsides free of features that may increase the severity of losses of control? - steep side slopes; - rigid obstacles (trees, poles, rocks, etc.); - inadequate end treatment of rigid structures (bridges, barriers, drainage structures, etc.); - rigid obstacles in front of T intersections. Are safety barriers in good condition? Is roadside equipment free of damage that may have been caused by errant vehicles? Are roadsides free of features or activities that may cause excessive distraction (e.g. commercial signs)?			
Access	Are the locations and geometry of road accesses safe? - avoid road accesses in intersection corners; - avoid too-narrow or too-wide accesses; - if necessary, provide channelization to minimize traffic conflicts (splitter island, median barrier, entrance or exit lane, etc.).			
Road signs Traffic signals	Do the intersection road signs and signals comply with standards? - missing or superfluous equipment, size, location (height and lateral offset); - check location of stop sign(s). Is the warning level well-suited to the situation? - check whether advance warnings are required (e.g. first mandatory stop after several kilometers, end of high-speed road)? Are the visibility and conspicuity of signs and signals adequate? - beware of seasonal or temporary sight obstructions (parked or stopped vehicles, vegetation, etc.); - beware of situations that reduce signal lenses visibility and require special treatments (shield, special type of light). Are signs/devices/signals in good condition? - worn, broken, unclean, non-retro-reflective. Are poles shielded or made frangible if needed?			

Step 4 - DETAILED OBSERVATIONS – INTERSECTIONS

INTERSECTIONS (continued)		YES	NO	COMMENTS
ROAD CHARACTERISTICS				
Marking	Does the marking comply with standards? - centerline, edgeline, laneline, stop line; - crossings (pedestrians, cyclists, others); - marking width, length, color, location, alignment. Is the location of each lane and travelling path clearly delimited by marking and channelization? Are resulting lane and shoulder widths adequate for road category and traffic conditions? Is the marking clearly visible under all conditions? - night, sunrise and sunset, rain, winter, etc. Has possible confusion been avoided? - between permanent and temporary markings; - between old and new markings.			
Road lighting	Does the road lighting equipment comply with standards? Are road lights functioning properly? Are road lighting poles adequately shielded or made frangible if required (high-speed roads)? Is the intersection free of hazardous lighting conditions at all times? - sunrise or sunset, winter, fog; If not, have adequate measures been taken to reduce the risk?			
Hazardous combination of features	Is the intersection free of nearby features that increase accident risk or severity (horizontal or vertical curve, railroad crossing, bridge, etc)?			
Pedestrian	Are pedestrian or cyclist crossings provided if needed? Does their location suit the needs of these road users? Is the level of protection provided to pedestrians appropriate for the road category and traffic conditions? - if high speeds, high volumes or heavy vehicles are involved, crossing manoeuvres should be separated in time (exclusive phase) or in space (grade-separated crossing); Do the pedestrian/bicycle crossings comply with standards? - location, type, width, signing. Have safety fences been installed where necessary to guide pedestrians to crossings? Are sight distances adequate? - vehicles must be able to see pedestrians/cyclists and vice versa; - beware of temporary or seasonal obstructions. Have median refuges been provided where required?			

Step 4 - DETAILED OBSERVATIONS – INTERSECTIONS

INTERSECTIONS (continued)		YES	NO	COMMENTS
ROAD CHARACTERISTICS				
Pedestrian	Have the needs of all pedestrians been properly addressed? - baby carriages, children, elderly people, disabled persons, wheelchairs, (e.g. low curbs, gentle slopes, handrails, etc). Are there adequate road signs warning drivers of the presence of pedestrians? Are pedestrian facilities adequate for night use?			
	Traffic signals Does the signal timing provide adequate protection to pedestrians and cyclists? - exclusive phase if required, adequate phase length and sequence (pedestrian/cyclist must phase follows the main phase). Are pedestrian signal heads clearly visible?			
Truck	Are turning radii appropriate for heavy vehicle characteristics? - encroachments. Are sight distances adequate for safe truck manoeuvring? Are acceleration/deceleration lane features adequate for heavy-vehicle characteristics and performance? - length, width, tapers			
Bus	Are existing bus facilities compatible with safe traffic operations? - is there sufficient protection for bus users entering or leaving bus? - does the presence of a bus shelter or a stopped bus impede visibility? Check suitability of bus stops in reducing pedestrian crossings and related traffic conflicts.			

ADDITIONAL DATA COLLECTION

ELEMENTS	OK	COMMENTS
Pictures	❏	
Videos	❏	
Condition diagram	❏	

OPTIONAL DATA (depending on study needs)

ELEMENTS	OK	COMMENTS
Traffic count	❏	
Traffic conflicts	❏	
Spot speed	❏	
Travel time and delay	❏	
Sight distances	❏	
Traffic signal timing	❏	

SUMMARY REPORT

Municipality: ______________________________

Location: ______________________________

Date: ______________________________

Analyst: ______________________________

SITE HISTORY	
CATEGORIZATION	
ACCIDENTS	
SITE OBSERVATIONS	
RECOMMENDATIONS	

APPENDIX 6-4

Example

Safety diagnosis
CHECKLISTS

Municipality: Saint-Gilles

Location: Route 325 and Route 328

Date: June 2000

Analyst: Benoit Taillefer

Analysis objectives: A first safety analysis has been conducted at this site in 1995, which led to minor signing and marking improvements. However, road users continued to complain and a new analysis was requested in 2000 by the Municipal council.

Step 1 - SITE HISTORY *(based on the 1995 safety analysis)*

Check for availability of the following information:

ELEMENT	OK	COMMENTS
Data		
Accidents: *from 1 Jan'92 to 31 Dec'94*	☒	*7 accidents/3 years (see collision diagram).*
Traffic	☒	*7,566 vpd, (see the 1995 traffic count).*
Geometry	☒	*see the condition diagram.*
Conclusions of previous studies (safety, sight distance, spot speed, skid resistance, etc.)	☒	*- Site was not identified as hazardous (accident rate lower than critical rate)* *- Traffic signs were brought up to standards.*
Maintenance reports	☒	*unavailable*
Photos/videos	☒	*see 1995 pictures.*
Employees' knowledge	☒	*unavailable*
Requests/complaints/discussions (road users, local residents, local government officials)	☒	*The municipality's request mentioned difficulties for heavy-vehicle drivers in completing turning manoeuvres at the intersection.*
Others	☒	*Visibility in NORTH-EAST quadrant is restricted by presence of a historic building.*

Conclusions

A safety analysis conducted in 1995 revealed the following problems:

1. *The sight distance is restricted by the presence of a historic building in the NORTH-EAST quadrant.*
2. *Difficulties for heavy vehicles in turning at the intersection(encroachments).*

Actions taken: *– Road signs were brought up to standards;*
– Stop lines were marked away from the intersection.

Step 2 - SITE CATEGORIZATION

Road category: *T intersection, crossing of two main roads, stop on stem, urban area (small town)*

Step 3 - ACCIDENT ANALYSIS

TASK	OK	COMMENTS
Select accident period and retrieve data from 1 Jan 1997 to 31 Dec 1999	☒	*see the 1995 collision diagram .*
Select reference population ***(Appendix 5.1)***	☒	*T intersection with 1 stop on T stem in urban area.*
Prepare accident summaries ***(Section 6.3.2)***		
Collision diagram	☒	*Included.*
Summary tables	❑	
Comparative tables	☒	*Comparative tables included.*
Calculate safety indicators (criteria) ***(Section 5.3.1)***	☒	*Accident frequency: 21 accidents / 3 years.* *Accident rate: (1.82 acc / Mveh-km).* *Critical accident rate: (1.2 acc / Mveh-km).*
Determine abnormal accident patterns ***(Section 5.3.2)***	☒	*The following accident types need to be analyzed:* *Angle accidents. 43%* *Accidents involving a heavy vehicle. 17%*
Search for accident factors ***(Appendix 6-2)*** (to be completed at the site)	❑	

Conclusions:

- the accident rate is larger than the critical accident rate (the site is hazardous).

- angle accidents and accident involving a heavy vehicle need to be analyzed.

IMPORTANT

Bring relevant Accident Tables to the site

Step 4 - SITE OBSERVATIONS – PREPARATION

Gather the following items:

ITEM	OK
In all studies:	
Camera (film or memory, batteries)	☒
Video recorder and sufficient recording medium	☒
Measuring tape and measuring wheel	☒
Notebook, pencils, eraser, rule	☒
Cell phone	☒
Existing drawings	☒
Conclusions from previous studies	☒
Diagnostic checklists	☒
Accident tables	☒
According to study requirements:	
Sighting rod and target rods ***(sight distance study)***	☒
Radar or laser gun ***(spot speed study)***	❑
Stop watch (***delay***, ***travel time***, ***traffic count***, traffic signal timing)	☒
Tally sheets or mechanical or electronic counter ***(traffic count)***	☒
Level (superelevation)	❑
Tape recorder	❑
For the analysts' safety:	
Safety helmet, jacket and boots	☒
Flashing lights and other signalling equipment	☒
Police assistance (where necessary)	❑

IMPORTANT

The site visit must be scheduled at a time when the detected problems are most likely to be observed.

Step 4 - SITE OBSERVATIONS – FAMILIARIZATION

TASKS	OK	COMMENTS
Travel through the site in all directions and note obvious problems: - road characteristics; - traffic operation; - road user behaviour.	 ☒ ☒ ☒	
Verify the overall coherence of the road environment based on: (see details below)	☒	*Residents inform us that a large sawmill was established in the municipality in 1997. A new traffic count is requested.*
Check for obvious human factor problems: (***drivers'expectancies***, ***driving task***) Features that drivers may find surprising (violation of expectancies) unusual or unexpected change in alignment, cross-section, road surface, signing, marking, traffic, land use Check violations of: - short-term expectancies (acquired during the trip); - long term expectancies (acquired during a driver's life) - event related expectancies (rare events) Overload possibilities - Too many stimuli - Information too complex Drowsiness or inattention possibilities	 ☒ ☒ ☒	*The main road changes direction.* *First stop for 12 km for users coming from the NORTH. However, they have been travelling in an urban area for 2 km.*

Road category

	main	minor
artery	☒	☒
collector road	❑	❑
local road	❑	❑

Section ❑

Intersection ☒

Type	
T	☒
+	❑
Y	❑
X	❑
>4	❑
roundabout	❑

Number of lanes (road)

	main	minor
1 lane	❑	❑
2 lanes	☒	☒
multi-lane	❑	❑

Area

rural	❑
urban	☒

Traffic control

none	❑
yield	❑
stops (minor)	☒
multiple stops	❑
traffic signals	❑

Road type

	main	minor
undivided	☒	☒
divided	❑	❑
freeway	❑	❑

Speed limit

Main *50* km / h

Minor *50* km / h

Is the posted speed coherent with the road function, road characteristics, road use and land use?

yes	no
❑	❑

Traffic

	Volume
motorized	*10,526*
passenger	
2-wheel	
bus	
heavy vehicle	
others	
non-motorized	
pedestrian	
cyclist	
others	

Adjacent land use

residential	☒
commercial	☒
industrial	❑
agricultural	❑
forestry	❑
others	❑

Step 4 - SITE OBSERVATIONS – SITE HISTORY

TASK	OK	
Check whether problems detected in past studies have been successfully treated.	☒	

Conclusions:

- *Road signs have been installed.*
- *Stopped lines are faded.*

STEP 4 - SITE OBSERVATIONS – PROBLEMS AT SIMILAR SITES

TASK	OK	
Check whether problems that are frequently observed at similar sites are present at this site (*based on results of previous studies at similar sites, available guides, etc.*).	❑	

Conclusions:

Step 4 - SITE OBSERVATIONS – ACCIDENT FACTORS

TASK	OK	
Complete the accident analysis that has been initiated in step 3 by verifying, for each deviant accident pattern, the potential contributive factors and possible actions (based on Tables in ***Appendix 6-2***).	☒	

Conclusions:

With heavy vehicles

A sawmill situated 2 km from the intersection (towards the North) generates a high volume of heavy vehicles.

Heavy vehicles turning right at the intersection (WB to NB) encroach onto the opposite lane. Some vehicles that are stopped at the intersection (on the SB approach) must back up to enable them to complete the manoeuvre.

The presence of a railway line, a bridge and a historic building close to the intersection makes geometric improvements difficult.

Angle

The presence of the historic building in the NORTH-EAST quadrant compels vehicles to edge forward into the intersection to have sufficient sight distance.

Heavy vehicles turning at the intersection encroach onto the opposite lane (WB to NB).

Line-ups have been observed on the stem of the T in the evening peak hour (SB approach).

Step 4 - DETAILED OBSERVATIONS – INTERSECTIONS

INTERSECTIONS		YES	NO	COMMENTS
TRAFFIC OPERATIONS				
General	Have site observations been completed without seeing any hazardous traffic conditions? - excessive delays (motorized, non motorized); - queues of vehicles; - hazardous manoeuvres (short gap acceptance); - poor compliance with traffic regulations (incomplete stop, red light running, no yield to pedestrians); - If needed, conduct a ***traffic count***, ***delay study***, capacity analysis.		✔	*Some users of stem of T facing long waiting times execute hazardous manoeuvres.*
Traffic control device	Is the traffic control device appropriate for traffic conditions? - (none, yield, stop on minor legs, all-way stops, traffic signals); - is the timing of traffic signals appropriate (number and length of each phase, including clearance intervals)?		✔	*Queues of vehicles observed on stem of T. Capacity calculations need to be made.*
Traffic pattern	Is the intersection free of unusual traffic patterns that may surprise drivers (e.g. change of main road direction)?		✔	*Main road changes direction.*
Travel path	Are travel paths easy to identify?		✔	*Heavy vehicles encroach onto opposite lanes during their turning manoeuvres (WB to NB).*
Speed	Are operating speeds adequate for road conditions? - if needed, conduct a ***spot speed study***.	✔		
Traffic conflict	Have site observations been completed without seeing any obvious traffic-conflict problem (motorized - motorized, motorized - non-motorized) - if needed, conduct a ***traffic conflict study***.		✔	*Pedestrians have difficulties in crossing the intersection.*

See also:

Pedestrians/cyclists
Trucks

Step 4 - DETAILED OBSERVATIONS – INTERSECTIONS

INTERSECTIONS (continued)		YES	NO	COMMENTS
ROAD CHARACTERISTICS				
Type of intersection	Is the presence of this type of intersection (e.g. T, +, roundabout): - coherent with the road environment? - allowed by existing norms. Is the density of intersections suited to the road category and traffic conditions?	✔		
Layout	Are intersection characteristics adequate for the road category and traffic conditions? - excessive intersection areas; - insufficient turning radii (encroachments of large vehicles); - unusual or complex intersection layouts (more than 4 legs, skewed, offset).		✔	
Sight distance	Is the intersection obvious to all road users? Are available sight distances sufficient to allow safe stopping manoeuvres (throughout the intersection)? - compare available sight distances with required stopping distances; ***[braking distance (curve)]*** - check sight distances at possible end of vehicle queues. Are available sight distances sufficient to allow safe completion of all permitted manoeuvres? - compare available sight distances with manoeuvring distances; - check for visual obstructions at each intersection corner (horizontal curve, building, stand, bridge, landscaping, pole, etc.); - beware of seasonal or temporary sight obstructions that may not be present during the site visit (parked vehicles, stopped bus, seasonal vegetation, etc.).		✔	*Restricted sight distance in NORTH-EAST quadrant.*
Horizontal and vertical alignment	Is the intersection free of horizontal curve or grade that may reduce visibility and increase manoeuvring difficulties?	✔		
Lane	Is the number of lanes adequate for the road category and traffic conditions? - too many or too few lanes. Have turning lanes been provided if required? Are turning lane characteristics safe? - advance warning of turning lane; - sufficient length to avoid blockage of through lanes; - tapers (length, alignment). Is the continuity of each lane provided before and after the intersection? Are lane widths adequate? - too narrow or too wide. Is each traffic lane clearly delimited (marking and/or channelization)?	✔		
Channelization	Does the existing channelization improve the safety of all road users? - clear delineation of each travel path (e.g. traffic island to separate conflicting manoeuvres, median refuge, etc.). Are the channelization features safe for all road users? - channelization alignment, height of curbs, end treatments, etc.	✔		

Step 4 - DETAILED OBSERVATIONS – INTERSECTIONS

INTERSECTIONS (continued)		YES	NO	COMMENTS
Drainage	Is drainage capacity adapted to rainfall conditions? - water accumulation, road erosion. Are drainage structures safe for all road users, including two-wheelers? - avoid deep and open drainage structures close to traffic lanes.	✔		
Surface condition	Is the skid resistance adequate? - surface polishing, bleeding, contamination; - ***friction tests*** (if needed). Is surface evenness adequate? - potholes, waves, rutting, etc. Is the road surface free of water (or traces thereof)? Is the road surface free of loose material (sand, rocks, leaves, etc.)?	✔		
Roadsides	In the required clearance zone, are roadsides free of features that may increase the severity of losses of control? - steep side slopes; - rigid obstacles (trees, poles, rocks, etc.); - inadequate end treatment of rigid structures (bridges, barriers, drainage structures, etc.); - rigid obstacles in front of T intersections. Are safety barriers in good condition? Is roadside equipment free of damage that may have been caused by errant vehicles? Are roadsides free of features or activities that may cause excessive distraction (e.g. commercial signs)?	✔		
Access	Are the locations and geometry of road accesses safe? - avoid road accesses in intersection corners; - avoid too-narrow or too-wide accesses; - if necessary, provide channelization to minimize traffic conflicts (splitter island, median barrier, entrance or exit lane, etc.).		✔	*A restaurant is located opposite the stem of the intersection. This access is non-standard (too wide).*
Road signs Traffic signals	Do the intersection road signs and signals comply with standards? - missing or superfluous equipment, size, location (height and lateral offset); - check location of stop sign(s). Is the warning level well-suited to the situation? - check whether advance warnings are required (e.g. first mandatory stop after several kilometers, end of high speed road)? Are the visibility and conspicuity of signs and signals adequate? - beware of seasonal or temporary sight obstructions (parked or stopped vehicles, vegetation, etc.); - beware of situations that reduce signal lenses visibility and require special treatments (shield, special type of light). Are signs/devices/signals in good condition? - worn, broken, unclean, non-retro-reflective. Are poles shielded or made frangible if needed?		✔	*The stop sign on the stem of T is not clearly visible (placed back from the road).*

Step 4 - DETAILED OBSERVATIONS – INTERSECTIONS

INTERSECTIONS (continued)		YES	NO	COMMENTS
ROAD CHARACTERISTICS				
Marking	Does the marking comply with standards? - centerline, edgeline, laneline, stop line; - crossings (pedestrians, cyclists, others); - marking width, length, color, location, alignment. Is the location of each lane and travelling path clearly delimited by marking and channelization? Are resulting lane and shoulder widths adequate for road category and traffic conditions? Is the marking clearly visible under all conditions? - night, sunrise and sunset, rain, winter, etc. Has possible confusion been avoided? - between permanent and temporary markings; - between old and new markings.		✔	*Marking erased in some places*
Road lighting	Does the road lighting equipment comply with standards? Are road lights functioning properly? Are road lighting poles adequately shielded or made frangible if required (high-speed roads)? Is the intersection free of hazardous lighting conditions at all times? - sunrise or sunset, winter, fog. If not, have adequate measures been taken to reduce the risk?	✔		
Hazardous combination of features	Is the intersection free of nearby features that increase accident risk or severity (horizontal or vertical curve, railroad crossing, bridge, etc)?	✔		
Pedestrian	Are pedestrian or cyclist crossings provided if needed? Does their location suit the needs of these road users? Is the level of protection provided to pedestrians appropriate for the road category and traffic conditions? - if high speeds, high volumes or heavy vehicles are involved, crossing manoeuvres should be separated in time (exclusive phase) or in space (grade-separated crossing). Do the pedestrian/bicycle crossings comply with standards? - location, type, width, signing. Have safety fences been installed where necessary to guide pedestrians to crossings? Are sight distances adequate? - vehicles must be able to see pedestrians/cyclists and vice versa; - beware of temporary or seasonal obstructions. Have median refuges been provided where required?		✔	*No pedestrian crossing.*

Step 4 - DETAILED OBSERVATIONS – INTERSECTIONS

INTERSECTIONS (continued)		YES	NO	COMMENTS
Pedestrian (continued)	Have the needs of all pedestrians been properly addressed? - baby carriages, children, elderly people, disabled persons, wheelchairs(e.g., low curbs, gentle slopes, handrails, etc). Are there adequate road signs warning drivers of the presence of pedestrians? Are pedestrian facilities adequate for night use?			
	Traffic signals Does the signal timing provide adequate protection to pedestrians and cyclists? - exclusive phase if required, adequate phase length and sequence (pedestrian/cyclist must phase follows the main phase). Are pedestrian signal heads clearly visible?			
Truck	Are turning radii appropriate for heavy vehicle characteristics? - encroachments. Are sight distances adequate for safe truck manoeuvring? Are acceleration/deceleration lane features adequate for heavy-vehicle characteristics and performance? - length, width, tapers.		✔	*Encroachments.*
Bus	Are existing bus facilities compatible with safe traffic operations? - is there sufficient protection for bus users entering or leaving buses? - can the presence of a bus shelter or a stopped bus impede visibility? Check suitability of bus stops in reducing pedestrian crossings and related traffic conflicts.	✔		

ADDITIONAL DATA COLLECTION

ELEMENTS	OK	COMMENTS
Pictures	☒	
Videos	❑	
Condition diagram	☒	

OPTIONAL DATA (depending on study needs)

ELEMENTS	OK	COMMENTS
Traffic count	☒	*Included*
Traffic conflict	❑	
Spot speed	❑	
Travel time and delay	❑	
Sight distance	❑	
Traffic signal timing	❑	

SUMMARY REPORT

Municipality: Saint-Gilles

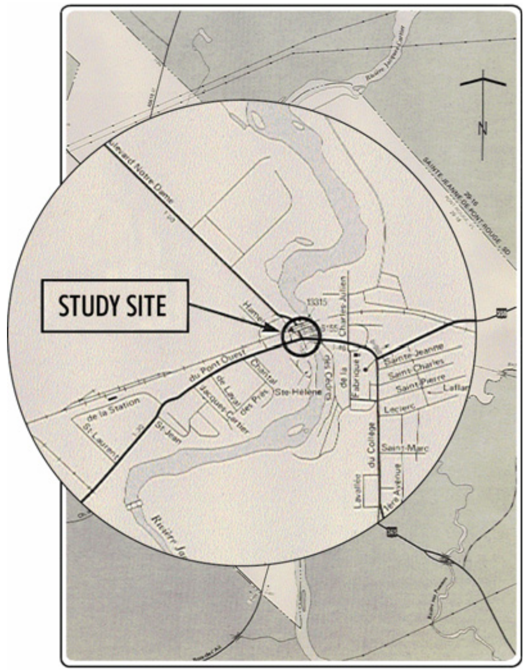
Location: Route 325 and Route 328

Date: June 2000

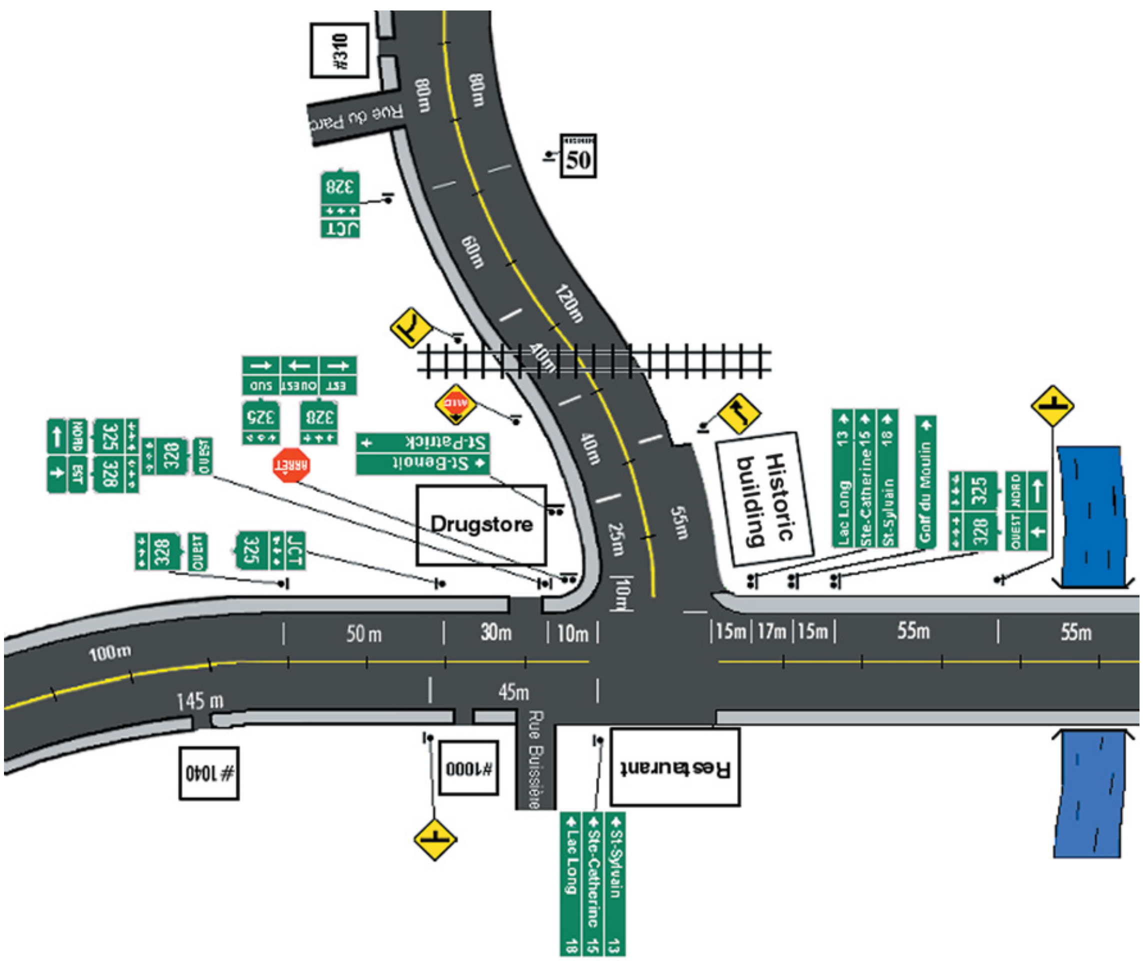
Analyst: Benoit Taillefer

SITE HISTORY	• Heavy-vehicle drivers have problems completing turning manoeuvres; • Restricted sight distance due to the presence of a historic building in NORTH-EAST quadrant.
CATEGORIZATION	• T intersection, crossing of two main roads, stop on stem, urban area (small town).
ACCIDENTS	• 21 accidents in 3 years; • 43% of accidents are angle collisions; • 43% of accidents occur between 3pm and 6pm; • 17% of collisions involve a heavy vehicle; • Accident rate (1.82 acc/Mveh-km) higher than critical rate (1.2 acc/Mveh-km).
SITE OBSERVATIONS	• Restricted visibility in NORTH-EAST quadrant; • Non-conforming commercial access at intersection (restaurant); • Tight curve radii at intersection (North-East corner); • Geometric improvement difficult (bridge, historic building and railway line); • Heavy vehicles encroach onto opposite lanes during their turning manoeuvres; • Queues at rush hours; • Hazardous manoeuvres by some users on stem of T; • Stop not clearly visible on stem of T; • Marking deficient at intersection: stop lines, pedestrian crossings.
RECOMMENDATIONS	• Based on capacity calculations, traffic signals are warranted. Signals will therefore be installed and will include an all-walk phase for pedestrians; • Pedestrian crossings will be provided; • Stop lines will be relocated to facilitate heavy-vehicle turning manoeuvres; • The excessive width of accesses will be made standard.

SITE LOCATION



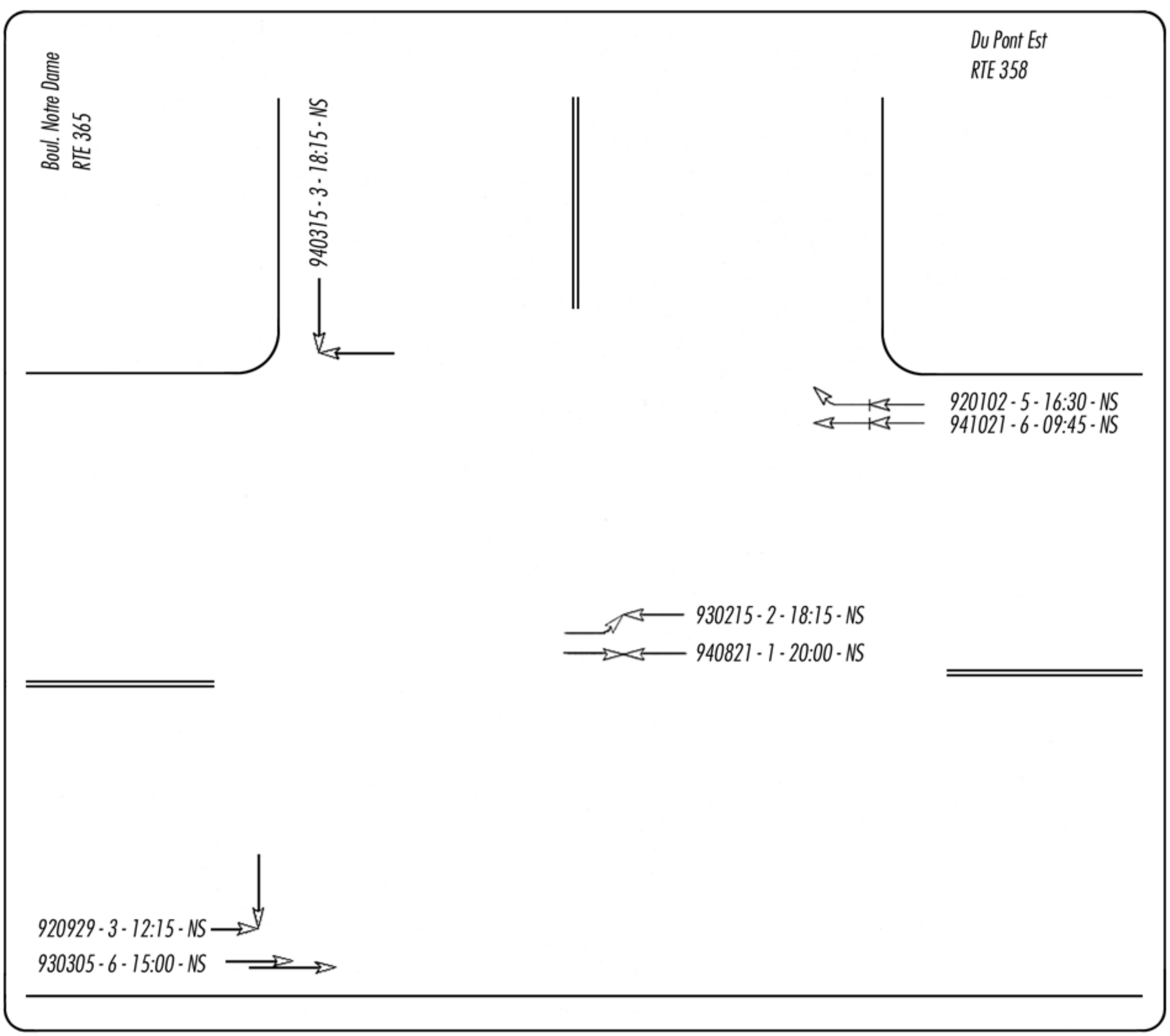
CONDITION DIAGRAM



TRAFFIC COUNT 1995

	EAST				WEST				NORTH				
	L	T	R	Total	L	T	R	Total	L	T	R	Total	Total
7:00 - 8:00	6	102	137	245	24	52	1	77	105	0	44	149	471
8:00 - 9:00	7	102	130	239	26	71	1	98	119	0	34	153	490
9:00 - 10:00	0	96	123	219	26	57	2	85	122	0	31	153	457
10:00 - 11:00	4	93	112	209	25	69	2	96	133	0		158	463
11:00 - 12:00	19	88	118	225	34	93	7	134	138	7	29	174	533
12:00 - 13:00	10	72	155	237	51	105	3	159	124	15	26	165	561
13:00 - 14:00	9	83	145	237	25	100	3	128	97	6	25	128	493
14:00 - 15:00	1	87	118	206	30	80	1	111	106	0	28	134	451
15:00 - 16:00	7	86	142	235	25	80	1	106	99	0	41	140	481
16:00 - 17:00	7	78	180	265	51	110	3	164	144	6	30	180	609
17:00 - 18:00	11	74	175	260	61	121	2	184	131	7	28	166	610
18:00 - 19:00	4	82	119	205	30	82	0	112	107	5	28	140	457
Total	85	1043	1654	2782	408	1020	26	1454	1425	46	369	1840	6076
AADT	2782				1454				1840				6076

COLLISION DIAGRAM 1995



COMPARATIVE TABLES 1995

Accident type				
Accident statut	Site		Pop	Site>Pop
	Nb	%	(%)	
Rear	2	29	17	66
Right angle	2	29	16	69
Single Vehicle	0	0	26	0
Lateral	1	14	8	56
Opposite Left	1	14	5	70
Head-On	1	14	4	75
Others	0	0	25	0

Kind of Accident				
Accident statut	Site		Pop	Site>Pop
	Nb	%	(%)	
Car (11)	7	100	68	93
Pedestrian (12)	0	0	2	0
Train (13)	0	0	0	0
Animal (15)	0	0	4	0
Fixed Objects (17 to 21 + 29)	0	0	8	0
Roadside (17 to 99)	0	0	17	0

Surface Condition				
Accident statut	Site		Pop	Site>Pop
	Nb	%	(%)	
Dry	7	100	57	98
Wet	0	0	19	0
Snow-covered	0	0	13	0
Icy	0	0	8	0
Others	0	0	1	0
Wet / snow-covered / icy	0	0	41	0
Snow-covered / icy	0	0	0	0

Day of week				
Accident statut	Site		Pop	Site>Pop
	Nb	%	(%)	
Sunday	2	29	11	82
Monday	0	0	12	0
Tuesday	1	14	11	44
Wednesday	1	14	13	38
Thursday	2	29	17	66
Friday	0	0	20	0
Saturday	1	14	15	32
Monday-Thursday	4	57	54	41
Friday-Sunday	3	43	46	30

Severity				
Accident statut	Site		Pop	Site>Pop
	Nb	%	(%)	
Fatal	0	0	1	0
Serious	0	0	4	0
Light	0	0	17	0
PDO	7	100	79	81
EPD	0	0	0	0
Light / PDO	7	100	96	25
Fatal / serious	0	0	5	0

Vehicle Type				
Accident statut	Site		Pop	Site>Pop
	Nb	%	(%)	
Car / lorry (41 + 42 + 51)	14	100	85	90
Heavy lorry / Bus (43 to 50)	0	0	7	0
Motor cycle/moped (53 + 54)	0	0	1	0
Bicycle (57)	0	0	2	0
Snowmobile (56)	0	0	0	0
Others (99)	0	0	0	0

Weather				
Accident statut	Site		Pop	Site>Pop
	Nb	%	(%)	
Clear	7	100	55	98
Cloudy	0	0	23	0
Rain / mist (R/M)	0	0	9	0
Snow / hail (S/H)	0	0	8	0
Blizzard / Storm (B/S)	0	0	1	0
Clear / Cloudy	7	100	78	82
Others	0	0	2	0
Not clear (R/M + S/H = B/S)	0	0	18	0

Month				
Accident statut	Site		Pop	Site>Pop
	Nb	%	(%)	
January	1	14	11	44
February	1	14	8	56
March	2	29	7	92
April	0	0	7	0
May	0	0	6	0
June	0	0	9	0
July	0	0	9	0
August	1	14	8	56
September	1	14	7	60
October	1	14	9	52
November	0	0	8	0
December	0	0	10	0
Winter (Dec-Jan-Feb-Sept)	4	57	36	78
Summer (June-Jul-Aug-Sept)	2	29	33	27
Others	1	14	30	8

Time				
Accident statut	Site		Pop	Site>Pop
	Nb	%	(%)	
00h00-00h59	0	0	1	0
01h00-01h59	0	0	2	0
02h00-02h59	0	0	2	0
03h00-03h59	0	0	2	0
04h00-04h59	0	0	1	0
05h00-05h59	0	0	1	0
06h00-06h59	0	0	1	0
07h00-07h59	0	0	2	0
08h00-08h59	1	14	5	70
09h00-09h59	1	14	4	75
10h00-10h59	0	0	5	0
11h00-11h59	0	0	6	0
12h00-12h59	1	14	7	60
13h00-13h59	0	0	7	0
14h00-14h59	0	0	7	0
15h00-15h59	1	14	8	56
16h00-16h59	1	14	9	52
17h00-17h59	0	0	6	0
18h00-18h59	1	14	6	65
19h00-19h59	0	0	5	0
20h00-20h59	1	14	4	75
21h00-21h59	0	0	4	0
22h00-22h59	0	0	3	0
23h00-23h59	0	0	3	0
99	0	0	2	0
Peak hour: 07h00-08h59	1	14	7	60
Day: 09h00-14h59	2	29	35	23
Peak hour: 15h00-17h59	2	29	23	50
Evening: 18h00-22h59	2	29	20	58
Night: 00h00-06h59	0	0	13	0

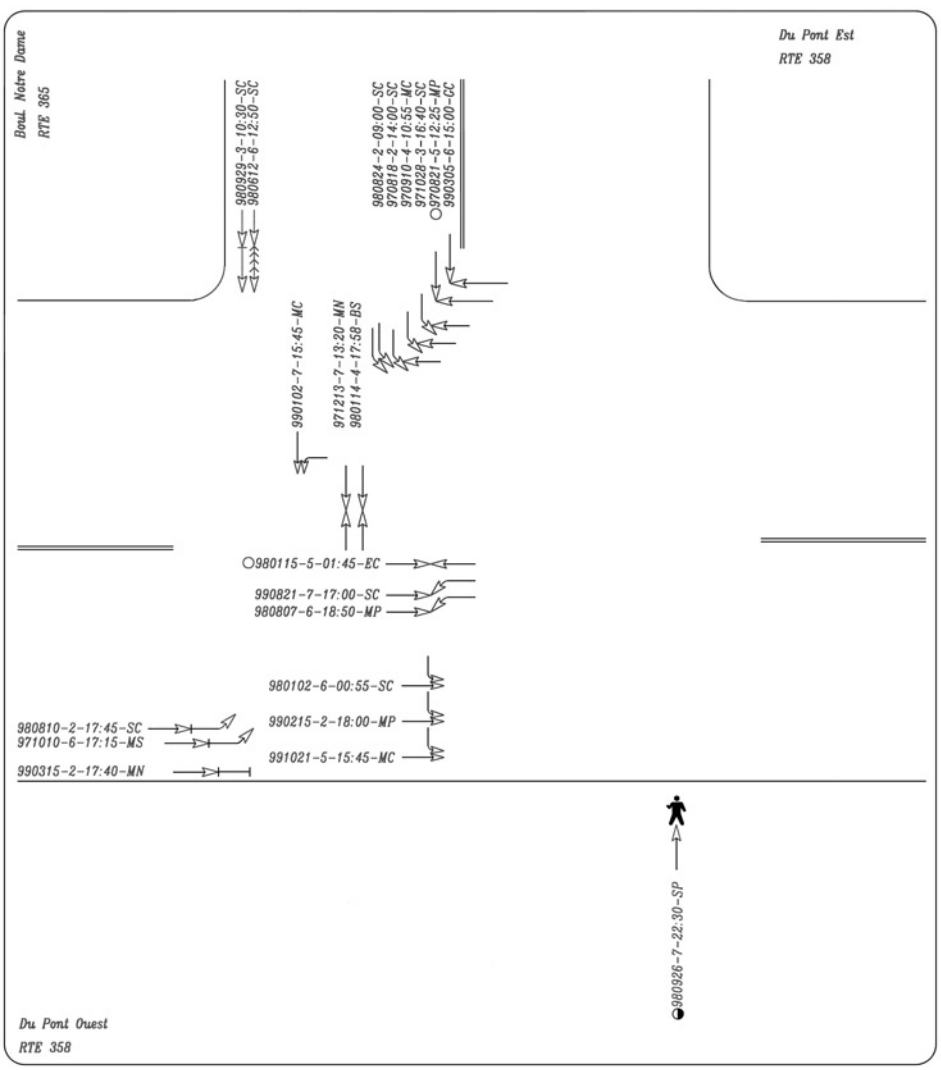
Years				
Accident statut	Site		Pop	Site>Pop
	Nb	%	(%)	
1988	2	29	20	58
1989	2	29	20	58
1990	3	43	20	85

Numbers of vehicles				
Accident statut	Site		Pop	Site>Pop
	Nb	%	(%)	
1 vehicle	0	0	27	0
2 vehicles	7	100	69	93
3 or more vehicles	0	0	4	0

TRAFFIC COUNT 2000

	EAST				WEST				NORTH				
	L	T	R	Total	L	T	R	Total	L	T	R	Total	Total
7:00 - 8:00	3	109	168	280	28	68	1	97	224	0	51	275	652
8:00 - 9:00	4	87	203	294	30	86	2	118	165	0	42	207	619
9:00 - 10:00	0	0	0	0	0	0	0	0	174	0	0	174	174
10:00 - 11:00	0	0	0	0	0	0	0	0	236	0	0	236	236
11:00 - 12:00	13	44	100	157	17	72	1	90	213	4	26	243	490
12:00 - 13:00	29	128	245	402	61	119	8	188	268	9	40	317	907
13:00 - 14:00	5	73	91	169	20	72	2	94	220	3	24	247	510
14:00 - 15:00	0	0	0	0	0	0	0	0	244	0	0	244	244
15:00 - 16:00	0	0	0	0	0	0	0	0	212	0	0	212	212
16:00 - 17:00	4	129	295	428	63	168	1	232	292	6	346	644	1304
17:00 - 18:00	15	94	268	377	42	123	3	168	241	5	280	526	1071
18:00 - 19:00	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	73	664	1370	2107	261	708	18	987	2489	27	809	3325	6419
AADT	2107				987				3325				6419

COLLISION DIAGRAM 2000



COMPARATIVE TABLES 2000

Accident type

Accident statut	Site		Pop	Site>Pop
	Nb	%	(%)	
Rear	5	24	17	72
Right angle	9	43	16	100
Single Vehicle	1	5	26	0
Lateral	1	5	8	17
Opposite Left	2	10	5	72
Head-On	3	14	4	95
Others	0	0	25	0

Kind of accident

Accident statut	Site		Pop	Site>Pop
	Nb	%	(%)	
Car (11)	20	95	68	100
Pedestrian (12)	1	5	2	65
Train (13)	0	0	0	0
Animal (15)	0	0	4	0
Fixed Objects (17 to 21 + 29)	0	0	8	0
Roadside (17 to 99)	0	0	17	0

Surface condition

Accident statut	Site		Pop	Site>Pop
	Nb	%	(%)	
Dry	9	43	57	6
Wet	9	43	19	99
Snow-covered	1	5	13	5
Icy	1	5	8	17
Others	1	5	1	81
Wet / snow-covered / icy	11	52	41	80
Snow-covered / icy	2	10	0	100

Month

Accident statut	Site		Pop	Site>Pop
	Nb	%	(%)	
January	4	19	11	81
February	1	5	8	17
March	2	10	7	56
April	0	0	7	0
May	0	0	6	0
June	1	5	9	14
July	0	0	9	0
August	6	29	8	100
September	3	14	7	82
October	3	14	9	71
November	0	0	8	0
December	1	5	10	11
Winter (Dec-Jan-Feb-Sept)	8	38	36	50
Summer (June-Jul-Aug-Sept)	10	48	33	88
Others	3	14	30	3

Severity

Accident statut	Site		Pop	Site>Pop
	Nb	%	(%)	
Fatal	0	0	1	0
Serious	1	5	4	42
Light	2	10	17	11
PDO	18	86	79	67
EPD	0	0	0	0
Light / PDO	20	95	96	20
Fatal / serious	1	5	5	34

Vehicle Type

Accident statut	Site		Pop	Site>Pop
	Nb	%	(%)	
Car / lorry (41 + 42 + 51)	33	80	85	9
Heavy lorry / Bus (43 to 50)	7	17	7	97
Motor cycle/moped (53 + 54)	1	2	1	66
Bicycle (57)	0	0	2	0
Snowmobile (56)	0	0	0	0
Others (99)	0	0	0	0

Weather

Accident statut	Site		Pop	Site>Pop
	Nb	%	(%)	
Clear	13	62	55	66
Cloudy	2	10	23	3
Rain / mist (R/M)	4	19	9	89
Snow / hail (S/H)	2	10	8	49
Blizzard / Storm (B/S)	0	0	1	0
Clear / Cloudy	15	71	78	16
Others	0	0	2	0
Not clear (R/M + S/H = B/S)	6	29	18	84

Day of week

Accident statut	Site		Pop	Site>Pop
	Nb	%	(%)	
Sunday	0	0	11	0
Monday	5	24	12	90
Tuesday	2	10	11	31
Wednesday	2	10	13	22
Thursday	3	14	17	28
Friday	5	24	20	59
Saturday	4	19	15	61
Monday-Thursday	12	57	54	53
Friday-Sunday	9	43	46	31

Time

Accident statut	Site		Pop	Site>Pop
	Nb	%	(%)	
00h00-00h59	1	5	1	81
01h00-01h59	1	5	2	65
02h00-02h59	0	0	2	0
03h00-03h59	0	0	2	0
04h00-04h59	0	0	1	0
05h00-05h59	0	0	1	0
06h00-06h59	0	0	1	0
07h00-07h59	0	0	2	0
08h00-08h59	0	0	5	0
09h00-09h59	1	5	4	42
10h00-10h59	2	10	5	72
11h00-11h59	0	0	6	0
12h00-12h59	2	10	7	56
13h00-13h59	1	5	7	22
14h00-14h59	1	5	7	22
15h00-15h59	3	14	8	77
16h00-16h59	1	5	9	14
17h00-17h59	5	24	6	99
18h00-18h59	2	10	6	64
19h00-19h59	0	0	5	0
20h00-20h59	0	0	4	0
21h00-21h59	0	0	4	0
22h00-22h59	1	5	3	53
23h00-23h59	0	0	3	0
99	0	0	2	0
Peak hour: 07h00-08h59	0	0	7	0
Day: 09h00-14h59	7	33	35	36
Peak hour: 15h00-17h59	9	43	23	97
Evening: 18h00-22h59	3	14	20	18
Night: 00h00-06h59	2	10	13	22

Years

Accident statut	Site		Pop	Site>Pop
	Nb	%	(%)	
1997	6	29	20	77
1998	9	43	20	99
1999	6	29	20	77

Numbers of vehicles

Accident statut	Site		Pop	Site>Pop
	Nb	%	(%)	
1 vehicle	1	5	27	0
2 vehicles	20	95	69	100
3 or more vehicles	0	0	4	0

PHOTOS – 1995


Westbound.


Eastbound.


Southbound.

At intersection, towards left.


At intersection, straight ahead.

At intersection, towards right.

PHOTOS – 2000 (after the traffic signal installation)

Eastbound.

Southbound.

Restaurant access.

Truck at intersection.

CHAPTER 7
Priority ranking

Chris Baguley and Goff Jacobs

CHAPTER 7

Priority ranking

LIST OF FIGURES

LIST OF TABLES

7.1 INTRODUCTION

The two previous chapters have described how to identify road safety deficiencies and conduct safety diagnoses at these locations. It has been shown that the identification can be either pro-active or reactive in nature and that corrective measures may be targeted on blackspots, routes, area, or may consist of mass action *(Chapter 5)*.

The next important step is to set up a system for prioritizing the various treatments required. At the first level, it is necessary to establish the relative importance of pro-active and reactive measures and decide on the budget proportion that will be allocated to the correction of each category of reactive measures (blackspot correction, route improvement, etc.).

The second level for setting priorities is within each category of action. This provides a basis for the preliminary ranking of sites so that those most likely to be improved by engineering measures will be the first to be examined in greater detail.

The third priority-setting level is again within each category of action but takes place when the most suitable remedy has been identified for each site being investigated. These can be several non-related blackspots, a group of sites being considered for a mass action, or several routes or corridors assessed for possible route action plans. At this level, priorities are based primarily on the economic assessment of each scheme.

This chapter outlines the methods available to set priorities on the basis of a cost-benefit assessment, in addition to covering the main issues involved in an economic assessment of road improvement schemes. In this approach, the priority assessment and ranking of schemes are based on their expected costs and benefits. While costs (of construction and maintenance over the life of the project) are relatively easy to assess, benefits are primarily based on anticipated accident reductions.

Economic assessments are extremely useful when a range of schemes can be produced well in advance of their year of implementation. Decisions inevitably need to be made at the national or regional levels on the amount of funds available for road engineering work compared with other safety initiatives, such as publicity campaigns, education programs, etc. With limited financial resources, an annual budget needs to be devoted to road safety engineering improvements by giving careful consideration to how this sum is spent.

It could be argued that in order to make key decisions on resource allocations, an engineer or planner needs not only to assess the anticipated accident reductions, but also a number of political, social, and environmental issues. These might include public demand, public acceptance, road user needs (including pedestrians and cyclists), loss of amenity, fuel consumption, gas and noise pollution, etc. Prioritizing can thus become a rather complex process and multi-criteria methods have been developed to take into account this reality. However, the engineer normally has to start with a more objective economic evaluation in order to readily compare sites and countermeasures. This chapter focuses on the economic assessment of projects, although it must be noted that occasionally one or more of the above issues may override the economic argument.

Once the priorities have been ranked, the cut-off for implementation of schemes is necessarily governed by the available budget and the main accident reduction target *(Chapter 2)*. In other words, for the accident reduction target to be achieved or exceeded, it has to be matched in monetary terms by the planned expenditure.

7.2 STEPS - ACCIDENT REDUCTION PROGRAM

An ideal accident reduction program will include the following step:

1. **determination of a range of measures** that should prevent/reduce the dominant accident patterns. Methods have been described in ***Chapter 6*** to assist in this task;
2. **assessment of side effects.** Carefully consider whether these measures will have an adverse impact on other accident types and ensure that no unacceptable effects on traffic or the environment are likely;
3. **priority assessment - First and second levels** (i.e. non economic - see above);
4. **economic assessment of costs and benefits** for those projects identified at step 3;
5. **selection of measures yielding the greatest benefits;**
6. **organization of a public consultation** to ensure acceptance by the community and affected road users;
7. **preparation of a priority listing** of sites and development of action plans.

Thus, before the priority listing can be drawn up, it is best to have chosen the optimum package of measures for each particular site.

As we have already mentioned, additional factors may affect the actual implementation of schemes such that the original ranking of priorities is subsequently altered. For example, if major road intersection changes are planned at a particular site in the near future, it may be sensible to defer installation of the accident countermeasures or incorporate amendments to the responsible agency's plans.

7.3 ECONOMIC ASSESSMENT

This section presents the parameters that are required to conduct an economic assessment and describes the main decision criteria that can be used to make those assessments.

7.3.1 PARAMETERS

An economic assessment of projected remedial actions is important to ensure that the likely benefits will outweigh the cost of implementing and maintaining the scheme and that the best value for money is obtained. In order to carry out such an economic assessment, it is necessary to obtain the following information for each alternative improvement scheme:

1. initial cost (engineering and capital);
2. annual maintenance and operating costs;
3. terminal salvage value (if any);
4. service life of scheme;
5. best estimate of resulting accident changes (taking into account general trends: normal growth in accidents);
6. estimate of any side effects (e.g. increased fuel consumption), if applicable;
7. generally accepted monetary values for the different categories of road accidents;
8. discount rate used for schemes.

Each of these is briefly discussed below.

Initial cost (engineering and capital)

This is simply the project's capital cost to design and build the countermeasure. If the implementation is expected to span two or more financial years, an annual breakdown of expenditures is also required.

Annual maintenance and operating costs

The cost of the expected regular maintenance also needs to be estimated, if indeed this is necessary by virtue of the type of countermeasure taken. For example, simple curb line alterations will probably not require maintenance, whereas roundabouts may (particularly if their centre is landscaped) and traffic signals certainly will.

Terminal salvage value

Some countermeasures may have a residual value if they are removed. For example, an intersection may be temporarily equipped with traffic signals for a number of years until a by-pass is completed and, after completion, lower subsequent traffic flows may warrant the removal of the traffic signals. If it can be used elsewhere, the recovery of this cost should be taken into account. However, in most cases, any residual value is likely to be negligible.

Service life

For the economic assessment, it is also necessary to take account of how long the installation is likely to last; that is, before major rehabilitation or replacement is necessary.

Estimate of resulting accident changes

The benefits of road safety engineering schemes are usually expressed in terms of the monetary savings resulting from accident prevention or reduction (over a given number of years). The difficulty in estimating this, of course, arises from the uncertainty in accident occurrence and can only be based on previous experience. It is particularly helpful to engineers having to make such an economic assessment if a coordinated, nationwide database has been kept on the effectiveness of different types of accident countermeasures. An example of such a database in the UK is MOLASSES (Monitoring of Local Authority Safety Schemes). Results from some of the most common schemes are shown in Table 7-1 (Mackie, 1997). Note, however, that these results may well be UK-specific and it is important for countries to develop their own estimates of reductions following different types of treatment since accident reductions may differ.

However, if there is currently little or no data on which to base an estimate of the likely effectiveness of a treatment, in most cases an average reduction of approximately 25-33% of all accidents can conservatively be assumed. It should be noted that where costs and benefits cover more than one year, values must be discounted back to a "present value". The ***discount rate*** used should be that commonly used for national highway (and other public-sector) projects.

Estimate of any side effects

Some accident countermeasures will inevitably produce side effects on traffic movement that could be considered as adverse effects. For example, road closures require drivers to take alternative routes, and speed-reducing measures may increase travel time and fuel consumption. The additional costs incurred should be calculated and deducted from the benefits of the scheme.

Table 7-1 Percentage accident reductions for common treatment types (UK)

TREATMENT	NUMBER OF LOCATIONS	PERCENTAGE ACCIDENT REDUCTION "ALL"	"TARGET"
Priority intersection visibility	11	73	73
New mini-roundabout	6	71	81
Pedestrian facility anti-skid	7	71	33
Priority intersection geometry	14	69	76
Link/route anti-skid	13	68	53
Pedestrian refuges	17	68	71
Yield intersection right-turn lanes[a]	22	68	51
Yield intersection signing	7	68	84
Link/route signing	12	65	63
Curve curbing	21	61	88
Curve visibility	15	58	66
Link/route re-surfacing	16	57	72
Curve signing	14	57	70
Pedestrian barriers	6	54	100
Link lighting	6	53	56
Signal intersection, new pedestrian phase	5	53	100
New pelican crossing	25	48	58
New signal intersection	11	38	100
Link markings	20	29	64
Link/route signs and marking	21	27	94
TOTAL	269	53	73

Note: "All": all injury accidents at the treated sites.
"TARGET": only those injury accident types which the countermeasures were specifically aimed at reducing.
[a] Left-hand-side driving
Source: Mackie, 1997

Monetary values for different categories of road accidents

The benefits resulting over time from an engineering countermeasure are estimated by placing an economic value on accidents and applying this to the expected reduction in accidents. Values should not be derived on a project-by-project basis, but should be set at the national level by transport economists and updated annually.

Costs must be determined for accidents of varying levels of severity - usually fatal, serious, slight, and damage-only. These severity levels have to be carefully defined. In most countries:

- a fatal accident is one in which a person dies within 30 days of the accident;
- a serious accident is one in which there are no deaths, but at least one injured person is hospitalized or receives a specific injury, such as a fracture, internal injury, severe lacerations, etc.;
- a slight accident is one in which there are no deaths or persons seriously injured, but at least one person receives a minor injury such as a cut, sprain, or bruise;
- a damage-only accident is one in which no one is injured, but damage to vehicles or property is sustained.

Costs are always based on average values, and in some countries are also determined for broad road categories (e.g. urban, rural, freeway). For illustrative purposes, an example of costs by road category and accident severity for Great Britain in 2001 is shown in Table 7-2. Costs for a number of other developed countries are available from EC Cost 313 Report (Alfaro et al., 1994). It can be seen that costs increase from built-up roads to non-built-up roads to freeways, indicating the effect of greater speeds on accident severity levels. It can also be seen that there are, very approximately, ten-fold increases in costs between severity levels. That is, the cost of a slight accident is about ten times that of a damage-only accident, a serious accident is about ten times that of a slight accident and a fatal is about ten times that of a serious accident.

Table 7-2 Example – Average cost of road accidents (Great Britain, 2001)

	COST PER CASUALTY UK £ (US $)	COST PER ACCIDENT UK £ (US $)			
ACCIDENT TYPE	ALL ROADS	URBAN ROADS	RURAL ROADS	MOTORWAYS	ALL ROADS
FATAL	1,194,240 (1,731,648)	1,287,160 (1,866,382)	1,421,660 (2,061,407)	1,439,900 (2,087,855)	1,365,310 (1,979,700)
SERIOUS	134,190 (194,576)	151,910 (220,270)	176,920 (256,534)	186,110 (269,860)	160,850 (233,233)
SLIGHT	10,350 (15,008)	15,130 (21,939)	18,150 (26,318)	21,350 (30,958)	16,030 (23,244)
ALL INJURY	38,050 (55,173)	42,380 (61,451)	91,340 (132,443)	68,370 (99,137)	54,710 (79,330)
DAMAGE ONLY	– –	1,330 (1,929)	1,970 (2,857)	1,900 (2,755)	1,420 (2,059)

Source: Department for Transport, 2002

For the purpose of prioritizing actions aimed at reducing accident frequency, a single average cost for all injury accidents is generally considered sufficient, particularly in view of the difficulty in predicting the specific severities of accidents that might be prevented.

There have been many projects and considerable debate about the best way to determine accident costs (Hills and Jones-Lee, 1983, Alfaro et al., 1994, Jacobs, 1995), but it is now generally accepted that only two methods should be considered: the "willingness-to-pay" and the "human-capital" approaches. In general, most developed countries now use the willingness-to-pay approach, while the human-capital method is acceptable in developing countries – as long as sums are included to reflect the "pain, grief and suffering" involved in a road accident.

Andreassen (2001) has developed an approach for calculating costs of individual accident types in Australia (e.g. vehicle hits pedestrian; single vehicle on curve hits object – ***Chapter 5, table 5-4***) and for assessing countermeasures by applying estimated changes in specific accident types (target accidents) that are reduced by such countermeasures.

Although this approach may arguably produce more accurate cost estimates, it may not be a worthwhile endeavour in most countries in view of the uncertainty in predicting accident changes. In such cases, the average accident costs should be used in economic project assessments.

Indeed, if no widely accepted study of accident costs has been made, a country may have to use only a very approximate estimate. For example, an average injury accident cost could be obtained by dividing the total cost of accidents to the nation (which is likely to be between 1 and 2% of the Gross National Product (GNP)) by the total number of recorded accidents ***(Chapter 1)***.

Discount rate

In any economic road project assessment, it is important to identify a given base year from which all future costs and benefits can be assessed. Since sums accruing in the future are "worth less" than if they were received in the base year, they must be discounted back over a defined life of the project to a "present value". The relevant discount rate is that used nationally by government economists and need not be calculated by the road safety engineer. The application of discounting is discussed further in ***Section 7.3.2***.

7.3.2 ECONOMIC ASSESSMENT CRITERIA

As indicated above, the standard approach for the ranking of treatments is to carry out a cost-benefit analysis, i.e. to compare the estimated benefits of each scheme (in terms of the value of accidents that will be prevented) in relation to its costs (implementation, maintenance, others). The treatments are then prioritized in accordance with the best economic returns. As previously mentioned, estimating likely accident reductions resulting from remedial work is often difficult, because it can only be based on previous experience with similar schemes (Turner and Hall, 1994; Kulmala, 1994; Mackie, 1997). It should also be noted that most countries do not have an accurate, centralized accident database for property damage only, and thus the accident savings generally refer only to injury accidents. If there is no information available on the likely effects of any measures, perhaps the best way to proceed is to implement the least expensive schemes first, because they are likely to provide the greatest overall benefit. If the least expensive scheme proves to be ineffective in practice, then the alternative schemes could be tried in order of increasing cost.

Temporary materials should be used for initial trials wherever possible. For example, pre-cast concrete slabs could be tied together and pinned to the road surface to try out a particular size and position of splitter island before making a permanent, more expensive installation.

There are many very different methods of carrying out an economic assessment, but perhaps the most widely used in road schemes are:

- First Year Rate of Return (FYRR);
- Net Present Value (NPV);
- Net Present Value/ Present Value of Cost Ratio (NPV/PVC);
- Incremental Benefit-to-Cost Ratio (IBCR);
- Internal Rate of Return (IRR).

First year rate of return (FYRR)

This is simply the net monetary value of savings and drawbacks anticipated in the first year of the scheme expressed as a percentage of the total capital cost.

$$\text{FYRR}(\%) = \frac{\text{Benefits } (1^{st} \text{ year}) \times 100}{\text{Capital costs}} \qquad \text{[Eq. 7-1]}$$

where:

benefits = accident savings in monetary terms ± change in maintenance costs ± change in journey costs

N.B. the last two elements might be considered to be small, particularly for low-cost schemes, and are often ignored such that:

benefits = value of accident savings

This is not a rigorous evaluation criterion for prioritizing, since it ignores any benefits or changes in maintenance costs after the first year. However, it is very simple to calculate and given that road safety engineering schemes often produce first-year rates of return in excess of 100%, more sophisticated decision criteria may not be necessary. This method usually yields high values with low-cost schemes, but with relatively small accident savings.

Example – First year rate of return (FYRR)

Example: assume that a country has produced the road accident cost breakdown shown in Table 7-2. The average cost per accident is generally higher than the cost per casualty because, on average, there is more than one casualty in each accident. The average cost of an injury accident for 2001 has been calculated to be $79,330.

Now consider an intersection that had 12 injury accidents in 3 years, 9 of which involved right-angle collisions with drivers overshooting the stop line - this being the treatable group of accidents. Let us assume from past experience that the installation of a roundabout is likely to prevent two-thirds of these collisions. If the target FYRR for all schemes to be undertaken in the year in question has been set at 50%, then the maximum budget for the scheme may be calculated as:

$$\text{per cent FYRR} = \frac{\text{Annual Acc. Saving x 100}}{\text{Scheme cost}}$$

$$50 = \frac{\{(2/3) \text{ x } (9/3) \text{ x } 79{,}330\} \text{ x } 100}{\text{Scheme cost}}$$

$$\text{scheme cost} = \frac{158\ 660 \text{ x } 100}{50}$$

$$= \$317{,}320$$

In other words, the scheme should not cost more than $317, 320 in order to achieve a 50% rate of return.

In the above example, the First Year Rate of Return has been used to determine the maximum cost of the scheme if a 50% rate of return is to be achieved. If the scheme did in fact cost $200,000, then the First Year Rate of Return would be more than 50% (actually 79%). This method could then be used to rank alternative schemes in order of their First Year Rate of Return.

The First Year Rate of Return can also be used to assess the timing of a particular project by comparing it with the discount rate. If the First Year Rate of Return is greater than the discount rate, the project can, in theory, proceed. (This says nothing, however, of how it compares with other projects). If it is less than the discount rate, the project should, at the very least, be postponed.

More detailed assessments will be needed (see below) for schemes where traffic accidents and traffic levels are expected to change substantially from year to year. For example, a scheme with an 80% FYRR may not be worthwhile if subsequent road closures due to the construction of a new road limit the benefit to just one year.

Net present value (NPV)

This type of evaluation expresses (in a single amount) the difference between discounted costs and benefits of a scheme, which may extend over a number of years.

Unfortunately, it would be incorrect to assume that the benefit as stated above in year 1 can be summed to obtain the overall benefit over the life of the scheme. As stated earlier, future benefits must be adjusted or “discounted” before being summed to obtain a “present value”. Changes may also take place over the life of the scheme that affect benefits in future years.

Let us assume (for ease of calculation) that the current rate used by the government for highway schemes is 10%, which in the prevailing economic climate might be considered as somewhat high in most countries. This means that $100 in benefits accruing this year will be worth 10% less if it accrues next year. A further year’s delay will reduce the benefit again and so on. These figures can be summed over the life of the scheme to obtain the Present Value of Benefits (PVB).

Equation 7-2 is used to calculate discount factors and resulting values are shown in ***Table 7-A1*** and ***7-A2*** (cumulative discount factors) of Appendix 7-1.

$$\text{discount factor} = \frac{1}{(1+r)^n} \qquad \text{[Eq. 7-2]}$$

where:
r = discount rate
n = number of years

The overall economic worth or Net Present Value (NPV) of the scheme is then obtained by deducting the Present Value of Costs (PVC)[1]:

$$NPV = PVB - PVC \qquad \text{[Eq. 7-3]}$$

A scheme is only considered worthwhile if its NPV figure is positive.

Example – NPV assessment

Let us assume that the anticipated initial cost of redesigning an intersection will be $200,000 spread out equally over two years, with annual maintenance costs over the next 5 years (the life of the scheme) of $8,000. Assume the discount rate to be 10%.

As noted above, the benefits are always difficult to estimate and will often require an educated guess. In this example, let us assume, based on previous experience in similar circumstances, that 10 injury accidents over the first two years (5 per year) will be saved, and that this will drop to 3 per year afterwards due to changes in traffic. If the average cost of an injury accident is $79,330, as shown in Table 7-2, the total savings would amount to $396,650 in each of the first two years, followed by $237,990 in each of the remaining 3 years. The Net Present Value is calculated in Table 7-3 to be $852,002.

Table 7-3 Example – Costs and benefits at a treated site

YEAR (1)	DISCOUNT FACTOR (2)	COST ($) (3)	BENEFIT ($) (4)	NET COST (-) OR BENEFIT (+) ($) (5) = (4) - (3)	NET PRESENT VALUE OF COST (-) OR BENEFIT (+) ($) (6) = (5) X (2)
0	1.000	100,000		-100,000	-100,000
1	0.909	100,000		-100,000	-90,909
Installation complete					
2	0.826	8,000	396,650	+388,650	+ 321,198
3	0.751	8,000	396,650	+388,650	+ 291,998
4	0.683	8,000	237,990	+229,990	+ 157,086
5	0.621	8,000	237,990	+239,990	+ 142,806
6	0.564	8,000	237,990	+239,990	+ 129,823
Net Present Value (NPV):					+ 852,002

In other words, in this particular project (discounted) benefits exceed costs by more than $850,000. The project certainly appears to be worthwhile.

If the estimated benefits do not vary throughout the scheme, the calculation of NPV is simplified by the use of cumulated discount values, which are shown for various discount percentages in ***Table 7-A2*** For example, if the same benefit is repeated over a 5 year period and the discount rate is 10%, the cumulative discount rate is 3.79. Assuming that the value of the annual benefits is $50,000, the total net benefit is then:

$50,000 x 3.79 = $189,500

NPV can be calculated with the ***"Economic assessment"*** calculator: see ***Example – NPV***.

[1] These costs also have to be discounted if they are spread out over more than one year

With respect to implementation priorities, the economic criteria for scheme assessment using the NPV approach are:

- all schemes with a positive NPV are worthwhile in economic terms;
- for a particular site, the most worthwhile option is the one with the highest NPV.

Care needs to be taken in using the NPV as the only investment criterion since it tends to indicate projects with higher costs.

Net present value / Present value of cost ratio (NPV/PVC)

An interesting alternative to the NPV criteria is the Net Present Value (NPV) to Present Value of Costs (PVC) ratio. By dividing the NPV, as calculated above, by the sum of all discounted costs, the bias towards high-cost projects is eliminated. Projects can then be ranked according to their derived NPV/PVC ratio.

Example

Table 7-4 shows an example of a remedial works priority program ranked in terms of the scheme's NPV/PVC ratio for a 5-year period.

In this example, the NPV/PVC's site ranking is similar to the FYRR's ranking, but somewhat different from the one produced by the NPV.

Using this listing, a line can be drawn for a particular budget. Let us assume in this case a budget limit of $500,000. The full list of 10 sites could be implemented only with a budget of $683,700. The line indicating where the budget runs out is usually described as the **"cut-off" rate**.

This calculation can also be made with the ***"Economic assessment"*** calculator. The result is shown in Figure 7-1 ***(Example NPV/PVC)***.

Table 7-4 Example – Projects ranked by NPV/PVC

SCHEME	FYRR %	NPV (5YRS) $	PVC (5YRS) $	NPV / PVC
1	550	772,000	38,600	20.0
2	520	957,000	66,000	14.5
3	320	346,400	34,000	10.2
4	200	224,300	41,500	5.4
5	220	692,800	141,400	4.9
6	110	342,200	90,000	3.8
7	95	162,000	54,000	3.0
Discounted costs to here $465,500 (cut off rate = 3.0)				
8	100	190,400	68,000	2.8
9	68	122,000	64,200	1.9
10	85	129,000	86,000	1.5
Discounted costs for all schemes $683,700				

There may occasionally be two alternative ways of improving the road safety of a specific site (e.g. roundabout or traffic signals). Clearly, only one option is required, but the incremental NPV/PVC ratio can be used to make a decision. Consider the following example.

Example

Let us say that there are in fact two options for improvement, as follows. Option A corresponds to scheme 7 in Table 7-4 but option B is as shown in Table 7-5. The calculation of the NPV/PVC ratio is shown at the bottom of this table. The value of 1.1 can now be compared with the cut-off rate of 3.0 shown in Table 7-4. Although the more expensive scheme B has a higher NPV, its incremental value of 1.1 is well below the cut-off rate, which indicates that it is not justified. In other words, whatever sums are available for site improvement, any amount in excess of the value of option A would be better spent elsewhere.

Table 7-5 Example – NPV/PVC

	BENEFITS $	COSTS (PVC) $	NPV $
OPTION A	216,000	54,000	162,000
OPTION B	280,000	85,000	195,000

$$\frac{NVP}{PVC} = \frac{(NVP)_B - (NVP)_A}{(PVC)_B - (PVC)_A}$$

$$= \frac{195{,}000 - 162{,}000}{85{,}000 - 54{,}000} = 1.1$$

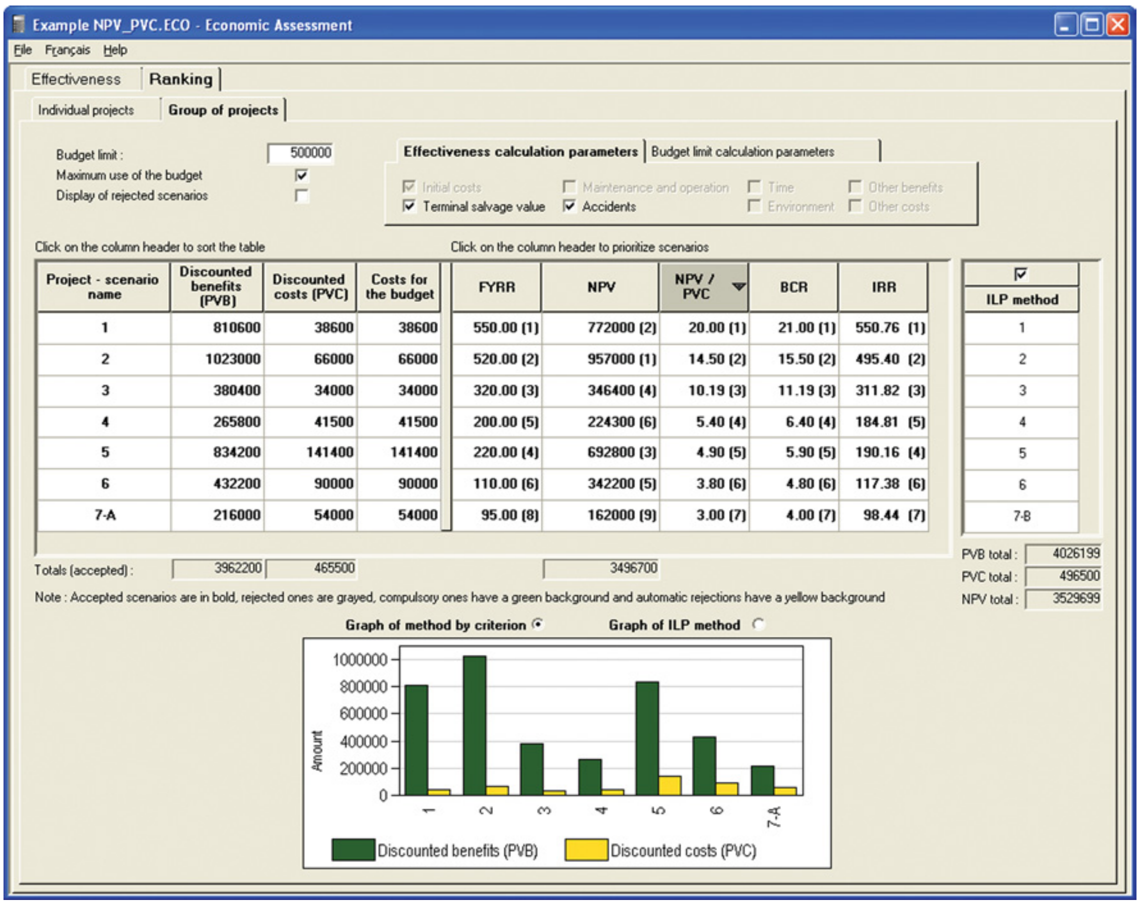
Integer linear programming method (ILP)

This criterion determines the combination of projects yielding the highest discounted benefits for a given budget. The result is obtained by using a computer program that completes a series of iterations on possible project combinations (FHWA, 1981).

Such a program has been included to the “Economic assessment” calculator (Figure 7-1).

[ECONOMIC ASSESSMENT]

Figure 7-1 Example – “Economic assessment” calculator



Incremental benefit-to-cost ratio (IBCR)

As indicated by its name, a benefit to cost ratio is obtained by dividing the discounted benefits of a project by its discounted costs: [Eq. 7-4]

$$BCR = PVB/PVC$$

And the incremental benefit-to-cost ratio involves ranking a pair-wise comparison of all alternatives with a BCR greater than 1 to determine the marginal benefit obtained for a marginal increment in cost. Thus, after eliminating all schemes with a BCR less than 1, the schemes are listed in order of ascending cost and the marginal benefit: cost ratio is determined by a pair-wise comparison of alternatives starting with the lowest and second-lowest cost alternatives. That is:

$$IBCR_{x/x+1,n,i} = \frac{PVB_{x+1,n,i} - PVB_{x,n,i}}{PVC_{x+1,n,i} - PVC_{x,n,i}} \qquad \text{[Eq. 7-5]}$$

where:

x et x + 1 : the lowest and next to lowest cost alternatives
n : service life of the scheme
i : discount rate
x/x + 1 : alternative x compared to alternative x + 1

If the IBCR is greater than 1, alternative x+1 is preferred, since the marginal benefit is greater than the marginal cost. Conversely, if the IBCR is less than 1, alternative x is preferred. The preferred option is then taken and the pair-wise comparison continued until only a single alternative remains, which should then be the most economically desirable of all the options considered.

However, Ogden (1996) concludes that the BCR approach is more cumbersome to use than the NPV approach and may produce more ambiguous and misleading results depending on how benefits and costs are defined. Thus, it is not recommended and the NPV/PVC approach is much preferred.

Internal rate of return (IRR)

Another important criteria used for assessing costs and benefits of highway schemes is the Internal Rate of Return. This is in effect the discount rate that makes the NPV equal to Zero or makes the Benefit/Cost ratio equal to 1.0 precisely. A theoretical example of how the discount rate affects the NPV of a project is shown in Figure 7-2 below.

At discount rates of 8% or 10%, the project has a positive NPV while it is negative at 12% or 14%. The NPV is zero at 11% discount rate, which is known as the internal rate of return (IRR). The IRR is preferred by multilateral aid agencies, such as the World Bank, because it avoids the use of local discount rates which, depending on their value, can significantly affect the NPV or NPV/PVC ratio. The IRR is not particularly useful for ranking projects, but is included for the sake of comprehensiveness.

Figure 7-2 Influence of the discount rate on NPV-calculated "theoretical" values

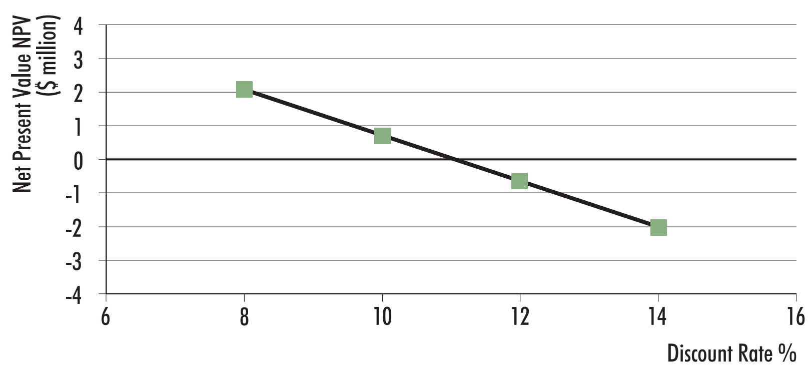


Table 7-6 describes summarily which decision criteria described above are the "best" to use under certain circumstances.

Table 7-6 Summary of the use of decision criteria

	NPV	IRR	NPV/PVC	FYRR
ECONOMIC VALIDITY OF PROJECT	good	good	good	poor
MUTUALLY-EXCLUSIVE PROJECTS	very good	poor	good[1]	poor
PROJECT TIMING	fair	poor	poor	good
ROBUSTNESS TO CHANGES IN ASSUMPTIONS	good	good	very good	poor
PROJECT SCREENING	poor	good	very good	poor
FOR USE WITH BUDGET CONSTRAINTS	fair[2]	poor	very good	poor

1 Needs incremental analysis
2 Needs continuous recalculations

7.4 OTHER FACTORS AFFECTING PRIORITY LISTING

It should be emphasized that the priority listing obtained by using one of the above criteria is not "the perfect answer" and other factors may come into play which affect the selection and ranking of those sites that should be treated. However, a well-grounded scheme appraisal may help to prevent emotional pressures from using up scarce resources without any other consideration. For example, if an authority is being pressured politically or otherwise to treat a site that is off this list or below the cut-off level, the table can be used to point out that resources should be focused on sites with the greatest potential benefits. This is, after all, more likely to yield the best contribution to the nation's casualty-reduction targets.

In some cases, a site may be at a location included in a major capital works program, such as a flyover or traffic signal installation. If the implementation schedule for the program is fairly close, it may be best to "do nothing" at this stage and incorporate the project into the major scheme. However, if the program is unlikely to be carried out within 2 or 3 years, short-term (perhaps lower-cost) measures are probably justified.

For this and other reasons (e.g. seasonal weather preventing certain road works) that may lead to "slippage" in timetables, it is always worthwhile to investigate more sites and to prepare more schemes than can be carried out in the current budget period to allow for these minor re-allocations of funds.

In practice, "easy" sites are normally best tackled first to yield cost-effective results as quickly as possible ***(Chapter 6).*** However, it is likely that the "harder" sites, which may require more staff resources to study extensively, will have high numbers of accidents. These sites should not be put on one side and simply ignored.

7.5 CONCLUSION

This chapter has described how projects can be ranked according to the relative costs and benefits of each scheme. All costs need to be discounted to a base year over an agreed time period (often 5 years for engineering improvement schemes at hazardous sites). Among the various ways of assessing costs and benefits, the NPV/PVC ratio is preferred, particularly when the objective is to rank schemes in order of priority.

It is important to appreciate that the assessment of sites for treatment should be a continuous process. For example, schemes not selected for immediate implementation, either because of a low or negative NPV or because of budget constraints, should be re-evaluated at a future date if there is reason to believe the situation has changed. An increase in accidents at a site would make a scheme with a negative NPV more attractive. Other changes may also occur, such as an increase in traffic volumes, etc.

What can be stated is that investment in low-cost engineering improvements at high-accident sites can yield extremely high rates of return. For example, for general highway improvement projects, such as road re-surfacing or realignment, first-year rates of return of 20-30% can be considered to be reasonably high, indicating projects well worth undertaking. However, low-cost improvements at high-accident sites can often produce first-year rates of return well in excess of 100%. A significant proportion of a national road safety budget should therefore be allocated to engineering improvement projects of specific sites, along corridors or within specific areas. Such an investment is likely to pay for itself many times over within the life of the project.

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APPENDIX 7-1

Tables of discount factors

Table 7-A1 Discount factors

YEAR	RATE (%) 5	6	7	8	9	10	11	12	13	14	15
1	0.952	0.943	0.935	0.926	0.917	0.909	0.901	0.893	0.885	0.877	0.870
2	0.907	0.890	0.873	0.857	0.842	0.826	0.812	0.797	0.783	0.769	0.756
3	0.864	0.840	0.816	0.794	0.722	0.751	0.731	0.712	0.693	0.675	0.658
4	0.823	0.792	0.763	0.735	0.708	0.683	0.659	0.636	0.613	0.592	0.572
5	0.784	0.747	0.713	0.681	0.650	0.621	0.593	0.567	0.543	0.519	0.497
6	0746	0.705	0.666	0.630	0.596	0.564	0.535	0.507	0.480	0.456	0.432
7	0.711	0.665	0.623	0.583	0.547	0.513	0.482	0.452	0.425	0.400	0.376
8	0.677	0.627	0582	0.540	0.502	0.467	0.434	0.404	0.376	0.351	0.327
9	0.645	0.592	0.544	0.500	0.460	0.424	0.391	0.361	0.333	0.308	0.284
10	0.614	0.558	0.508	0.463	0.422	0.386	0.352	0.322	0.295	0.270	0.247
11	0.585	0.527	0.475	0.429	0.388	0.350	0.317	0.287	0.261	0.237	0.215
12	0.557	0.497	0.444	0.397	0.356	0.319	0.286	0.257	0.231	0.208	0.187
13	0.530	0.469	0.415	0.368	0.326	0.290	0.258	0.299	0.204	0.182	0.163
14	0.505	0.442	0.388	0.340	0.299	0.263	0.232	0.205	0.181	0.160	0.141
15	0.481	0.417	0.362	0.315	0.275	0.239	0.209	0.183	0.160	0.140	0.123
16	0.458	0.394	0.339	0.292	0.252	0.218	0.188	0.163	0.141	0.123	0.107
17	0.436	0.371	0.317	0.270	0.231	0.198	0.170	0.146	0.125	0.108	0.093
18	0.416	0.350	0.296	0.250	0.212	0.180	0.153	0.130	0.111	0.095	0.081
19	0.396	0.331	0.277	0.232	0.194	0.164	0.138	0.116	0.098	0.083	0.070
20	0.377	0.312	0.258	0.215	0.178	0.149	0.124	0.104	0.087	0.073	0.061
21	0.359	0.294	0.242	0.199	0.164	0.135	0.112	0.093	0.077	0.064	0.053
22	0.342	0.278	0.226	0.184	0.150	0.123	0.101	0.083	0.068	0.056	0.046
23	0.326	0.262	0.211	0.170	0.138	0.112	0.091	0.074	0.060	0.049	0.040
24	0.310	0.247	0.197	0.158	0.126	0.102	0.082	0.066	0.053	0.043	0.035
25	0.295	0.233	0.184	0.146	0.116	0.092	0.074	0.059	0.047	0.038	0.030

Table 7-A2 Cumulative discount factors

YEAR	RATE (%) 5	6	7	8	9	10	11	12	13	14	15
1	0.9524	0.9434	0.9346	0.926	0.917	0.909	0.901	0.893	0.885	0.877	0.870
2	1.8594	1.8334	1.8080	1.783	1.759	1.736	1.713	1.690	1.668	1.647	1.626
3	2.7232	2.6730	2.6243	2.577	2.531	2.487	2.444	2.402	2.361	2.322	2.283
4	3.5460	3.4651	3.3872	3.312	3.240	3.170	3.102	3.037	2.974	2.914	2.855
5	4.3295	4.2124	4.1002	3.993	3.890	3.791	3.696	3.605	3.517	3.443	3.352
6	5.0757	4.9173	4.7665	4.623	4.486	4.355	4.231	4.111	3.998	3.889	3.784
7	5.7864	5.5824	5.3893	5.206	5.033	4.868	4.712	4.564	4.423	4.288	4.160
8	6.4632	6.2098	5.9713	5.747	5.535	5.335	5.146	4.968	4.799	4.639	4.487
9	7.1078	6.8017	6.5152	6.247	5.995	5.759	5.537	5.328	5.132	4.946	4.772
10	7.7217	7.3601	7.0236	6.710	6.418	6.145	5.889	5.650	5.426	5.216	5.019
11	8.3064	7.8869	7.4987	7.139	6.805	6.495	6.207	5.938	5.687	5.453	5.234
12	8.8633	8.3838	7.9427	7.536	7.161	6.814	6.492	6.194	5.918	5.660	5.421
13	9.3936	8.8527	8.3577	7.904	7.487	7.103	6.750	6.424	6.122	5.842	5.583
14	9.8986	9.2950	8.7455	8.244	7.786	7.367	6.982	6.628	6.302	6.002	5.724
15	10.379	9.7122	9.1079	8.559	8.061	7.606	7.191	6.811	6.462	6.142	5.847
16	10.838	10.106	9.4470	8.851	8.313	7.824	7.379	6.974	6.604	6.265	5.954
17	11.274	10.477	9.7630	9.122	8.544	8.022	7.549	7.120	6.729	6.373	6.047
18	11.690	10.828	10.059	9.372	8.756	8.201	7.702	7.250	6.840	6.467	6.128
19	12.085	11.158	10.336	9.604	8.950	8.365	7.839	7.366	6.938	6.550	6.198
20	12.462	11.470	10.594	9.818	9.129	8.514	7.963	7.469	7.025	6.623	6.259
21	12.821	11.764	10.836	10.017	9.292	8.649	8.075	7.562	7.102	6.687	6.312
22	13.163	12.042	11.061	10.201	9.442	8.772	8.176	7.645	7.170	6.743	6.359
23	13.489	12.303	11.272	10.371	9.580	8.883	8.266	7.718	7.230	6.792	6.399
24	13.799	12.550	11.469	10.529	9.707	8.985	8.348	7.784	7.283	6.835	6.434
25	14.094	12.783	11.654	10.675	9.823	9.077	8.422	7.843	7.330	6.873	6.464

CHAPTER 8
Evaluation

Chris Baguley and Goff Jacobs

CHAPTER 8

Evaluation

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8.1 INTRODUCTION

As explained in ***Chapter 2***, a comprehensive ***action plan*** is required to deal effectively with road safety problems in any country. Such a plan is likely to cost a substantial amount of money each year, and all road safety activities must therefore be monitored to ensure that investments are effective. As each initiative is implemented, the effectiveness of that measure should be monitored, ideally by analyzing accident data during specific "before" and "after" periods.

8.1.1 MONITORING NATIONAL TARGETS

With many changes taking place simultaneously, it may be difficult to tie specific accident reductions to specific improvements. However, this chapter will explain how changes taking place at the national level can be taken into account when assessing the effect of such things as low-cost engineering improvements at specific sites.

From an overall perspective, it is important to identify the impact of a national road safety action plan and to monitor the achievement of any goals that have been set. For example, in the 1980s, Great Britain set a national target: by the year 2000, casualties would be reduced by one-third from the average annual values prevailing from 1981 to 1985. Since then, national statistics have been carefully monitored in order to determine the impact of a wide range of remedial measures, including physical improvements, changes in legislation, etc. The overall effects are summarized in Table 8-1.

Table 8-1 Changes in casualties – Great Britain

SEVERITY	1981-85 AVERAGE	1999	PERCENTAGE CHANGE
FATAL	5,598	3,423	– 39.0
SERIOUS	74,534	39,122	– 47.5
SLIGHT	241,787	277,765	+ 15.0
TOTAL	321,919	320,310	– 0.5

The table shows that there have been significant reductions in fatal and serious casualties but an increase in slightly injured. What appears to have taken place in Britain over the last 15 years or so is a very noticeable reduction in the severity of injuries, with little change in the total number of casualties. More detailed analyses indicate changes on roads of different categories and between classes of road users. They also reveal that traffic has increased by over 50% since 1981-85 and that the overall casualty rate (casualties per million vehicle kilometers) has decreased by 37%.

8.1.2 MONITORING CHANGES IN DEVELOPING COUNTRIES

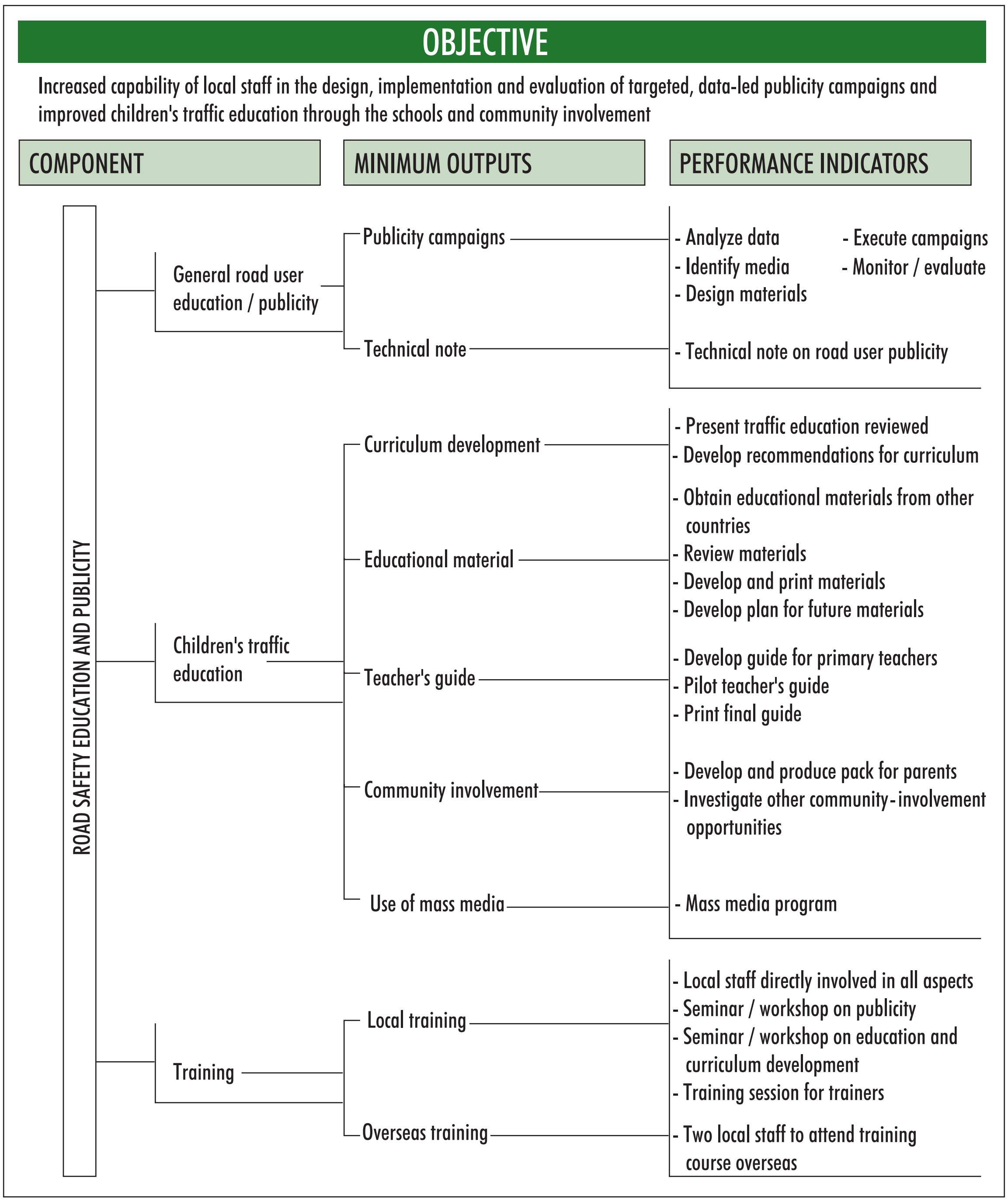
Since road safety programs use scarce financial resources, it is important in any country that they be properly monitored to ensure that they are effective in achieving objectives and reducing the numbers and severity of road accidents in the long term. This is particularly so in developing countries where comprehensive action plans have been developed fairly recently with limited funds from central governments and multilateral and bilateral aid agencies.

Action plans should set quantifiable targets for numbers (or rates) of accidents and casualties to enable assessment of program effectiveness. In addition to monitoring numbers of accidents and casualties, a newly established action plan should, possibly under the auspices of a ***National Road Safety Council*** (or equivalent), seek to ensure that progress is actually being maintained, in other words, that the various agencies and government departments concerned are actually implementing the improvements outlined in the plan.

Specific programs have been developed in various countries to do this, with each part of the action plan being provided with a clear objective, required outputs, and a series of performance indicators for each output. Road safety objectives can thus be assessed in terms of progress being made towards a minimum desired level of activity in that sector. This idealized framework then provides a "scoring frame of reference" against which actual performance can be evaluated.

For example, any action plan should include activities related to road safety education and publicity. Figure 8-1 shows what may be taken to be the component parts of this activity: the minimum outputs and the performance indicators. Progress relating to education and publicity can be assessed on a regular basis by referring to this figure.

Figure 8-1 Road safety education and publicity - Proposed framework for assessment



As stated above, such a framework should be developed for each part of the action plan.

8.2 OBSERVATIONS AND BEHAVIOURAL STUDIES

Once an authority has devoted considerable effort and expenditure to improving safety at hazardous sites, corridors or areas of a town or city, it needs to evaluate these improvements, particularly with respect to the fundamental safety indicator, i.e. accident occurrence. This is to ensure that the investment has been effective, and to learn from the successes and failures of the remedial work in order to influence future decisions on improvements. As discussed in Chapter 7, in most developed countries the monetary savings from the expected accident reduction are used to justify expenditures on the remedial measures. Since highway authorities are normally held accountable for their actions, they need to determine how well this objective has been met in order to demonstrate value for money.

This chapter therefore focuses on accident changes and describes simple statistical tests used to assess the results obtained. Unfortunately, a difficulty arises in considering accidents on their own, since these are random and relatively rare events at individual sites. It may therefore be necessary to wait several years after the countermeasure or package of measures has been introduced to validate the changes in accident statistics. It could be argued, however, that the safety engineer's duty is to ensure that the public is not subject to an increased hazard as a result of the scheme or schemes introduced. Thus, rather than wait for years to prove that the scheme is working as intended and that nothing has gone wrong, more immediate feedback may be required. Proxy measures for safety that might be used for monitoring the effectiveness of schemes are usually observational-type measurements, and these are briefly discussed in this section.

Thus, the evaluation process could be regarded as comprising two types:

- monitoring by observation-based methods (sections 8.2.1 and 8.2.2);
- accident-based evaluation ***(Section 8.3)***.

8.2.1 MONITORING BY OBSERVATIONS

The treated site, route or area should be observed immediately after completion of the construction work, and regular visits made in the following days, weeks or months until the team is satisfied that the scheme is operating as expected.

It is recommended that any earlier behavioural measurements made at the investigation stage (e.g. traffic conflict counts, speed measurements) be repeated, as this will lend weight to any argument for making further changes or, indeed, proving success. Some feature of a scheme may, for instance, produce an unforeseen reaction in drivers or riders, creating a potentially hazardous situation. Monitoring should highlight this problem at an early stage so that appropriate action can be taken quickly to remove this hazard.

At best, it may be possible to alleviate this hazard easily, for example, by realigning the curb lines to prevent a hazardous manoeuvre. At worst, it could lead to the complete withdrawal of a scheme and the need to reassess alternative schemes.

Effective monitoring is essential, if only to avoid the “bad publicity” that could result if a road safety scheme was seen to be actually causing accidents.

Recording the results of the monitoring measures is also important in order to build up a database of types of treatment and their effects, thereby providing information for future safety engineering work.

8.2.2 MONITORING BY MEANS OF BEHAVIOURAL STUDIES

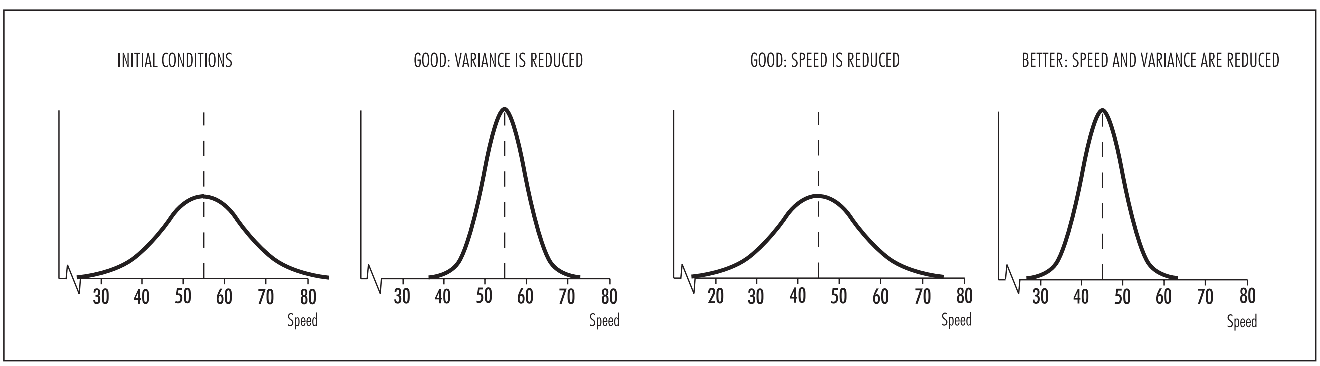
A before-and-after analysis is the technique usually used to monitor or measure the effect of a safety improvement. The most important measurement of success is, of course, whether the safety work has actually improved the accident situation. Such assessments are always required, and statistical evaluation methods will be discussed in ***Section 8.3.4*** and in ***Appendix 8-1***.

However, as indicated earlier, this process may take several years, and more immediate feedback is often required. Such feedback can be obtained by considering other factors that are likely to have a bearing on road users' safety at the treated site. By monitoring these factors, authorities should be able to determine if the countermeasures have produced the desired effect. While not exhaustive, the following list outlines such factors.

- spot speed
- speed variance
- traffic conflict studies
- traffic volumes
- travel time/delay
- compliance with traffic control devices
- skid resistance
- sight distance
- pedestrian safety (gaps, delays, crossing times)

The need to conduct speed, conflict, volume, and travel time studies are covered in following sections. Specific studies on pedestrian movements should also be undertaken if the accident records show that a high proportion of accidents involve pedestrians. Similarly, a high incidence of skidding under wet road conditions may indicate the need for specific studies on skid resistance (also associated at times with the use of limestone aggregate). In developing countries where road user behaviour is often poor, studies on driver behaviour at signals, pedestrian crossings, and uncontrolled intersections may also be worthwhile.

Figure 8-2 Positive effects of speed-related actions



The nature of the identified accident problems at the site should guide the choice of studies to be conducted. Table 8-2 provides indications in this respect.

Table 8-2 Studies that may be appropriate for particular accident problems

PREDOMINANT ACCIDENT TYPE	STUDIES				
	TRAFFIC COUNT	SPOT SPEED	TRAFFIC CONFLICTS	SKID RESISTANCE	ADDITIONAL
INTERSECTION					
Right angle/ Sideswipe	•	•	•		Obedience to control devices Sight distance Signal timing if signalized
Skidding/loss of control		•		•	Surface drainage
Darkness	•	•			Surface luminance Signing and delineator inventory
Pedestrians	•	•	•		Crossing flows Crossing times Safety gaps and delays
2-wheelers	•	•	•		Sight distance (other vehicles blocking)
Rear-end	•	•	•	•	Gap / headways Signal timing if signalized
NON-INTERSECTION					
Skidding/loss of control		•		•	Drainage
Darkness		•			Surface luminance Delineator inventory
Pedestrians	•	•	•		Pedestrian flows crossing and along sidewalks Frequency and position of crossings / median refuges
2-wheelers	•				Road width
Horizontal curve	•	•		•	Superelevation
Passing	•	•			Frequency and position of passing Passing sight distance
Rear-end	•	•	•	•	Gap / headways
Single-vehicle Run-off-road		•		•	Road inventory

It would be impractical to carry out detailed behavioural studies for all minor alterations, but such studies may be particularly important for expensive schemes such as area-wide or ***mass action*** treatments. It must be noted, however, that non-accident variables do not provide a direct measurement of the size of the safety improvement. There are, in practical terms, no variables for which the precise relation to accidents is certain. For example, a measured reduction in mean speed cannot be translated into an estimate for the number of accidents saved. This is a considerable drawback, because the measurement can only be said to give an indication of a change in safety. Nevertheless, objective measurements such as those discussed below are often considered worthwhile.

It is generally preferable to allow the scheme to operate for about two months before conducting a behavioural "after" study. This should serve as a "settling-in" period, during which regular users get used to a new road feature and any learning effects have largely disappeared.

Traffic speed

Speeding is frequently reported as being a major contributing factor in accidents (Vasco, 2000; Taylor et al., 2000), and there can be no disputing the fact that speeding reduces safety margins and the likelihood of escaping injury. If speed reduction is one of the objectives of the scheme, then speeds should obviously be monitored. Similar and appropriate locations should be carefully chosen for the before and after studies, preferably using automatic equipment.

The ***spot speed study*** in Part 4 of the manual describes how to measure speeds.

A ***t-test*** can be used to determine whether any changes in the measured mean speeds between two measurement periods are statistically significant or, indeed, whether there is a significant difference between the speeds of different vehicle types (e.g. passenger cars and trucks). Changes in the actual distribution of speeds following introduction of a speed-reducing measure can be tested with the ***Kolmogorov-Smirnov test***.

[SPOT SPEED STUDY] [T-TEST] [KOLMOGOROV-SMIRNOV TEST]

Traffic conflicts

Establishing the factors that lead to accidents at specific sites using accident data only is difficult due to low numbers and incomplete data or unreliable information. The traffic-conflict technique has been used successfully in several countries, and is a formalized method of observing a site using personnel trained to detect and record details of "near-miss" situations involving road users. Traffic conflicts are those events where there is a possibility of an accident, but where a collision does not occur because one or more of the parties involved take avoiding action.

Recording conflicts is generally only a practical method at intersections where, at the diagnostic stage, they can provide useful clues about why road users are failing to cope with an existing road layout. Conflict studies can also be a way of monitoring the location before and after introducing the remedial action.

The ***traffic conflict study*** in Part 4 of the manual describes how to observe traffic conflicts.

Traffic volumes

The collection of accurate traffic data is important when comparing accident sites. The traffic data needs to be compatible with the accident data (e.g. for the same period) and in sufficient detail to be appropriate for the particular evaluation. If a countermeasure is expected to affect manoeuvres at an intersection or drivers' choice of route in any other way, then traffic flow data should be collected throughout the local network before and after introducing the measure.

The number of vehicles and pedestrians passing through a site will provide useful information on the exposure to risk of the various road user groups. If, for example, significant proportions of cyclists and corresponding accident types have prompted the introduction of segregated cycle lanes, it will be important to monitor how well these are being used and whether they have attracted new cycle traffic.

The ***traffic count study***, in Part 4 of the manual describes how to conduct this study.

If an area-wide scheme has been introduced, it may also be advisable to expand the traffic survey to provide “origin and destination” information so that estimates of through traffic can be obtained to determine how drivers’ choice of route has been affected by the scheme.

Travel times

In some cases monitoring may require an estimate of changes in travel time for residents and through traffic by carrying out “origin and destination” travel time studies. This will be important where traffic severance forms part of the scheme, and traffic is being re-routed. In economic evaluations ***(Chapter 7)***, if the extra time lost due to re-routing is likely to be significant, then value-of-time considerations should be taken into account (as a disbenefit).

The ***travel time and delay study*** in Part 4 of the manual describes how to conduct this type of analysis.

Public perception

Often one of the main reasons for implementing an area-wide scheme is that residents may have campaigned strongly for something to be done. One of the most important parts of an area-wide scheme, therefore, is public consultation. Thus, one factor to monitor is how the residents and other road users feel about the safety elements of the scheme.

Ideally, public attitudes should be assessed before a scheme is implemented by mailing questionnaires to or conducting interviews with residents and interviewing road users in the treatment area. The public should, of course, be informed about the details of a proposed scheme, as well as its necessity and suitability, before its implementation. A similar survey should then be conducted several months after the scheme has been installed to monitor general and specific satisfaction (or dissatisfaction).

Effects on adjacent areas

Some schemes can affect adjacent areas, possibly leading to an increase in traffic speeds, volumes and accidents. Thus, it is important to monitor these factors carefully in all relevant areas adjacent to the road(s) where the scheme was introduced.

8.3 EVALUATION – ACCIDENT-BASED STUDIES

8.3.1 THE IMPACT ON ACCIDENTS

The most important form of evaluation of any safety measure is, of course, determining its effect on accidents, that is, whether the treatment has achieved its objective of reducing the number of accidents by the expected amount. Normally, the countermeasure package at a site will have been specifically designed to reduce the common patterns of accidents identified, that is, the target group of accidents (i.e. the group of accidents to be reduced). This therefore requires comparing the number of accidents in the target group before the treatment with the number after treatment (with the assumption that the original pattern of accidents would continue if nothing were done), and requires investigating whether any other accident type has increased.

However, to be reasonably sure that the random nature of accidents has been taken into account, it will normally be necessary to wait for several years for a valid result to be available. As mentioned earlier, more immediate feedback is often necessary and sometimes a shorter-term monitoring method may be applied ***(Section 8.3.3)***.

Apart from the time scale issue, there are other factors that complicate the (apparently straightforward) process of assessing the effectiveness of accident changes at hazardous sites, routes or areas. The main ones to consider are:

- regression-to-mean;
- accident migration;
- behavioural adaptation.

Each of these is discussed below.

8.3.2 FACTORS TO CONSIDER

Regression-to-mean

This effect complicates evaluations at high-accident locations. These sites have usually been chosen because they were the scene of numerous accidents in a particular year. However, accidents at these sites will tend to fall in the next year even if no treatment is applied. Even if 3-year accident periods are considered at the worst accident sites in an area, these accident frequencies were likely at the high end of naturally occurring random fluctuations, and in subsequent years these sites will experience lower numbers. This is known as regression-to-mean. This phenomenon is sometimes (incorrectly) described as ***"bias by selection"***. In fact,"bias by selection"may occur because of the "regression-to-mean effect".

As an example, consider ***Table 8-3***, which gives the actual numbers of recorded accidents involving personal injury for 122 sites in a particular town over a two-year period. For sites with 5 or more accidents in year 1, there were overall fewer accidents in the following year. Conversely, sites with 4 or fewer accidents had more accidents in year 2. If an accident countermeasure were taken at the 9 worst sites at the end of year 1, a highly significant reduction of 37% might be claimed after year 2, even though the measure might have been completely ineffective (this same result would be obtained by doing nothing). An even higher false result would be obtained if the other 113 (low-accident) sites were used as ***control sites*** since this group experienced an overall increase in accidents.

Table 8-3 Injury accidents at 122 intersections in a town

NO. OF INJURY ACCIDENTS PER SITE IN 1999	NO. OF SITES	TOTAL ACCIDENT NUMBER 1999	TOTAL ACCIDENT NUMBER 2000	CHANGE IN ACCIDENTS (UNCONTROLLED)
9-10	1	10	6	- 40%
7-8	2	15	10	- 33%
5-6	6	32	20	- 38%
3-4	17	61	68	+12%
0-2	96	76	119	+57%
TOTAL	122	194	223	

In practice, it is believed that the regression-to-mean effect can overstate the effect of a treatment by 5% to 30%. The most straightforward way of allowing for both the regression-to-mean effect and changes in the environment may be to use control sites chosen in exactly the same way as the treated sites and identified as having similar problems, but left untreated. In practice, as stated earlier, it is both difficult to find matched control sites and, if investigated, to justify not treating them.

There has been much debate among statisticians over many years on this subject and on how to deal with the problem (e.g. Abbess et al., 1981; Hauer and Byer, 1983; Wright and Boyle, 1987; Maher and Mountain, 1988; Kulmala, 1994; Radin Umar et al., 1995).

However, the effect does tend to diminish if considered over longer periods of time. For example, in a study conducted in two counties in the UK in 1981, Abbess et al. calculated that regression to the mean had the following effects, on average, on accident frequencies (Table 8-4) at high-accident sites (e.g. more than 8 injury accidents per year).

Table 8-4 Empirical regression-to-mean effects on accident rate

REGRESSION-TO-MEAN CHANGE IN ANNUAL ACCIDENT FREQUENCY	ACCIDENT PERIOD
15 to 26%	1 year
7 to 15%	2 years
5 to 11%	3 years

It is suggested, therefore, that where the highest accident sites are chosen for treatment, the above allowances should be made when calculating the actual reduction in accidents produced by the countermeasures. More accurate estimates can be obtained, using data from sites similar to the treated sites. A method described by Abbess et al. (1981) is outlined in ***Appendix 8-1***. The « *regression-to-mean*» calculator is based on this method.

[REGRESSION TO MEAN]

Accident migration

There is still some controversy over whether or not this effect actually exists, but some researchers contend that it is real (Boyle et al., 1984; Persaud, 1987). It is simply that accidents tend to increase at sites adjoining a successfully treated site, producing an apparent accident transfer or “migration”. Why this effect occurs is unclear, but the hypothesis is that drivers are “compensating” for the improved safety at treated sites by being less cautious elsewhere.

Obviously, to detect such an occurrence, one needs to compare the accident frequencies in the surrounding area of the treated sites before and after treatment with a suitable control group.

However, there are no established techniques yet available to estimate such an effect for a particular site. The first reported occurrence of this feature (Boyle et al., 1984) found an overall increase in the surrounding areas of about 9% and a later study (Persaud, 1987) of a larger number of sites estimated the increase at 0.2 accidents/site/year.

Behavioural adaptation

This is an even more controversial effect, though related to the previous section. The philosophy of "risk compensation" or "risk homeostasis" theory suggests that road users will change their risk-taking behaviour to compensate for any improvements in road safety. The early theory developed by Wilde (1978) proposed that road users tend to maintain a fixed level of accepted risk, so will take more risks when given greater accident protection, such as seat belts or anti-lock brakes.

Once again, the extent of this effect is extremely difficult to monitor, but an engineer should be aware of potential behavioural adaptation when introducing countermeasures. For example, pedestrians' right-of-way enhancements with raised sections of road known as speed tables or raised pedestrian crossings (which give the impression of extending the sidewalk) may lead pedestrians into taking less care when crossing the road. However, it is generally believed that the evidence that behavioural adaptation will seriously reduce the effectiveness of safety measures is weak, and poses little threat to current road safety practice.

For further reading on this subject, see references (Adams, 1985; Mountain, 1992; Grayson, 1996).

8.3.3 GRAPHICAL ANALYSES

A simple visual method that has been used in some countries (e.g. Radin Umar et al., 1995) is to monitor the trend in accidents over time. In this method, the cumulative accident numbers (and types) are plotted together with their cumulative mean (see definitions below).

However, it should be noted that this is more useful for mass-action plans and not really suitable for single sites (due to the lower numbers of accidents involved).

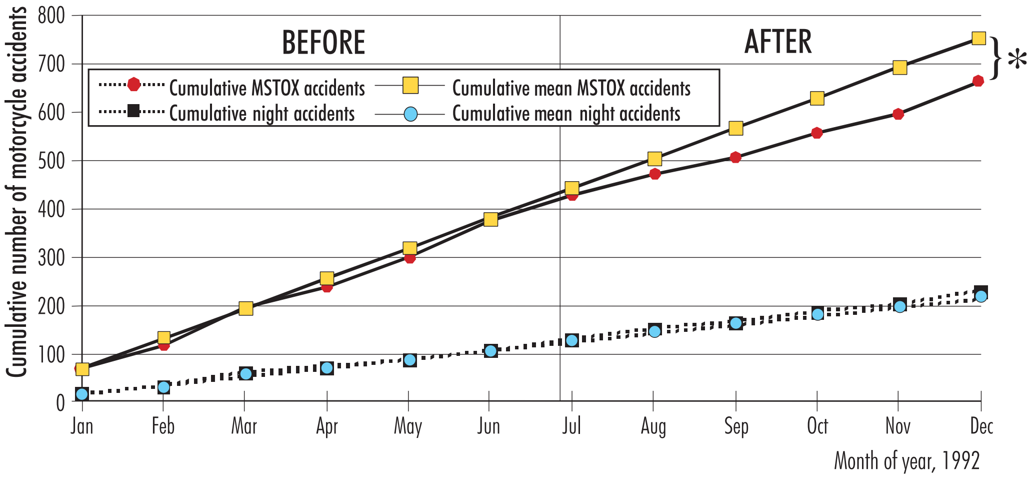
An example is shown in ***Figure 8-3***, where the graph illustrates that a Malaysian motorcycle daytime running headlight campaign was apparently effective in reducing accidents related to daytime conspicuity (MSTOX = motorcycles moving straight or turning when other road users cross their path) while, as might be expected, having no effect on nighttime accidents.

The table in ***Figure 8-3*** shows the monthly cumulative frequency of related accidents in the second row, which totals the actual number of accidents six months before and after the measure (end of June). The cumulative mean (third row of the table) is obtained by simply calculating the average monthly accident frequency over the before period (in this case 6 months) as the first month and then adding this figure onto each subsequent month. This is the number of accidents that one would have expected, had the measure not been taken. Lines 5 and 6 of this table show an equivalent number for night accidents. In this case, the cumulative means are:

For MSTOX accidents: (68 + 48 + 79 + 44 + 61 + 73) / 6 = 62
For nighttime accidents: (17 + 16 + 28 + 11 + 15 + 20) / 6 = 18

It can be seen that during the after period (July to December), there is an increasing gap between the observed number of daytime accidents (second row) and the expected number of accidents (third row). Since the expected number of accidents is larger than the observed number, the measure is seen to have had a positive effect. The (✻) sign in ***Figure 8-3*** represents the effect of the measure. In comparison, the observed and expected number of night accidents remain quite similar in the after period.

Figure 8-3 Example – Motorcycle accidents in pilot areas of “running headlight” campaign



COLLISION TYPE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MSTOX daytime accidents	68	48	79	44	61	73	53	43	38	49	40	68
Cumulative MSTOX accs.	68	116	195	239	300	373	426	469	507	556	596	664
Cumulative Mean MSTOX accs.	62	124	187	249	311	373	435	497	560	622	684	746
All m/c Nighttime accidents	17	16	28	11	15	20	23	13	13	21	17	26
Cumulative Night accs.	17	33	61	72	87	107	130	143	156	177	194	220
Cumulative Mean Night accs.	18	36	54	71	89	107	125	143	161	178	196	214

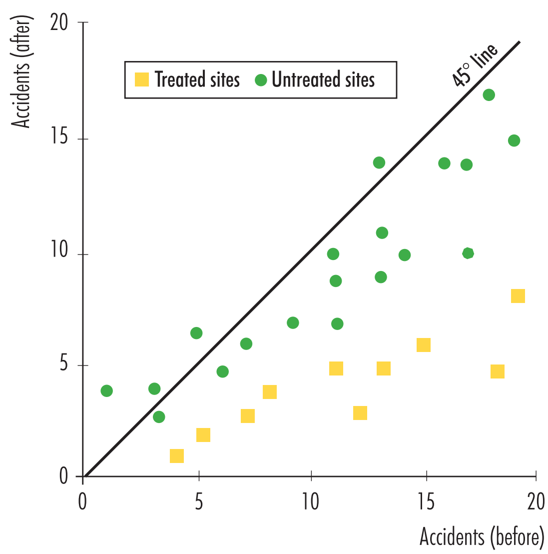
Note: MSTOX = m/c moving straight or turning when other road users crossed their path.

However, as already stated, to be sure that the random nature of accidents has been taken into account, a much longer waiting period is normally required (usually three years) for a statistically valid result to be available. For more immediate feedback, other behavioural data, as mentioned in the previous sections, should be collected to give indications that a scheme is working as intended.

Where control sites (or similar untreated sites) have been selected, another simple exploratory method for displaying the change in accidents at several treated sites has been described by Ogden (1996). For each site in both the control and treated groups, accidents in the before period and after period (of the same length) are plotted as shown in Figure 8-4. If there was no change in the number of accidents between the two periods, then all the points would lie around a 45-degree line. The extent to which there is a change in accidents in the after period is indicated by the departure from the 45° line.

If, as in Figure 8-4, the treated sites are trending markedly below the untreated sites, then it is suggested that the treatment is having a positive effect.

Figure 8-4 Comparison of accident data before and after treatment



Source: Ogden, 1996

8.3.4 STATISTICAL EVALUATION

In evaluating a particular treatment, the answers to the following questions will usually be required:

- has the treatment been effective?
- if so, how effective has it been?

(It is assumed that the user of this manual will only be required to interpret accident data practically, without necessarily having a full understanding of the underlying statistical theory).

The rare and random nature of road accidents can lead to fairly large fluctuations in frequencies at a site from year to year, even though there has been no change in the underlying ***safety level***. This extra variability makes the effect of the treatment more difficult to detect, but a test of statistical significance can be used to determine whether the observed change in accident frequency is likely to have occurred by chance or not.

When evaluating changes in accidents (and, indeed, strictly for most of the monitoring measures described in ***Section 8.2***), other factors not affected by the treatment, and which might also influence that measure, have to be taken into account. Examples include a change in the speed limit on roads that include the site; national or local road safety campaigns; traffic management schemes that might affect volumes of traffic: e.g. closure of an intersection near the site, producing a marked change in traffic patterns.

These features can be taken into account by using control site data, but in order for this to be valid, it is important that these other sites experience exactly the same changes as the site under evaluation.

Control sites

Changes related to external factors may be compensated for by comparing the site under study, for the same before and after periods, with "control sites" that have not been treated. Control data can be collected either by matched pairs or area controls.

A matched pair control site involves finding a site that is geographically close to the treated site (but not close enough to be affected by any traffic diversion), and has similar general characteristics. This is so that the control will be subject to the same local variations, that might affect safety (e.g. weather, traffic flows, and safety campaigns, etc.).

Although the matched pair is the best statistical method, in practice it may be difficult to find other sites with similar safety problems that will be left untreated purely for the sake of statistical tests. Area controls comprising a large number of sites are, therefore, much more frequently used.

When choosing sites for control groups:

- they should be as similar as possible to treated sites;
- they should not be affected by the treatment;
- the control area should be as large as is reasonable: as a guide, try to find a similar area or group of roads that have more than 10 times the number of accidents than the treated sites have.

For example, if the traffic signals at a site are to be modified, the engineer could choose all the other signalized intersections in town as the control group. If, however, there are only two other signalized intersections, and these had lower flows and much fewer accidents than others uncontrolled intersections, it would be better to use, for example, all signalized intersections in the state/county.

This manual does not attempt to describe in detail all the different statistical techniques available but suggests practical and simple ways in which schemes can be evaluated. The following sections generally refer to "a site", but the same techniques can be used for mass, route and area-wide action, as long as appropriate control groups are chosen.

The main problem with using accident data for evaluation (even assuming high recording accuracy) is distinguishing between a change due to treatment and that due to other sources. As explained earlier, even if the selected sites are good control groups, that take into account the environmental influences, there are other confounding factors that needs to be considered.

Before and after periods

There are a number of points to take into account when choosing time periods used to compare accidents taking place before and after treatment:

- the before and after periods at the treated site and at the control sites should be identical;
- the construction period should be omitted from the study. If this period was not recorded precisely, a longer period containing the installation period should be excluded;
- the before period should be long enough to provide a good statistical estimate of the true ***safety level*** (to eliminate random fluctuations as much as possible). It should not, however, include periods during which the site had different characteristics. As a general rule, three years is widely regarded as a reasonable period;
- the same rule applies to the after period, which ideally should also be three years. However, results are often required much sooner than this. A one-year after period can initially be used if there is no reason why this should bias the result (as long as the same period is used at the control sites). However, sensitivity is lost, and the estimate of the countermeasure's success should be updated later when more data become available.

Standard tests on changes in accidents

Clearly, this section of the manual cannot deal with the complex principles underlying the various statistical tests that can be used in accident investigations and for this the reader should refer to standard manuals on the subject. However, this chapter does cover, albeit briefly, various statistical tests that can be used to answer the key questions posed at the beginning of this section, i.e. has the treatment been effective and, if so, how effective has it been?

For this purpose it is sufficient to assume that the before and after accidents are drawn from a normal (or Gaussian) distribution. In other words, the distribution of accidents in a sample is symmetrically drawn from either side of a mean value.

This means that we can use the "Chi-square" test to answer the first question as to whether the remedial action has been effective, i.e. whether the accident changes at the site are statistically significant. If the same type of remedial treatment has been carried out at many sites, an additional calculation is required in order to determine the overall effect.

Appendix 8-1 presents a brief description of some of the main statistical tests associated with transport project evaluation. ***Table 8-5*** provides a list of these tests and their condition of use.

Table 8-5 Statistical tests described in Appendix 8-1

TEST	DESCRIPTION
1. STUDENT (t-TEST)	Used to determine whether the mean of one set of measurements is significantly different from another set.
2. KOLMOGOROV-SMIRNOV	This ''two-tailed'' test determines whether two independent samples have been drawn from the same population (or from populations with the same distribution).
3. k	This calculation is used to show how a number of events at a particular site (accidents for example), has changed relative to a set of control data.
4. CHI-SQUARE	This calculation used to determine whether a given change (in accidents for example) was produced by a given treatment or whether the change may have occurred by chance.

8.4 ECONOMIC EVALUATION

As described in ***Chapter 7***, for every scheme the evaluation should include an indication of the benefits actually achieved in relation to cost. Even if the scheme has been designed to tackle a very specific target group of accidents, it is normal practice to include all accidents at the site in a full evaluation – just in case the measure has had an unforeseen effect on other accident types.

Appendix 8-1 describes how the accident impact of a specific road improvement can best be estimated. Suppose that the estimated reduction was 68% (this is the result obtained in the example of Appendix 8-1 – ***k-test***). If the site was one of the worst in the district, then we ought to make some allowance for the regression-to-mean effect (e.g. ***Table 8-4***). Let us assume this amounts to as much as 11%, such that our best estimate of the true reduction in accidents is 57% (68% - 11%).

Since the original number of accidents in this example was 20, 11.4 accidents have been saved over the study period (or 3.8 accidents per year).

It should be noted that only injury accidents have been considered here but if there are a number of damage-only accidents occurring that are reliably reported, then these should also be included in the costing. However, it must be stressed that in most countries of the world, damage-only accidents are frequently not reported to the police and are thus a much more unreliable measure.

Based on an average injury-accident cost of $79,330 that has been used in the examples of the previous chapter, this accident saving amounts to $301,454 per year. This figure is then compared to treatment costs, i.e. $298,000. Assuming traffic delays due to the treatment are negligible, the First Year Rate of Return (FYRR) equals:

$$\text{FYRR} = 301{,}454/298{,}000 \times 100 = 101.2\%$$

The above FYRR figure should be rounded down to 101% to give an indication of the possible effect of using this treatment in the future.

Other economic criteria that have been described in the previous chapter could also be used. For example, the calculation of the Net present value (NPV) figures would be particularly advisable if, over future years, there are known to be inevitable new maintenance costs associated with the installed measure.

It is only by evaluating and recording results in this way that a database of implemented remedial measures and their effectiveness can be assimilated for use by road authorities throughout the country.

8.5 OVERALL EFFECTIVENESS AND FUTURE STRATEGY

This chapter has set out methods that can be used for evaluating the effects of specific schemes. One way of publicizing these results is for the road safety unit within a highway authority to produce a regular strategy document that outlines its main road safety achievements as well as the projected work.

A summary of this document should be included in the official road safety action plan of a country. This plan also includes, as background information, aggregate accident statistics by state, district, or municipality, broken down into various categories, such as road user class, road class, etc. These aggregate figures can be useful not only to indicate general priorities, but also to evaluate the effects of wide-scale safety campaigns, as well as legislative and/or enforcement changes.

However, as schemes are usually localized, their effects are often difficult to detect among much larger accident totals. Hence, the strategy document should probably include a summary listing of the effectiveness of all low-cost schemes (e.g. Table 8-6). This is more informative than a single overall figure as it displays the range of safety efforts taking place and the relative success of the various actions. The official publication of past achievements and future plans has been found useful not only in making the highway authority's road safety team accountable, but also in helping the team focus its efforts on a long-term casualty-reduction target. The document also provides valuable information to other workers, giving real evidence of the extent to which schemes are successful.

Table 8-6 Example report of local safety schemes from a strategy document

SCHEME LOCATION	NO. OF ACCIDENTS IN 3-YEARS PERIOD BEFORE SCHEME IMPL.	DATE OF IMPL.	COST (£)	ECONOMIC RATES OF RETURNS		NO. OF ACCIDENTS IN 3-YEARS PERIOD AFTER SCHEME IMPL.	NET SAVING IN ACCIDENT COSTS TO DATE (£)
				ANTICIPATED FYRR	ACTUAL RR SINCE IMPL. (3 YRS.)		
C111 BROADWAY/SHEEP DIP LANE, DUNSCROFT	8	Feb Yr1	7,218	146%	1,066%	2	660,115
A630 WARMSWORTH Rf/BARRELL	16	Jan Yr2	12,000	205%	1,283%	4	966,413
C765 GRANGE LANE/QUEEN MARY'S RD, ROSSINGTON	7	Feb Yr2	1,322	1,113%	4,854%	2	407,205
A630 TRAFFORD WAY	13	Feb Yr2	14,000	137%	825%	4	561,896
A6023 MEXBROUGH RELIEF RD/STATION RD	12	Feb Yr2	4,050	540%	3,168%	2	778,783
A638/LEISURE CENTRE ROUNDABOUT	10	Apr Yr3	1,100	504%	7,000%	4	338,983
A638/A18/C444 RACE-COURSE ROUNDABOUT (TEMP.)	27	Aug Yr3	3,000	11,170%	3,293%	15 (28mnths)	228,000
B1220 CHURCH LANE/ADWICK LANE, ADWICK-LE-STREET	12	Oct Yr3	4,485	426%	2,289%	4	332,390
A638 GREAT NORTH RD (BAWTRY CARAVANS)	8	Nov Yr3	3,360	723%	382%	7	69,020
C445 THOME RD/C676 TOWN MOOR AVENUE	8	Dec Yr3	4,000	450%	- 329%	9	- 21,666
GOODISON BOULEVARD, CANTLEY	3	Jan Yr4	1,530	395%	1,678%	0	10,890
A631 TICKHILL RD, BAWTRY	5	Mar Yr4	1,360	720%	3,775%	1	200,675

Abbreviations: FYRR = First Year Rate of Return; RR = Rate of Return; Impl. = implementation

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Appendix 8-1

Statistical tests

STUDENT'S t-TEST - COMPARISON OF SAMPLE MEANS

(e.g. sets of speed measurements)

To determine whether the mean speed of a set of speed measurements is significantly different from another (i.e. between a *before* and *after* study), it is appropriate to use Student's two-tailed t-test, making the reasonable assumptions that the variances of the two sets of measurements are drawn from the same population. The null hypothesis is thus that there is no difference in the means (i.e. that drivers' speed has not been affected by the scheme). It is first necessary to determine the standard deviation of the difference in means. We then calculate the equations below:

$$t = \frac{\bar{a} - \bar{b}}{\sigma} \sqrt{\frac{n_a \times n_b}{n_a + n_b}} \qquad \text{[Eq. 8-1]}$$

where:

$$\bar{a} = \frac{\sum(a_i)}{n_a} \qquad \bar{b} = \frac{\sum(b_i)}{n_b}$$

$$\sigma = \sqrt{\frac{\sum\left(a_i^2\right) - \frac{\left(\sum(a_i)\right)^2}{n_a} + \sum\left(b_i^2\right) - \frac{\left(\sum(b_i)\right)^2}{n_b}}{(n_a + n_b - 2)}}$$

$b_1, b_2, \ldots\ldots b_{nb}$ = *before* speed readings
$a_1, a_2, \ldots\ldots a_{na}$ = *after* speed readings
n_b = number of *before* readings
n_a = number of *after* readings

Having calculated the value of t, we need to look at a table of Student's t values (***Table 8-A1***) with $(n_a + n_b - 2)$ degrees of freedom (υ). If the calculated value of t exceeds that for the 5% level (the $t = 0.05$ column), we can be 95% confident that the true mean speed has changed.

Example

Assume that the following results were obtained from spot speed studies:

before a scheme		after a scheme	
n_b	= 210	n_a	= 220
$\bar{b}$	= 37 km/h	$\bar{a}$	= 33 km/h
$\sum b_i$	= 7,770	$\sum a_i$	= 7,260
$\sum (b_i)^2$	= 291,142	$\sum (a_i)^2$	= 243,760

From equation 8-1:

$$\sigma = \sqrt{\frac{243{,}760 - (7{,}260)^2/220 + 291{,}142 - (7{,}770)^2/210}{220 + 210 - 2}} \qquad \sigma = 4.278$$

$$t = \frac{33 - 37}{4.278} \sqrt{\frac{220 \times 210}{220 + 210}} \qquad t = 9.692$$

$$\upsilon = 220 + 210 - 2 \qquad \upsilon = 428$$

As the calculated t value (9.69) is greater than 1.96 (large number of degrees of freedom), we can say that the difference in mean speeds (a 4 km/h reduction) is significant at the 5% level.

This test can be conducted with the t-test calculator **[t-TEST]**.

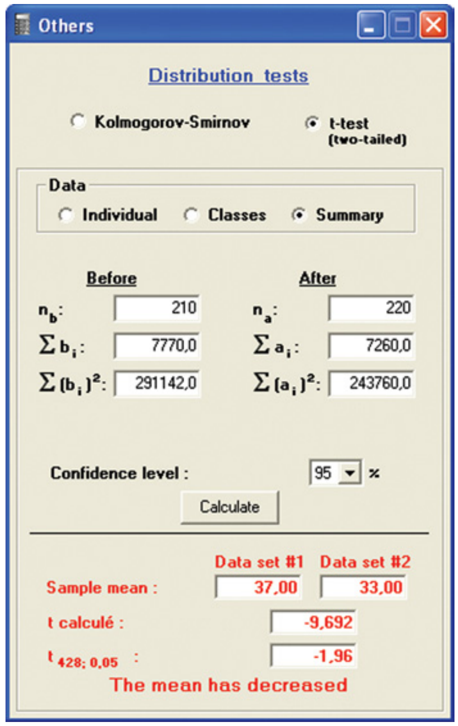


Table 8-A1 Table of *t*-distribution

DEGREES OF FREEDOM	*t*				
	0.10	0.05	0.02	0.01	0.001
1	6.314	1.706	31.821	63.657	636.619
2	2.920	4.303	6.965	9.925	31.598
3	2.353	3.182	4.541	5.841	12.941
4	2.132	2.776	3.747	4.604	8.610
5	2.015	2.571	3.365	4.032	6.859
6	1.943	2.447	3.143	3.707	5.959
7	1.895	2.365	2.998	3.499	5.405
8	1.860	2.306	2.896	3.355	5.041
9	1.833	2.262	2.821	3.250	4.781
10	1.812	2.228	2.764	3.169	4.587
11	1.796	2.201	2.718	3.106	4.437
12	1.782	2.179	2.681	3.055	4.318
13	1.771	2.160	2.650	3.012	4.221
14	1.761	2.145	2.624	2.977	4.140
15	1.753	2.131	2.602	2.947	4.073
16	1.746	2.120	2.583	2.921	4.015
17	1.740	2.110	2.567	2.898	3.965
18	1.734	2.101	2.552	2.878	3.922
19	1.729	2.093	2.539	2.861	3.883
20	1.725	2.086	2.528	2.845	3.850
30	1.697	2.042	2.457	2.750	3.646
40	1.684	2.021	2.423	2.704	3.551
60	1.671	2.000	2.390	2.660	3.460
120	1.658	1.980	2.358	2.617	3.373
∞	1.645	1.960	2.326	2.576	3.291

KOLMOGOROV-SMIRNOV TEST

The “two-tailed” test determines whether two independent samples have been drawn from the same population (or from populations with the same distribution). In some cases, two data sets may have the same mean but different dispersion, which may be the cause of safety problems. If the two samples have in fact been drawn from the same population (the null hypothesis), then the cumulative distributions of both samples may be expected to be fairly close to each other, i.e. they should show only random deviation from the population distributions. If the two sample cumulative distributions are too far apart at any point, this suggests that they come from different populations. Thus, a large enough deviation between the two sample cumulative distributions is evidence for rejecting the null hypothesis.

Let $S_{Na}(x)$ be the observed cumulative step function of the first speed sample: i.e. $S_{Na}(x) = K/N_a$ where K is the number of vehicles equal to or less than x km/h and N_a is the total number of vehicles of the sample. Let $S_{Nb}(x)$ be the cumulative step function of the second sample. Now the Kolmogorov-Smirnov two-tail test focuses on the maximum deviation, D.

$$D = \text{maximum } |S_{Na}(x) - S_{Nb}(x)| \qquad \text{[Eq. 8-A2]}$$

For large samples ($N > 40$), Kolmogorov-Smirnov tables show that the value of D must equal or exceed the following value to reject the null hypothesis at the 5% level, i.e. they are not from the same population:

$$1.36 \times \sqrt{\frac{N_a + N_b}{N_a\, N_b}} \qquad \text{[Eq. 8-A3]}$$

The “one-tailed” test determines whether the two samples have been drawn from the same population or whether the values of one sample are stochastically larger than the values of the population from which the other sample was drawn. The maximum deviation is again calculated using equation (Eq. 8-A2) and the significance of the observed value of D can be computed by reference to the chi-square distribution.

It has been shown that for large samples, the following statistic has a sampling distribution that is approximated to the chi-square distribution with two degrees of freedom. The chi-square table is given in ***Table 8-A2***.

$$\chi^2 = 4D^2 \frac{N_a\, N_b}{N_a + N_b} \qquad \text{[Eq. 8-A4]}$$

[KOLMOGOROV-SMIRNOV TEST]

Table 8-A2 Table of χ^2

DEGREES OF FREEDOM υ	0.99	0.98	0.95	0.90	0.50	0.10	0.05	0.02	0.01	0.001
1	0.000	0.001	0.004	0.015	0.455	2.710	3.840	5.410	6.640	10.830
2	0.020	0.040	0.103	0.211	1.386	4.610	5.990	7.820	9.210	13.820
3	0.115	0.285	0.352	0.584	2.366	6.250	7.820	9.840	11.340	16.270
4	0.297	0.429	0.711	1.064	3.357	7.780	9.490	11.670	13.280	18.470
5	0.554	0.752	1.145	1.610	4.351	9.240	11.070	13.390	15.090	20.520
6	0.872	1.134	1.635	2.204	5.350	10.650	12.590	15.030	16.810	22.460
7	1.239	1.564	2.167	2.833	6.350	12.020	14.070	16.620	18.480	24.320
8	1.646	2.032	2.733	3.490	7.340	13.360	15.510	18.170	20.090	26.130
9	2.088	2.532	3.325	4.168	8.340	14.680	16.920	19.680	21.670	27.880
10	2.558	3.059	3.940	4.865	9.340	15.990	18.310	21.160	23.210	29.590
11	3.050	3.610	4.570	5.580	10.340	17.280	19.680	22.620	24.730	31.260
12	3.570	4.180	5.230	6.300	11.340	18.550	21.030	24.050	26.220	32.910
13	4.110	4.760	5.890	7.040	12.340	19.810	22.360	25.470	27.690	34.120
14	4.660	5.370	6.570	7.790	13.340	21.060	23.690	26.870	29.140	36.120
15	5.230	5.990	7.260	8.550	14.340	22.310	25.000	28.260	30.580	37.700
16	5.810	6.610	7.960	9.310	15.340	23.540	26.300	39.360	32.000	39.250
17	6.410	7.260	8.670	10.090	16.340	24.770	27.590	31.000	33.410	40.790
18	7.020	7.910	9.390	10.870	17.340	25.990	28.870	32.350	34.810	42.310
19	7.630	8.570	10.120	11.650	18.340	27.200	30.140	33.690	36.190	43.820
20	8.260	9.240	10.850	12.440	19.340	28.410	31.410	35.020	37.570	45.320
21	8.900	9.910	11.590	13.340	20.340	29.610	32.670	36.340	38.930	46.800
22	9.540	10.600	12.340	14.040	21.340	30.810	33.920	37.660	40.290	48.270
23	10.200	11.290	13.090	14.850	22.340	32.010	35.170	38.970	41.640	49.730
24	10.860	11.990	13.850	15.660	23.340	33.200	36.420	40.270	42.980	51.180
25	11.520	12.700	14.610	16.470	24.340	34.380	37.650	41.570	44.310	52.620
26	12.200	13.410	15.380	17.290	25.340	35.560	38.890	42.860	45.640	64.050
27	12.880	14.120	16.150	18.110	26.340	36.740	40.110	44.140	46.960	55.480
28	13.560	14.850	16.930	18.940	27.340	37.920	41.340	45.420	48.280	56.890
29	14.260	15.570	17.710	19.770	28.340	39.090	42.560	46.690	49.590	58.300
30	14.950	16.310	18.490	20.600	29.340	40.260	43.770	47.960	50.890	59.700
40	22.164	23.838	26.509	29.051	39.335	51.805	55.759	60.436	63.691	73.402
50	29.707	31.664	37.689	37.689	49.335	63.167	67.505	72.613	76.154	86.661
60	37.485	39.699	43.188	46.459	59.335	74.397	79.082	84.580	88.379	99.607
70	45.442	47.839	51.739	55.329	69.334	85.527	90.531	96.388	100.425	112.317
80	53.539	56.213	60.391	64.278	79.334	96.578	101.880	108.069	112.239	124.839
90	61.754	64.634	69.126	73.291	89.334	107.565	113.145	119.646	124.116	137.208
100	70.065	73.142	77.929	82.358	99.334	118.498	124.342	131.142	135.807	149.449

k TEST

The *k* test can be used to show how the accident numbers at a site have changed compared to control data.

For a given site or group of similarly treated sites, we have:

$$k = \frac{b/a}{d/c} \qquad \text{[Eq. 8-A5]}$$

where:

- a = before accidents at site
- b = after accidents at site
- c = before accidents at control
- d = after accidents at control

If $k < 1$ then there has been a *decrease* in accidents relative to the control;

if $k = 1$ then there has been *no change* relative to the control;

if $k > 1$ then there has been an *increase* relative to the control.

If any of the frequencies are zero, then ½ should be added to each, i.e.:

$$k = \frac{(b + 1/2) \times (c + 1/2)}{(a + 1/2) \times (d + 1/2)} \qquad \text{[Eq. 8-A6]}$$

The percentage change at the site is given by:

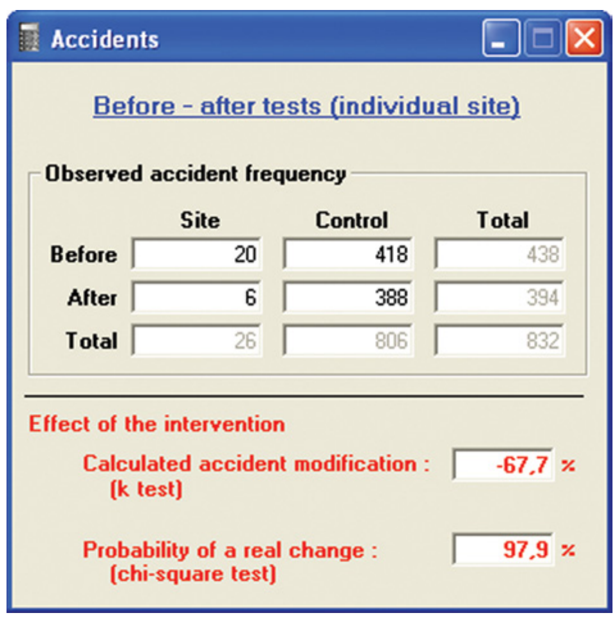
$$(k - 1) \times 100\% \qquad \text{[Eq. 8-A7]}$$

Example

Table 8-A3 shows the annual injury accident totals for a T-intersection in a semi-urban area that had stop signs on the minor road originally, but where a roundabout was installed three years ago. The control data used are accidents on all other priority intersections in the district over exactly the same 3-year before and 3-year after periods.

Table 8-A3 Injury accident frequencies at treated site and controls

	SITE	CONTROL	TOTAL
BEFORE	20 (a)	418 (c)	438 (g)
AFTER	6 (b)	388 (d)	394 (h)
TOTAL	26 (e)	806 (f)	832 (n)



Using the notation and equation above:

$$k = \frac{6/20}{388/418} = 0.32$$

Therefore, as k < 1, there has been a decrease in accidents relative to the controls of:

$$(k - 1) \times 100\ \% = 68\ \%$$

This test can be conducted with the ***"before - after tests (individual site)"*** calculator.

THE CHI-SQUARE TEST

This test can be used to determine whether the change in accidents was produced by the treatment or occurred by chance. The test thus determines whether the change is statistically significant. It is based on a contingency table showing both the observed values of a set of data (O) and the corresponding expected values (E). The chi-square statistic is given by:

$$\chi^2 = \sum_{i=1,\, j=1}^{n,m} \frac{(O_{ij} - E_{ij})^2}{E_{ij}} \qquad \text{[Eq. 8-A8]}$$

where:

O_{ij} is the observed value in column j, row i of the table
E_{ij} is the expected value in column j, row i of the table
m is the number of columns
n is the number of rows

A chi-square table is then used to look up this value, which shows the probability that the "expected" value and the "observed" values are drawn from the same population. The number of degrees of freedom is also required and this is given by:

$$\text{Degrees of freedom, } \upsilon = (n-1)(m-1)$$

For a site accident evaluation, where its accidents are compared in similar periods before and after treatment with a set of control sites for the same periods, we have a 2 by 2 contingency table (2 columns and 2 rows with degrees of freedom =1). For the test to be valid the value of any cell of the table should not be less than 5.

Using the notation from ***Table 8-A3***, the chi-square value can be calculated by the following equation:

$$\chi^2 = \frac{\left(|ad - bc| - \frac{n}{2}\right)^2 \times n}{efgh} \qquad \text{[Eq. 8-A9]}$$

This value is then compared with the chi-square values in ***Table 8-A2*** with degrees of freedom, υ = 1, and if it is greater than a particular value, it is said to be statistically significant at least at that percentage level.

Example

Using the data in the previous example and the Equation 8-A9, we obtain:

	SITE	CONTROL	TOTAL
BEFORE	20 a)	418 c)	438 g)
AFTER	6 b)	388 d)	394 h)
TOTAL	26 e)	806 f)	832 n)

$$\chi^2 = \frac{(|20 \times 388 - 6 \times 418| - 832/2)^2 \times 832}{26 \times 832 \times 438 \times 394}$$

$$\chi^2 = 5.38$$

Now looking at the chi-square distribution table ***(Table 8-A2)*** and the first line (one degree of freedom, υ =1), the value for chi-square of 5.38 lies between 3.84 and 5.41. This corresponds to a value of significance level (on the column header line) of between 0.05 and 0.02.

This means that there is only a 5% likelihood (or 1 in 20 chance) that the change in accidents is due to random fluctuation. Another way of stating this is that there is a 97,9% confidence that a real change in accidents has occurred at the intersection. The 5% level or better is widely accepted as indicating the remedial action has certainly worked, though the 10% level can be regarded as indicating an effect.

[CHI-SQUARE TEST]

GROUP OF SITES WITH THE SAME TREATMENT

For a number of sites, N, which have had the same treatment, determining the overall effect requires a rather more complex calculation, i.e. by solving the following equation for κ over all the sites, i.e. i = 1 to N. The other symbols are as in previous equations.

$$\sum_{i=1}^{N} \frac{a_i + b_i}{1 + \kappa\left(\frac{d_i}{c_i}\right)} = \sum a_i \qquad \text{[Eq. 8-A10]}$$

For testing, the natural logarithm of a variable such as is usually found to have a more symmetrical distribution (amenable to standard statistical treatments) and the standard error of $\log_e \kappa$ can be approximated to the following:

$$\sigma_{(\log_e \kappa)} = \sqrt{\frac{1 + \left(\frac{2}{\sum (a_i + b_i)}\right)}{\sum \frac{(a_i + b_i) \times d_i / c_i}{(1 + d_i / c_i)}}} \qquad \text{[Eq. 8-A11]}$$

The following ratio should then be calculated using $\log_e$ of the value of κ calculated above and its standard error from the previous expression:

$$\frac{(\log_e \kappa)}{\sigma_{(\log_e \kappa)}} \qquad \text{[Eq. 8-A12]}$$

And if this value is outside the range ±1.96 (Student's t), then the change is statistically significant (at the 95% level).

Now to test whether the changes at the treated sites are in fact producing the same effect on accident frequencies, we need to calculate the following chi-square value.

$$\chi^2 = \sum \frac{\left[(b_i + \kappa a_i) \times \frac{d_i}{c_i}\right]^2}{\kappa (a_i + b_i) \times \frac{d_i}{c_i}} \qquad \text{[Eq. 8-A13]}$$

If this is significant with N-1 degrees of freedom (refer to the $(N\text{-}1)^{th}$ row in the chi-square table, where N is the number of treated sites), then the changes at the sites are not producing the same effect. If it is not significant, however, then it is likely that the changes are producing the same effect.

[BEFORE-AFTER TEST (GROUP OF SITES)]

REGRESSION-TO-MEAN CORRECTION

To correct for the regression-to-mean effect, the ***safety level*** (or long-term average accident frequency) must be estimated. Several statisticians have proposed ways of doing this. For example, Hauer (1992) recommended using Empirical bayesian method to estimate the level of safety of a site and then use this value in safety studies (rather than the raw data). However, Abbess et al. (1981) previously described a simpler approach for a single site, in which the data was adjusted to correct for biases using assumptions about the distribution of accidents over a period of years.

Accident data must be gathered for sites that are similar to the treated site over the same time period. Using this full dataset, the mean number of accidents, *a*, and the variance of accidents, *var* (*a*), are calculated. The regression-to-mean effect, R (in %), is given by the following equation:

$$R = \left(\frac{(A_t + A)\, n}{(n_t + n)\, A} - 1 \right) \times 100 \qquad \text{[Eq. 8-A14]}$$

where:

A = number of accidents at the site

n = number of years

$$A_t = \frac{a^2}{(\mathrm{var}(a) - a)} \qquad \text{[Eq. 8-A15]}$$

$$n_t = \frac{a}{(\mathrm{var}(a) - a)} \qquad \text{[Eq. 8-A16]}$$

A_t and n_t are the estimates of the parameters of the statistical distribution showing the true underlying accident frequencies, i.e. the accident frequency's probability distribution before any data are available. The main assumption is, therefore, that the study site with a particular accident history will behave in the same way as the set of all similar sites with the same accident history.

[REGRESSION TO MEAN]

Example

Let us consider an intersection that has had an average of 15 accidents per year over the past 5 years. The site was widened, large new intersection signing, splitter islands and STOP signs were installed, after which the site has averaged 10 accidents per year over a similar period.

To correct for the regression-to-mean effect, we need to select similar uncontrolled intersection sites with similar traffic flows. If all these sites have produced a mean, *a*, of 12.6 accidents per year with a variance, *var* (*a*), of 2.91, the input values are:

a = 12.6 acc/year
$\mathrm{var}(a)$ = 2.91 (acc/year)^2
A = 75 acc/5 years
n = 5 years
$A_t = 12.6^2 / (2.91 - 12.6) = -16.38$
$n_t = 12.6 / (2.91 - 12.6) = -1.3$

Thus the regression effect:

$$R = \left(\frac{(-16.38 + 75)\, 5}{(-1.3 + 5)\, 75} - 1 \right) \times 100$$

$$R = 5.6\ \%$$

In other words, during the after period we would expect that if nothing were done to the site, the accidents would drop by 5.6%, or to 14.16 accidents per year. Thus, it is the figure of 14.16 accidents per year that should be compared with the 10 accidents per year that actually occurred to determine whether the reduction in accident frequency due to the improvements is statistically significant.

PART 3

Technical sheets

HORIZONTAL ALIGNMENT

Technical sheet

Carl Bélanger and Patrick Barber

HORIZONTAL ALIGNMENT

Technical sheet

LIST OF FIGURES

LIST OF TABLES

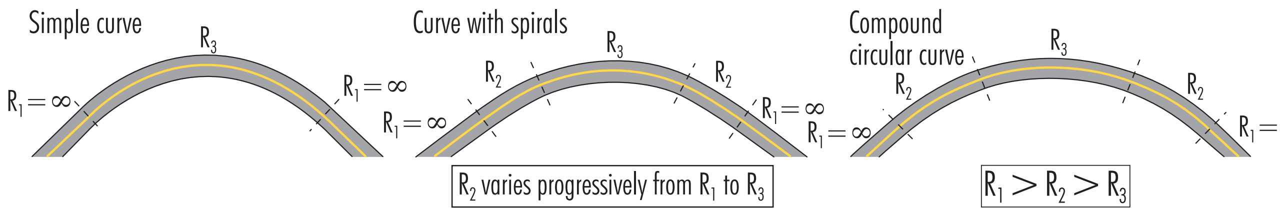
LIST OF ABBREVIATIONS		
α	=	incline of the superelevation (°)
Δ	=	deflection angle (°)
ΔV_{85} , ΔV_{99}	=	operating speed differentials, 85th and 99th percentiles (km/h)
A	=	parameter of the spiral curve (m)
CCR	=	curvature change rate (gon/km)
DC	=	degree of curve (°)
e	=	superelevation
F_c	=	centrifugal force (N)
F_{cp}	=	centrifugal force parallel to the road surface (N)
F_e	=	superelevation force (N)
F_t	=	force of transverse friction (N)
f	=	coefficient of friction
f_l	=	coefficient of longitudinal friction
f_r	=	coefficient of friction required (at V)
f_t	=	coefficient of transverse friction
f_{td}	=	coefficient of transverse friction (design)
h	=	height of the vehicle's center of gravity (m)
L_c	=	length of the curve (m)
L_s	=	distance (spiral curve) (m)
LC	=	lateral clearance (m)
L_t	=	tangent length (m)
R	=	curve radius (m)
R_{min}	=	minimum curve radius (m)
S	=	stopping distance (m)
t	=	track width (m)
TL_{min}	=	tangent length necessary for a vehicle to go from an initial speed (V_{C1}) to a final speed (V_{C2}) with an acceleration or deceleration rate of a or d.
TL_{max}	=	tangent length necessary for a vehicle to accelerate from an initial speed (V_{C1}) to a desired speed ($V_{t\ 85}$) and decelerate to a final speed (V_{C2}) with an acceleration and deceleration rate of a and d
v	=	speed (m/s)
V	=	speed (km/h)
V_{85}	=	operating speed (85th percentile) (km/h)
V_{99}	=	operating speed (99th percentile) (km/h)
V_{C1}	=	operating speed in curve 1 (km/h)
V_{C2}	=	operating speed in curve 2 (km/h)
V_r	=	overturning speed (km/h)
V_{skid}	=	skidding speed (km/h)
$V_{t\ 85}$	=	desired speed (km/h)
$V_{t\ max}$	=	maximum speed reached when the length of the tangent does not allow the motorist to reach the desired speed
W	=	weight of the vehicle (N)

SUMMARY

General principles

The horizontal alignment of a road comprises straight lines, circular curves (with a constant radius), and spiral curves, whose radius changes regularly to allow for a gradual transfer between adjacent road segments with different curve radii. Various sequences of these three basic components are possible. Figure HA-1 shows three types of common sequences: simple curve, curve with spiral(s), and curves made up of several decreasing radii.

Figure HA-1 Examples – Sequences of horizontal alignment components



Accidents

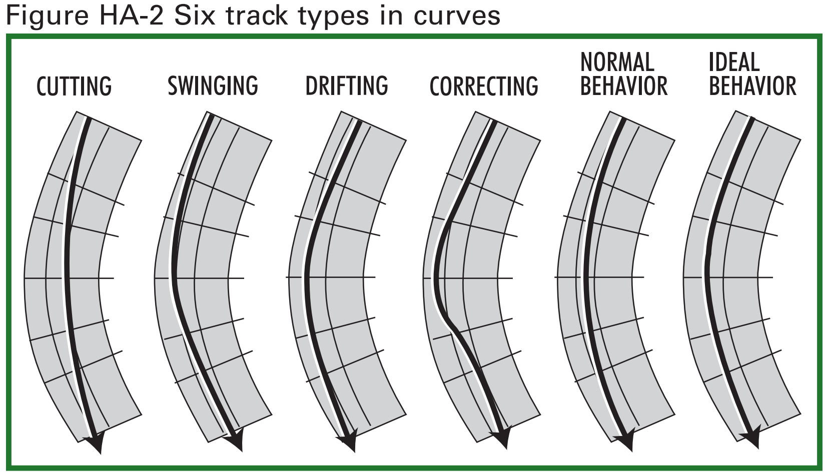
Several studies has been conducted to estimate the accident risk in horizontal curves. Their main conclusions are:

- the accident rate in curves is 1.5 to 4 times higher than in tangents (Zegeer et al., 1992);
- the severity of accidents in curves is high (Glennon et al., 1986). From 25 to 30% of all fatal accidents occur in curves (Lamm et al., 1999);
- secondary rural roads, which are built following lower design standards (including more and sharper horizontal curves) have on average a higher proportion of accidents in curves. In France, from 30 to 40% of all accidents on main rural roads occur in curves; the equivalent proportion on secondary roads is between 55 and 60% (SETRA, 1992);
- approximately 60% of all accidents to occur in horizontal curves are single-vehicle off-road accidents (Lamm et al., 1999);
- the proportion of accidents on wet surfaces is high in horizontal curves;
- accidents occur primarily at both ends of curves. Council (1998) notes that in 62% of fatalities and 49% of other accidents occurring in curves, the first manoeuvre that led to the accident was made at the beginning or the end of the curve.

The higher the required speed reduction in the curve, the greater the probability of error and accident (encroachment, skidding, run-off-the-road, etc.) The risk is even higher when the speed reduction is unexpected or unusual (isolated sharp curve).

Six track types have been recognized by Spacek (2000) to describe the behavior of drivers in curves (Figure HA-2). The correcting track type, which is due to an underestimation of the curve features, locally reduces the radius followed by the car and increases the risk of accident. Improvements to sight distance, curve conspicuity and warning devices may reduce this type of problem.

Figure HA-2 Six track types in curves



Source: Spacek, 2000

Observations

This technical sheet describes the key characteristics of horizontal curves that need to be considered in a safety analysis:

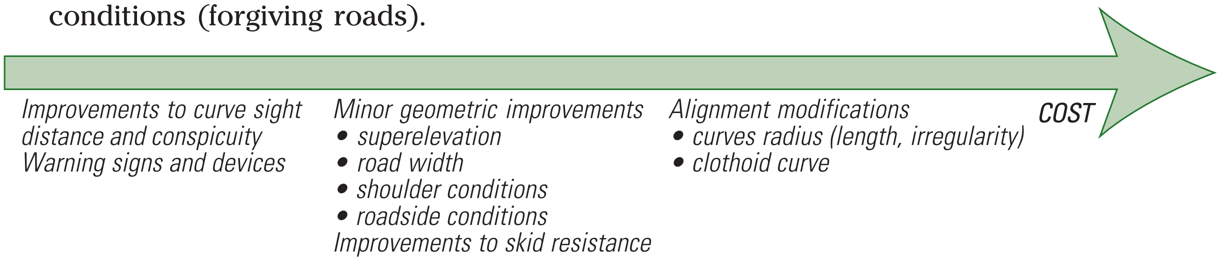
- ***curve radius (or degree of curve);***
- ***speed differentials;***
- ***surface condition;***
- ***overturning;***
- ***superelevation;***
- ***road width;***
- ***shoulders;***
- ***roadsides – sight distance;***
- ***roadsides – forgiving roads;***
- ***passing;***
- ***warning signs/devices;***
- ***combination of features.***

Potential solutions

Lengthening the radius of a curve is a solution that is often considered to reduce accidents in sharp horizontal curves. However, costs can be very high and the economic effectiveness of the measure needs to be properly assessed.

Other potential solutions include:

- improving warning and guidance provided for drivers: better sight distance, curve conspicuity, signing and marking, delineation;
- minor geometric improvements, including modifications to the shoulder and roadside conditions (forgiving roads).



Warning

The various road features that have an impact on driving speed – alignment, cross-section, roadside conditions, sight distance – should all be well-coordinated.

Hazardous situations may arise if improvements are made to one specific road element (e.g. increase in curve radius) while other elements are kept unchanged (narrow cross-section, steep side slopes and hazardous roadside obstacles). One should also ensure that the speed increase that may result from a curve improvement does not simply migrate the safety problem to the next sharp curve along the road.

Hazardous pole location in curve

CURVE RADIUS (OR DEGREE OF CURVE)

Description

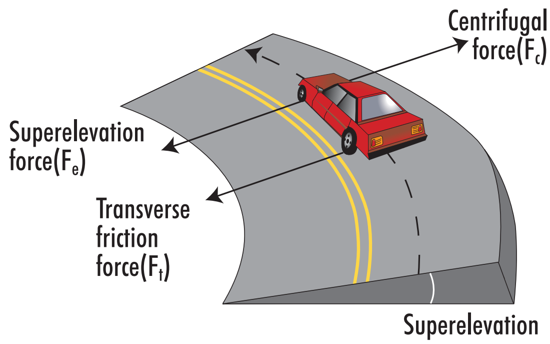
A vehicle traveling in a curve is pushed towards the exterior side of the road by the centrifugal force. Transverse friction between the tires and the road and superelevation counteract this force (Figure HA-3). The magnitude of the centrifugal force increases with speed, up to a point where it is equal to the sum of these two counteracting forces and skidding occurs:

$$F_c = F_e + F_t \qquad \text{[Eq. HA-1]}$$

where:

F_c = centrifugal force
F_e = superelevation force
F_t = transverse friction force

Figure HA-3 Curve – System of force



However, some vehicles having a high center of gravity may overturn before skidding ***(overturning)***.

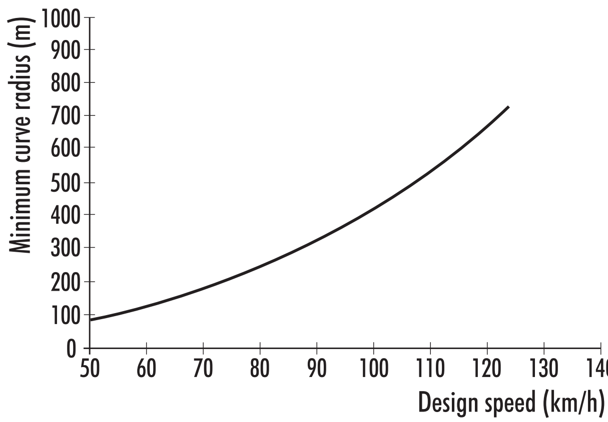
By transforming equation HA-1, one can derive the basic equation that is used to calculate the minimum curve radius, based on speed, friction and superelevation values (see ***Appendix HA-1***):

$$R_{min} = \frac{V^2}{127(e + f_t)} \qquad \text{[Eq. HA-2]}$$

where:

R_{min} = minimum curve radius (m)
V = speed (km/h)
e = superelevation (m/m)
f_t = coefficient of transverse friction

Figure HA-4 Minimum curve radius and design speed



Source: Krammes et Garnham, 1995

The minimum curve radii values used at the design stage range from about 100 m for a design speed of 50 km/h to about 500 m for a design speed of 100 km/h (Figure HA-4).

Such radius values may be calculated with Eq. HA-2, using low coefficients of transverse friction, in order to:

- take into account driving conditions that are difficult but not exceptional (wet pavement and worn tires);
- avoid substantial increases in curve braking distances;
- provide vehicle occupants with an acceptable level of comfort.

The “horizontal curve - Basic equations” calculator shows the interactions between the various terms of equation HA-2 (curve radius, speed, transverse friction, superelevation).

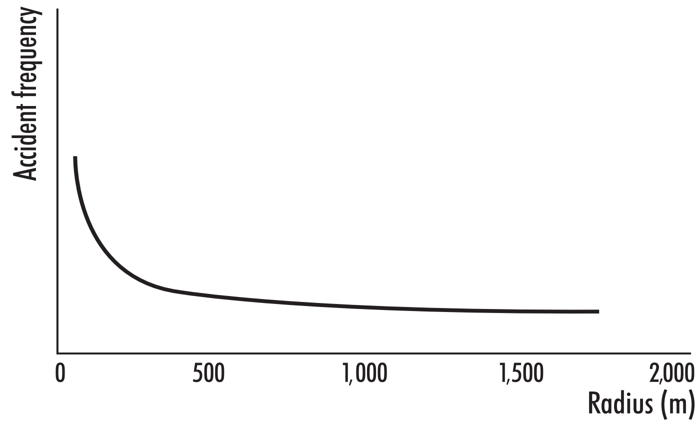
[BRAKING DISTANCE (CURVE)] [BASIC EQUATIONS]

Safety

On rural roads, accident frequencies are generally seen to increase as curve radii decrease. A convex downward relationship is often found as shown in Figure HA-5. The increase in accidents is significant when the radius is less than 400 m.

The accident frequency in a curve is not only influenced by the characteristics of the curve itself (radius, deflection angle, friction, superelevation, etc.) but also by the characteristics of the road alignment prior to the curve (length of tangent prior to the curve and general bendiness of the road). It is therefore not surprising for two similar curves to have different safety performances, depending on the road context in which they are located.

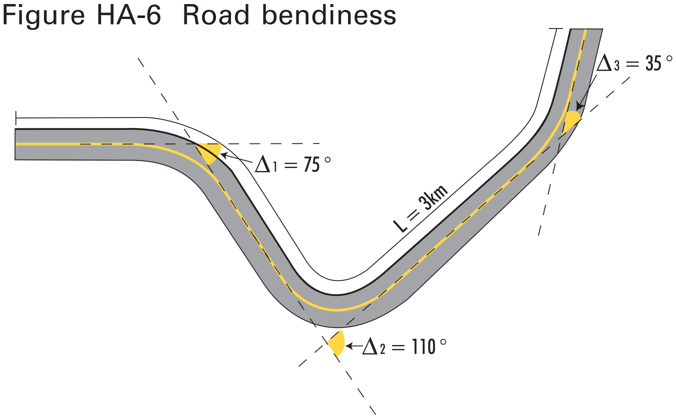
Figure HA-5 Accident frequency and curve radius



General bendiness[1]

The general bendiness of a road has a direct effect on the drivers' level of attention and expectations with respect to the forthcoming road alignment. A sharp curve is more hazardous on a fairly straight road than on a winding road. Figure HA-6 shows how to calculate bendiness.

Figure HA-6 Road bendiness



$$\text{Bendiness} = \frac{75° + 110° + 35°}{3\ \text{km}} = 73° / \text{km}$$

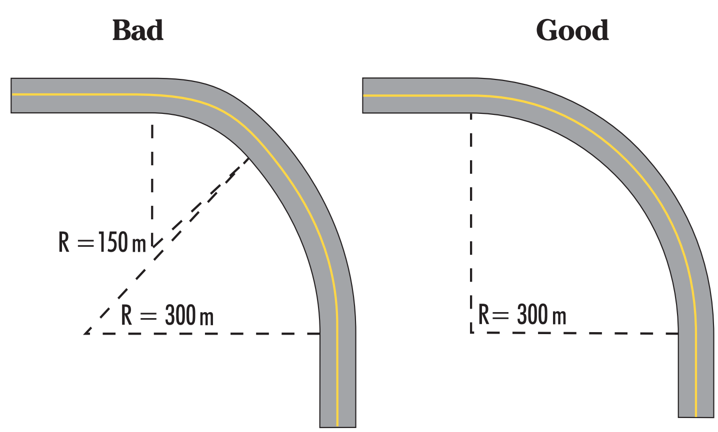
[1] Bendiness is defined as the sum of changes in direction (in degrees) per kilometer.

Note: 1 gon = 0.9°; for details, see ***appendix HA-2***.

Irregular curve radius

Marked changes in radius in a curve are to be avoided since they may surprise drivers and increase the risk of error. The accident risk is higher when a small radius follows a larger one. Yerpez and Ferrandez (1986) found that a 50% reduction in curve radius over a distance of more than 30 m increases the number of accidents. An irregular radius can usually be converted into an uniform circular radius or clothoid or a combination of both without major changes in road alignment (Figure HA-7).

Figure HA-7 Irregular curve radius



Spiral curve

Spiral curves (also called transition curves or clothoids) are the third element in a horizontal alignment, along with tangent and circular curves. According to Lamm et al. (1999), spiral curves:

- improve driving comfort by allowing a natural increase and decrease in centrifugal force as a vehicle enters and leaves a circular curve;
- minimize encroachments and increase speed uniformity;
- facilitate water runoffs in the superelevation transition zone;
- enhance the appearance of the highway by eliminating noticeable breaks at the beginning and end of circular curves;
- facilitate the transition in width where the pavement section is to be widened around a circular curve.

Spiral curves are calculated using the following equation:

$$R = \frac{A^2}{L_s} \qquad \text{[Eq. HA-3]}$$

where:

R = curve radius (at distance L) (m)
A = parameter of the spiral curve (m)
L_s = distance traveled from the starting point of the curve (m)

Figure HA-8 shows the resulting curves for A = 150 m and A = 300 m.

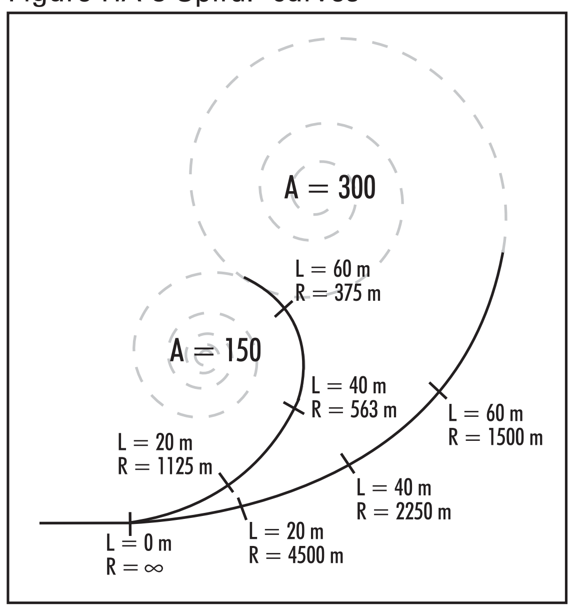
Overly long spiral curves should be avoided as they can hinder the visual perception of the curve and may contribute to drainage problems.

According to Council (1998), a spiral curve reduces accident rates by 8% to 25% on roads with high design standards. However, he concludes that safety improvements brought about by transition curves are less evident on roads with lower geometric standards.

Other studies report contradictory results, which probably led Lamm et al. (1999) to conclude that:

> *"Generally speaking, with respect to safety effects, the application of clothoids should not be overemphasized in the design process, as it has been done so far in several countries. Of course, one should not forget the importance of other design impacts that transition curves provide, besides accident-related issues…"*

Figure HA-8 Spiral curves



How to detect problems (curve radius)

Accidents:

- run-off-the-road accidents, head-on collisions, wet-surface accidents.

Traffic operation:

- encroachments, late braking, excessive speeds, skid marks.

How to detect problems (continued)

Road characteristics:

- compliance with standards (minimum curve radius);
- coherence of the curve radius within road environment;
- consistency of curve radii along the road (general bendiness of the road prior to the curve).

Potential measures

see: ***Horizontal Alignment – Summary – Potential Solutions***.

Table HA-1 shows accident reductions resulting from reductions in the degree of curve, based on the analysis of data collected at 10,900 horizontal curves in the United States (Zegeer et al., 1990).

Table HA-1 Accident reduction (%) due to a reduction in the degree of curve

		DEFLECTION ANGLE									
DEGREE OF CURVE[1]		10° ISOLATED[2]		20° ISOLATED		30° ISOLATED		40° ISOLATED		50° ISOLATED	
Old	New	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
30	25	16	17	16	17	16	17	15	16	15	16
30	20	33	33	32	33	31	33	31	33	30	33
30	15	49	50	48	50	47	50	46	50	46	50
30	12	59	60	57	60	56	60	55	60	55	60
30	10	65	67	64	66	63	66	62	66	61	66
30	8	72	73	70	73	69	73	68	73	68	73
30	5	82	83	80	83	79	83	78	83	78	83
25	20	19	20	19	20	18	20	18	20	17	20
25	15	39	40	38	40	36	40	36	40	35	40
25	12	50	52	49	52	48	52	46	52	46	51
25	10	58	60	56	60	55	60	54	59	53	59
25	8	66	68	64	68	62	68	61	67	60	67
25	5	77	80	75	80	74	79	72	79	72	79
20	15	24	25	23	25	22	25	21	25	20	24
20	12	38	40	36	40	35	40	34	39	33	39
20	10	48	50	45	50	44	49	42	49	41	49
20	8	57	60	54	60	52	59	51	59	50	59
20	5	71	75	68	74	66	74	64	74	64	74
15	10	30	33	23	33	26	33	25	32	24	32
15	8	43	46	40	46	37	46	35	45	34	45
15	5	61	66	56	66	53	65	51	65	50	65
15	33	73	79	68	79	64	78	63	78	63	78
10	5	41	49	36	48	32	48	29	47	28	47
10	3	58	69	50	68	45	67	43	66	42	66
5	3	22	37	15	35	13	33	11	32	11	31

Source: Zegeer et al., 1990.

[1] Degree of curve and deflection angle are defined in ***Appendix HA-2***.

[2] Isolated curve: tangent length of 200 m or more on either side of the curve.

SPEED DIFFERENTIALS

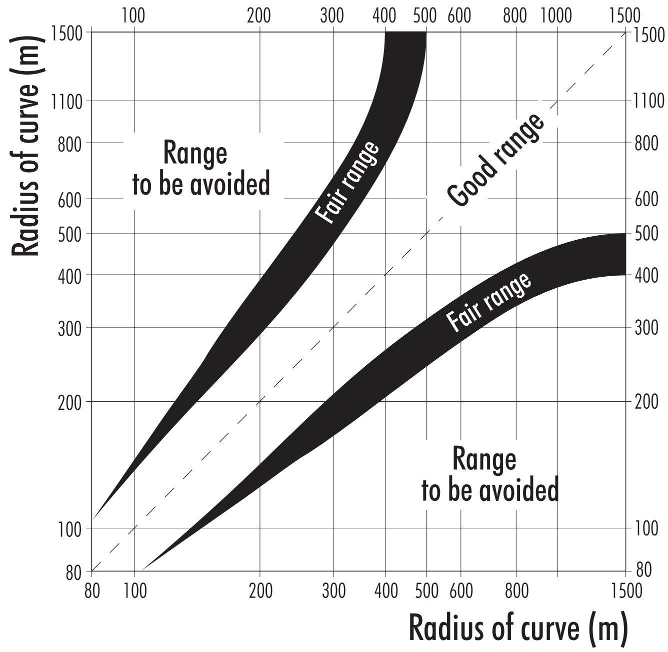
Description

Operating speed is influenced by several factors related to the driver, road and roadside conditions, vehicle characteristics, traffic conditions and weather conditions. Road alignment is undoubtedly the single most important factor among road characteristics that influence drivers' speeds.

Speed variations along a road have a direct impact on road safety; the greater and less expected the variations, the higher the probability of collision. High standard roads should be designed to allow drivers to travel safely at a relatively constant speed that meets their needs and expectations. Otherwise, driving errors are likely to occur.

In the early seventies, German researchers developed rules to help designers choose horizontal alignment sequences that would reduce operating speed variations along a route. Graphs were drawn up to indicate the design quality of various possible curve radii sequences (e.g. Figure HA-9). The method, known as relation design, is seen as a major improvement over traditional design methods that merely checked compliance with minimum radii values.

Figure HA-9 Tuning radii in curve sequences



Source : German design guidelines, from Lamm et al. (1999)

Relation design rules can also be expressed in terms of speed differentials. Lamm et al. (1999) recommend that a road's design quality be assessed by comparing the 85th percentile speed of passenger cars (V_{85}) on two successive road segments. If the speed differential is less than 10 km/h, the design is deemed good; between 10 km/h and 20 km/h, acceptable; over 20 km/h, poor. Spain uses a similar criterion, but based on the 99th percentile speed (V_{99}) (Table HA-2).

These speed differentials can be measured at the site but they can also be determined with speed regression models and selected acceleration and deceleration rates. The «Speed differentials» calculator can be used for this purpose; it is based on Lamm et al. (1999) but allows more flexibility concerning the choice of parameters. Details of the procedure are described in ***Appendix HA-3***.

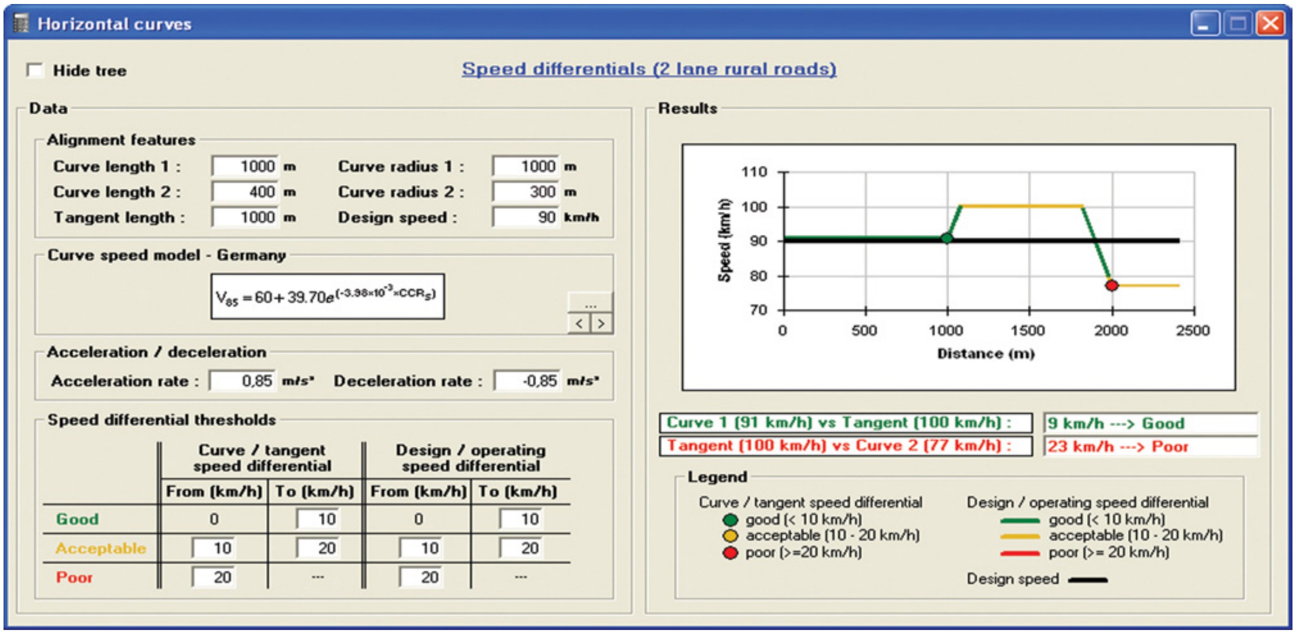
Table HA-2 Design quality – Speed differentials

LAMM ET AL 1999		SPAIN	
SPEED DIFFÉRENTIAL ΔV_{85} (km/h)	DESIGN QUALITY	SPEED DIFFÉRENTIAL ΔV_{99} (km/h)	DESIGN QUALITY
< 10	Good	< 15	Good
10 - 20	Acceptable	15 - 30	Fair
> 20	Poor	30 - 45	Poor
		> 45	Dangerous

Source: Lamm et al. in Highway design and traffic safety engineering handbook. Copyright 1999 by McGraw-Hill Compagnies, Inc.

[**SPEED DIFFERENTIALS**]

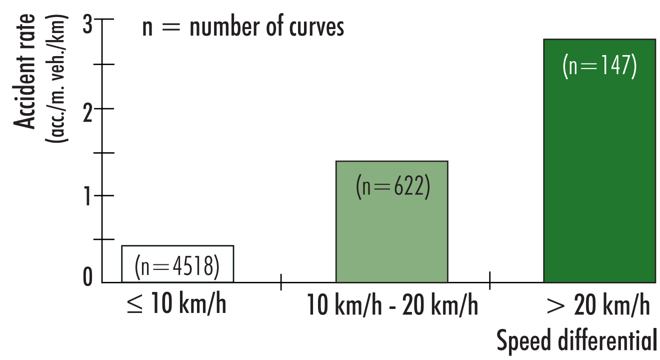
Figure HA-10 Operating speed differentials – Calculator (two-lane rural roads)



Safety

Anderson et al. (1999) analyzed the impact of operating speed differentials (V_{85}) on accidents. Based on data collected at 5,287 curves, they found that the accident rate in curves with a speed differential of over 20 km/h is two times higher than in those with a speed differential of 10 km/h to 20 km/h and six times higher than in those with a speed differential of less than 10 km/h (Figure HA-11).

Figure HA-11 Accident rates and speed differentials



Based on: Anderson et al., 1999

How to detect problems

Accidents:

- run-off-the-road accidents, head-on collisions, wet surface accidents.

Traffic operation:

- substantial speed reductions when approaching the curve, excessive speeds, late braking, skid marks, encroachments;
- operating speed differentials *(Appendix HA-3)*.

Potential measures

see: ***Horizontal Alignment – Summary – Potential Solutions***

SURFACE CONDITION

Description

The available transverse friction in a curve has a strong impact on the maximum speed at which it can be driven. For example, for a curve with a radius of 300 m, a superelevation of 0.06 and a coefficient of transverse friction (f_t) of 0.30, the maximum (theoretical) speed is 108 km/h. With an f_t value of 0.80, it rises to 148 km/h. Transverse friction values used at the design stage (f_{td}) are generally much lower than transverse friction values that are available on roads (f_t) (f_{td} values typically range between 0.08 and 0.16, depending on the design speed).

As previously mentioned, this choice of f_{td} values is based on the following objectives:

- providing a safety margin for adverse weather conditions;
- avoiding excessive increases in braking distances in curves (Figure HA-12);
- offering a comfortable ride to vehicles' occupants.

[BRAKING DISTANCE (CURVE)]

As a result, horizontal curves can often be driven faster than design and posted speeds (under favorable conditions). Realizing this, a number of drivers adopt relatively high speeds, thereby reducing their safety margin. It is a driving habit that may prove to be hazardous if the skid resistance at a specific curve is low and the driver does not decelerate sufficiently (drivers may have difficulties in identifying locations with skid resistance problems). When the friction available in the curve becomes lower than the required friction, the driver loses the control of his vehicles. The required friction (f_r), can be calculated with the following equation:

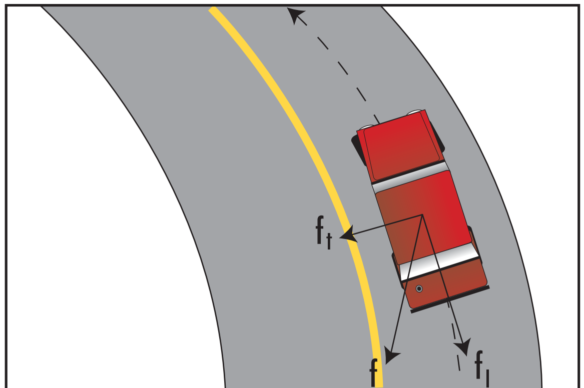
$$f_r = \frac{V_{85}^2}{127\,R} - e \qquad \text{[Eq. HA-5]}$$

where:

- R = curve radius (m)
- V_{85} = speed (km/h)
- e = superelevation (m/m)
- f_r = friction required at V_{85}

[FRICTION REQUIRED IN CURVE]

Figure HA-12 Friction in horizontal curve



$$f^2 = f_l^2 + f_t^2 \qquad \text{[Eq. HA-4]}$$

where:

- f = coefficient of friction (totale)
- f_l = coefficient of longitudinal friction
- f_t = coefficient of transverse friction

When braking in a curve, the total available friction is distributed between its longitudinal component (f_l), required for braking, and its transverse component (f_t), required for changes in direction. To avoid excessive increases in braking distances, f_{td} values no greater than 40 to 50% of the total friction expected under difficult conditions are selected, so that around 90% of the total friction remains available for braking manoeuvres ***(road surface friction)***.

Lamm et al. (1999) recommend assessing the quality of a horizontal alignment by comparing the coefficient of transverse friction used in design (f_{td}) with the coefficient of friction required (f_r) to take the curve (Table HA-3).

Table HA-3 Design quality – Friction differentials

FRICTION DIFFERENTIAL	DESIGN QUALITY
$f_{td} - f_r \geq +0.01$	Good
$-0.04 \leq f_{td} - f_r < +0.01$	Acceptable
$f_{td} - f_r < -0.04$	Poor

f_{td} : coefficient of transverse friction (design)
f_r : coefficient of friction required at speed V

Source: Lamm et al. in Highway design and traffic safety engineering handbook. Copyright 1999 by McGraw-Hill Compagnies, Inc.

Some countries recommend using higher minimum friction thresholds in horizontal curves. For example, on "*single carriageway non event sections*", Great Britain sets the investigatory skid resistance level at 0.40, increasing it to 0.60 in sharp horizontal curves[1].

The combination of other surface deficiencies (*ruts* or excessive *roughness)* may aggravate the situation.

[1] Curve radius smaller than 100 m and speed larger than 64 km/h (40 mph).

Safety

The presence of water between a tire and a road surface reduces the available friction. As a result, concentration of wet surface accidents may be indicative of a friction deficiency. The problem is more important in horizontal curves where friction requirements are higher. This was confirmed by Page and Butas (1986) who found that accident rates on wet roads were higher in curves than in tangents, particularly when the friction coefficient was low ***(road surface conditions)***.

How to detect problems (surface conditions)

Accidents:

- wet-surface accidents.

Traffic operation:

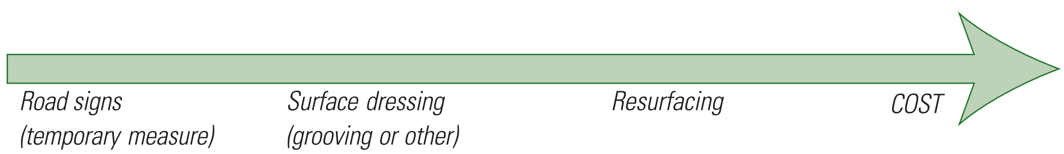
- skidding, brake marks, encroachments, avoidance manoeuvres caused by excessive surface roughness or defaults.

Road characteristics

Check:

- skid resistance (polishing, bleeding, contamination);
  - if need be, conduct instrumented ***friction tests***;
  - calculate f_r and compare to f_{td}.
- surface evenness (waves, potholes, rutting, etc.);
- water or debris accumulations on the road surface.

Potential measures



Skidding

Skidding occurs when the centrifugal force becomes greater than the resistance provided by the transverse friction (f_t) and the superelevation (e). In such conditions, the driver loses control of his vehicle, which is pushed toward the outside of the curve (although he may end up on the inside of the curve).

The skidding speed is influenced by several factors, including vehicle characteristics, driver manoeuvres and surface condition. Calculating the skidding speed accurately requires on-site instrumented friction tests and adjusting the findings to take into account differences between test conditions and driving conditions under study. This type of analysis is typically conducted in accident reconstructions. ***(Friction test – Adjustment Factors)***.

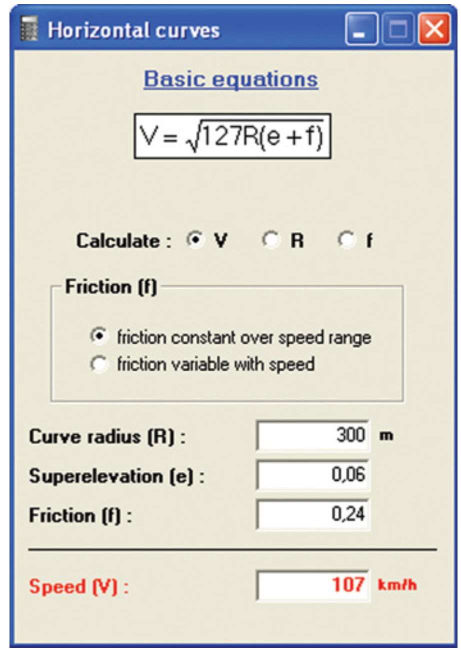
The speed at which skidding may occur should always be significantly higher than the posted speed. Otherwise, appropriate warning devices need to be installed sufficiently ahead of the curve to prepare drivers for the forthcoming situation.

$$V_{skid} = \sqrt{127R\,(e + f_t)} \qquad \text{[Eq. HA-6]}$$

where:

- V_{skid} = skidding speed (km/h)
- R = radius of the curve (m)
- e = superelevation (m/m)
- f_t = (available) coefficient of transverse friction

[HORIZONTAL CURVE - SPEED]

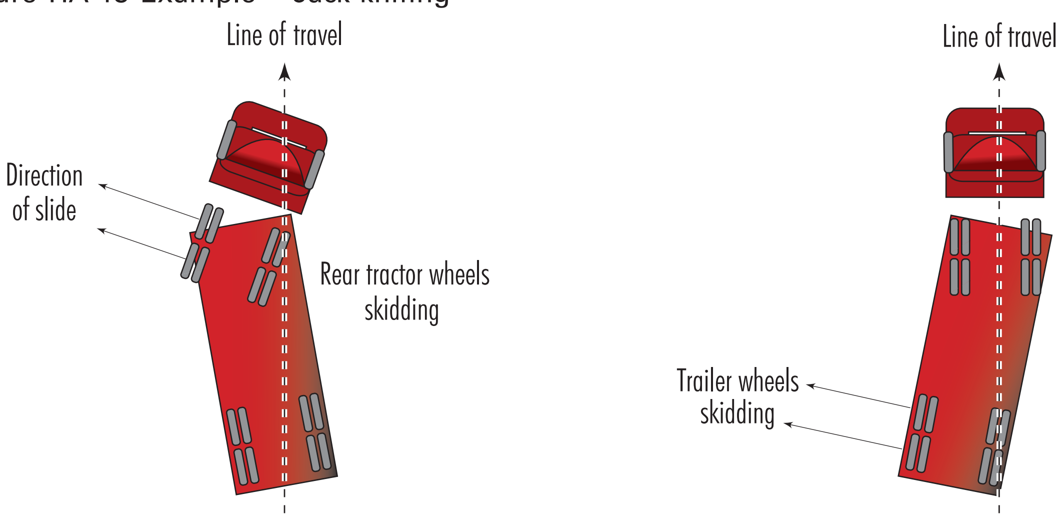


Jack-knifing

For various reasons, skidding may not be reached simultaneously on all wheels of a vehicle: different wheel loads, braking forces on each wheel, tire characteristics, road surface characteristics etc.

If a vehicle has a rigid configuration (e.g. single unit truck), friction can still develop at wheels which have not yet reached the skidding threshold. In the case of articulated vehicles (semi-trailers, trailers and road trains), the sliding of some wheels may initiate the rotation of its various rigid components around their kingpins and change the overall configuration of the vehicle. The most common example is that of a tractor semi-trailer on curves: if the tractor's rear wheels start sliding sideways, the semi-trailer rotates around the kingpin and the tractor's rear wheels get oriented such that they cannot contribute any valid transverse friction (Figure HA-13). This process is called jack-knifing, which is more likely to occur on wet pavement or during braking manoeuvres. Where semi-trailers account for a significant proportion of total traffic, jack-knifing may occur before skidding.

Figure HA-13 Example – Jack-knifing



OVERTURNING

Description

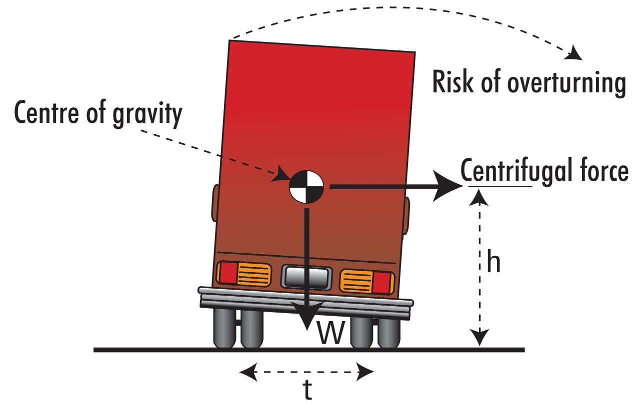
When the available friction is high, some heavy vehicles may overturn before skidding. A vehicle's overturning threshold (OT)[2] or static stability factor (SSF) depends of its track width and the height of its center of gravity:

$$OT = t/2h \qquad \text{[Eq. TP-7]}$$

where:

- OT = overturning threshold
- t = track width (m)
- h = height of the center of gravity (m)

Figure HA-14 Overturning



When the OT value is larger than the coefficient of transverse friction that can be mobilized in a curve (f_t), the vehicle will overturn before skidding, and inversely. The risk of overturning is usually low for passenger vehicles since their overturning threshold is relatively high (typically between 1 and 1.5g). However, some heavy vehicles have much lower OT values (in the order of 0.3 or 0.4g), and their risk of overturning is much higher.

The overturning speed equation is very similar to the skidding speed equation, except that the available coefficient of transverse friction (f_t) is replaced by the overturning threshold (t/2h):

$$V_r = \sqrt{127R\left(e + \frac{t}{2h}\right)} \qquad \text{[Eq. HA-8]}$$

where:

- V_r = overturning speed (km/h)
- R = radius of the curve (m)
- e = superelevation (m/m)

[OVERTURNING SPEED]

Heavy vehicle rollover (sharp curve on a rural arterial)

How to detect problems

Accidents:

- truck overturning accidents.

Traffic operation:

- operating speed.
- calculate overturning speed and compare with operating speed.

Potential measures

Warning signs *Superelevation adjustments* *Alignment modifications* *COST*

[2] The overturning threshold value represents the lower value of centrifugal acceleration that is sufficient to cause a vehicle to rollover (it is expressed in terms of «g»).

SUPERELEVATION

Description

Superelevation is a road's transverse incline toward the inside of a horizontal curve (Figure HA-15). It slightly reduces the friction needed to counter the centrifugal force and increases riding comfort. As a result, the maximum speed in a curve increases with superelevation (Table HA-4).

[HORIZONTAL CURVE - SPEED]

Excessive superelevation may cause slow vehicles to slide toward the inside of the curve when the friction level is very low (icy conditions). Superelevation values ranging from 5 to 8% are recommended in design.

A transition zone between the tangent and the horizontal curve is needed to gradually introduce the superelevation. In part of this zone, the road profile becomes flat on its outer side, which can lead to water accumulation and contribute to skidding (Figure HA-16). The end of this flat zone must be located before the start of the curve and special attention must be paid to the quality of drainage in that area.

The maximum curve radius at which a superelevation is deemed necessary varies substantially between countries (e.g. 900 m in France compared to 5,000 m in Spain on highways with high standards).

Figure HA-15 Superelevation in curve

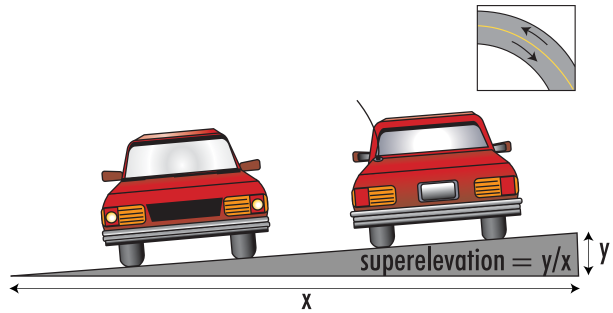
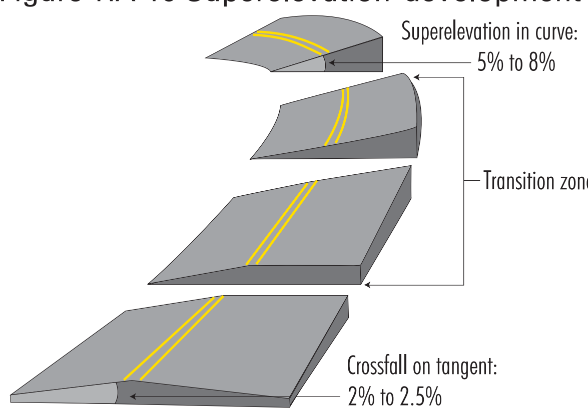


Table HA-4 Example – Relationship between superelevation and speed

SUPERELEVATION (m/m)	SPEED (km/h)
0.00	62
0.02	67
0.04	71
0.06	76
0.08	80

Radius = 250 m, coefficient of friction = 0.12

Figure HA-16 Superelevation development



Safety

Dunlap et al. (1978), found the number of accidents on wet pavements to be abnormally high in curves with a superelevation of less than 2%.

Zegeer et al. (1992) report that improving the superelevation reduces the number of accidents by 5 to 10%.

How to detect problems

Road characteristics:

- low, nil or inverted superelevation;
- sudden or irregular changes in superelevation;
- poor drainage, mainly in the transition zone.

Potential measures

Rectify the superelevation.

ROAD WIDTH

Description

In horizontal curves, the radius followed by a vehicle's front wheels is larger than the radius of its rear wheels, which increases the width swept (as compared to the situation in a tangent (Figure HA-17). This additional width is negligible in the case of passenger vehicles but can be significant with long articulated vehicles. Moreover, the difficulty stemming from changes in direction in a curve increases the risk of encroachment outside the traffic lane.

As a result, road width often needs to be increased in horizontal curves. The required width depends on the curve radius, operating speed and vehicle's characteristics.

Traffic volumes should also be considered. For example, the Canadian design guide indicates that on two-lane roads, pavement widening is not required when there is less than 15 trucks/h in both directions (Transportation Association of Canada, 1999).

There is little uniformity in the guidelines proposed in various countries to calculate the required widening. Table HA-5 presents the simple UK guidelines. The "road width" calculator is based on the more complex Canadian procedure (Transportation Association of Canada, 1999).

Table HA-5 UK Guidelines for curve widening

RADIUS (m)	ROAD OF STANDARD WIDTH	ROAD WITH LESS THAN STANDARD WIDTH
90 to 150	0.3 m/lane	0.6 m/lane
150 to 300		0.5 m/lane
300 to 400		0.3 m/lane

Source: The Stationery Office, 1993

[ROAD WIDTH]

Safety

Krebs and Kloeckner (1977) showed that increasing road width reduces accident rates. This relationship applied to the three radius categories they considered (Figure HA-18).

Table HA-6, based on a USA study conducted by Zegeer et al. (1990), shows accident reductions than can be expected from traffic lane/shoulder widening in curves.

Figure HA-17 Lane widening in curve

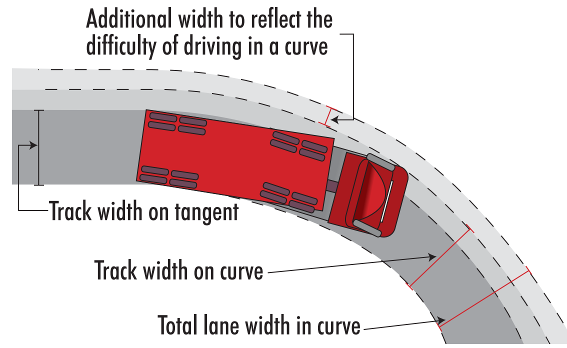
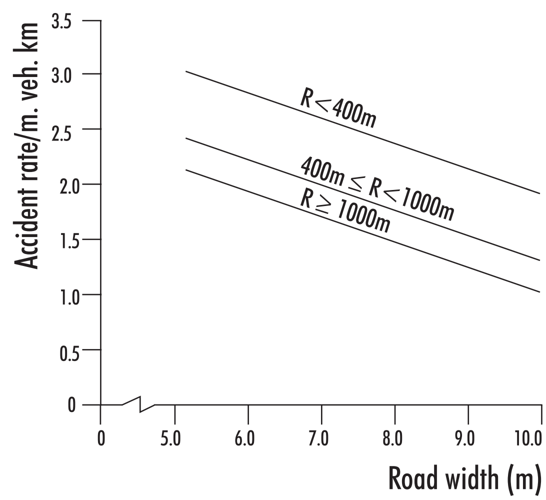


Figure HA-18 Accident rates in curve and road width



Source: Krebs and Kloeckner (1977)

Table HA-6 Accident reduction (%) due to lane or shoulder widening

WIDENING (m)		ACCIDENT REDUCTION (%) WIDENING OF		
TOTAL	PER SIDE	LANES	PAVED SHOULDERS	UNPAVED SHOULDERS
0.6	0.3	5	4	3
1.2	0.6	12	8	7
1.8	0.9	17	12	10
2.4	1.2	21	15	13
3.0	1.5		19	16
3.6	1.8		21	18
4.2	2.1		25	21
4.8	2.4		28	24
5.4	2.7		31	26
6.0	3.0		33	29

Source: Zegeer et al. (1990)

How to detect problems (road width)

Accidents:

- run-off the road accidents, head on collisions, sideswipes.

Traffic operation:

- encroachments (on adjacent lane or shoulder).

Road characteristics:

- compare the required curve road width and the available road width.

Possible measures

- road widening.

SHOULDERS

Description

On rural roads, shoulders should be clear of objects and stabilized, in order to facilitate recovery of encroaching vehicles. The quality of shoulders in curves deserve special attention, given that the probability of encroachment is higher at these locations.

Erosion can quickly degrade gravel shoulders, particularly in areas with heavy rainfall or abundant water run-off (e.g. at sag curves).

Drop-offs between lane and shoulder increase the risk of loss of control (Figure HA-19).

Figure HA-19 Examples – Shoulder maintenance problems

Pavement drop-off

Grass on shoulder

Safety

According to Zegeer et al. (1992), sealing shoulders reduces the number of accidents by 5%.

How to detect problems

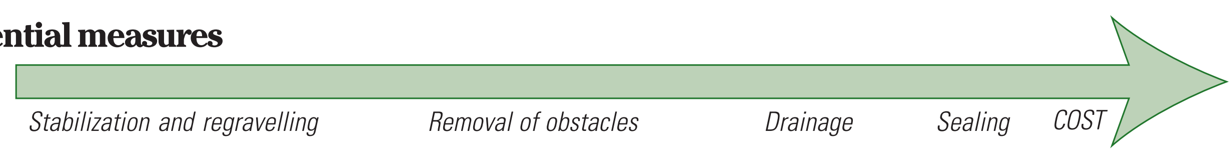
Accidents:

- run-off-the road accidents.

Road characteristics:

- check if shoulder condition allows the recovery of encroaching vehicles (width, stability, surface material, drop-off);
- check the presence of obstacles on shoulder (pole, mailbox, vegetation, etc.).

Potential measures



ROADSIDES – SIGHT DISTANCE

Description

As anywhere else on the road, the sight distance at any point of a horizontal curve must be sufficient to allow safe stopping manoeuvres. Various obstacles located on the inside of curves can hinder visibility, such as embankments, vegetation, buildings, and so on. Adequate lateral clearance (LC) on the inside of curves must be provided to ensure safety. The size of the lateral clearance zone depends on the curve braking distance (Figure HA-20).

[BRAKING DISTANCE (CURVE)]

For the calculation of the required LC zone, two cases can theoretically be distinguished: the stopping distance exceeds the length of the curve ($S > L_C$) or inversely ($S < L_C$). Formulas for the first case are more complex and they are in practice rarely used as LC is always larger when $S < L_C$ ***(Appendix VA-4)***. The lateral clearance distance calculator provides LC values for this latter case.

[LATERAL CLEARANCE]

On flat terrain, the lateral clearance zone can also be established graphically by drawing several lines along the curve. The length of each line corresponds to the stopping distance (one end of the line represents the driver position while the other end represents the object on the road) (Figure HA-21).

Relatively low objects located on the roadside may impede visibility. (Figure HA-22).

Figure HA-20 Lateral clearance in curve

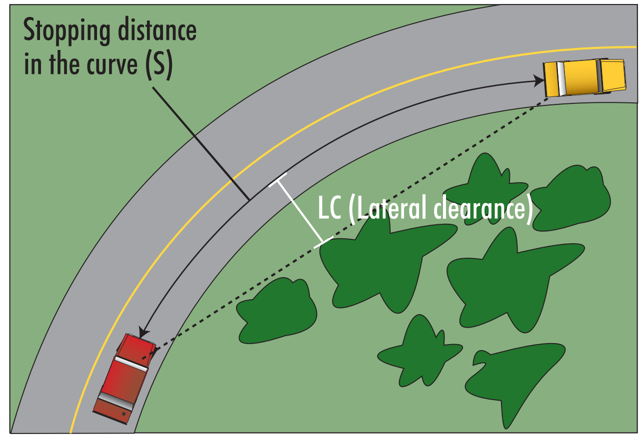


Figure HA-21 Graphical determination of vision lines in a curve

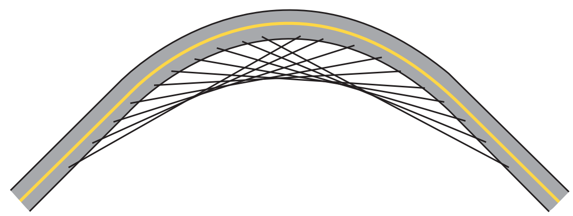
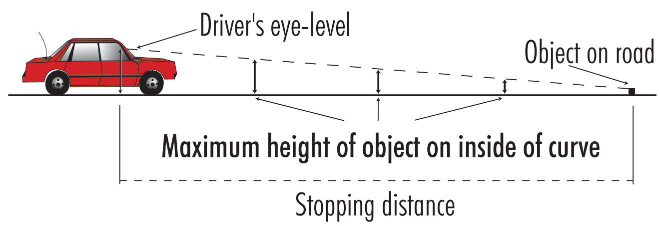


Figure HA-22 Maximum height of an object on the inside of a curve



The braking distance for heavy vehicles equipped with conventional braking systems is significantly longer than for passenger vehicles (Table HA-7). In some instances, the higher eye-level compensates for the increased braking distance. However, this may not be the case when roadside objects are high. In such situations, the lateral clearance distance should be calculated for heavy vehicles.

Table HA-7 Stopping distances – Passenger cars and trucks

	DESIGN SPEED (km/h)							
	40	50	60	70	80	90	100	110
Stopping distances (m)								
- Passenger cars	45	65	85	110	140	170	210	250
- Trucks	70	110	130	180	210	265	330	360

Source: Transportation Association of Canada, 1999

How to detect problems (sight distance)

Accidents:

- rear-end collisions, right-angle collisions (at intersection or road access), head-on collisions.

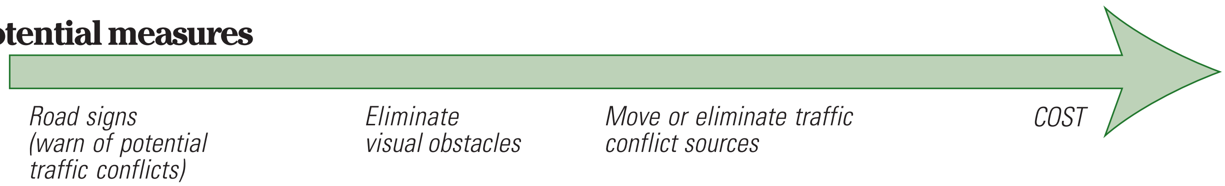
Traffic operation:

- traffic conflicts, skid marks.

Road characteristics:

- compare available sight distances at the site with stopping distances;
- check for permanent, temporary or seasonal sight obstructions (e.g. vegetation);
- check for sources of traffic conflicts where sight is restricted (intersection, crossing, driveway, etc.).

Potential measures



ROADSIDES – FORGIVING ROAD

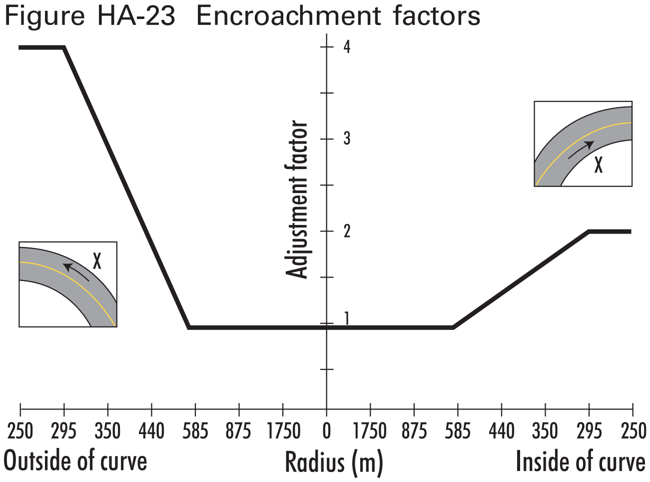
Description

The roadside encroachment rate is much higher in curves than in tangents. According to the Roadside design guide (American Association of State Highway and Transportation Officials, 2002), this rate is as much as four times higher on the outside of curves as in tangents and as much as twice as high as on the inside of curves (Figure HA-23).

To reduce the severity of off-road accidents, an obstacle-free area must be provided along the road. Given that the lateral extent of encroachment increases with speed, the clearance distance also increases with speed (Figure HA-24). Due to budgetary constraints, the width of the clearance zone is also influenced by the road category and the traffic volume.

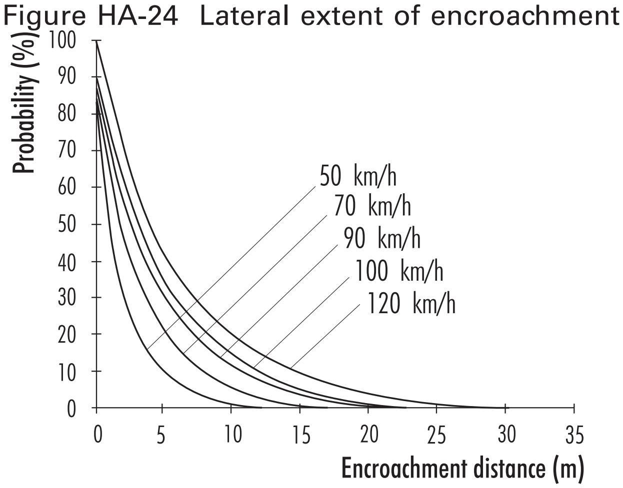
In North America, a clearance distance of 10 m is generally recommended on freeways and equivalent distances are even longer in some European countries. When land acquisition or terrain characteristics make it impossible to satisfy clearance requirements, lateral barriers need to be installed to shield road users against hazardous roadside conditions. However, it should be recognized that these equipments may themselves constitute road hazards and as such, they should not be preferred over a sound treatment of roadsides.

Figure HA-23 Encroachment factors



Source: Roadside Design Guide, Copyright 2002, by the American Association of State Highway and Transportation Officials, Washington, D.C. Used by permission.

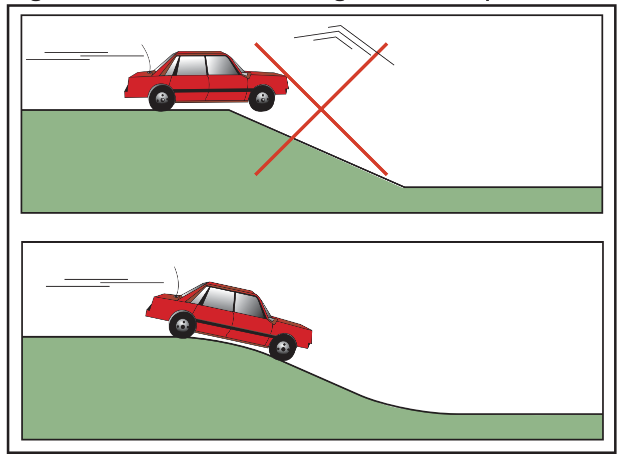
Figure HA-24 Lateral extent of encroachment



Source: Roadside Design Guide, Copyright 1996, by the American Association of State Highway and Transportation Officials, Washington, D.C. Used by permission.

Steep side slopes are simply another kind of roadside obstacle and should be avoided. The maximum gradient that can be travelled by errant vehicles in the order of 1:3 to 1:4. The angle between shoulder/slope and slope/adjacent land should also be smoothed.

Figure HA-25 Smoothing of sideslopes



Safety

Estimates of the total accident reduction resulting from roadside improvements are indicated in Tables HA-8 and HA-9, based on American studies conducted by Zegeer et al. (1990, 1992).

How to detect problems

Accidents:

- fixed objects accidents, rollover accidents;

Road characteristics

Check for:

- unprotected obstacles in the clearance zone, e.g. trees, rocks, rigid structures: bridge, wall, drainage facility, pole, road sign, mail box, etc.;
- steep side slopes;
- presence (and depth) of water in ditches;
- broken safety equipment (guardrails, crash cushions).

Table HA-8 Accident reduction (%) for increased lateral clearance zones

INCREASE OF THE LATERAL CLEARANCE ZONE (m)	ACCIDENT REDUCTION (%)
1.5	9
2.4	14
3.0	17
3.7	19
4.6	23
6.1	29

Source: Zegeer et al., 1992

Table HA-9 Accident reduction (%) due to the flattening of side slopes on curves

SIDE SLOPE BEFORE	SIDE SLOPE AFTER			
	4:1	5:1	6:1	7:1 or more
2:1	6	9	12	15
3:1	5	8	11	15
4:1	-	3	7	11
5:1	-	-	3	8
6:1	-	-	-	5

Source: Zegeer et al., 1990

Potential measures

In the case of unprotected obstacles, four types of measures can be taken:

- elimination;
- relocation;
- fragilization;
- protection.

In the case of steep side slopes:

- flatten the slope;
- smooth the angle between shoulder/slope and slope/adjacent land;
- install safety barriers.

PASSING

Description

Passing opportunities should be considered in the curve itself and in a longer road segment comprising the curve and several kilometers of roads around it.

In the curve

Straight segments or curves with long radii are required to obtain the necessary sight distance to pass safely. Passing is seldom possible in a right-hand curve unless it has a very long radius and even then, it is a dubious manoeuvre that should be avoided since the passed vehicle impedes visibility (right-hand side driving). Whenever the available sight distance is insufficient, pavement marking should clearly (and at all times) prohibit passing.

Intermediate radii that are too short for safe passing but can nonetheless encourage some motorists to engage in dangerous manoeuvres should be avoided (Table HA-10).

On a longer road segment

On two-lane rural roads, there must be sufficient passing opportunities to avoid long vehicle queues and dangerous manoeuvres that may result[3]. Some countries recommend minimum alignment percentages with passing sight distance (Table HA-11).

Table HA-10 Radii to be avoided

COUNTRY	RADII (m)
GREAT BRITAIN	700 - 2000
FRANCE	900 - 2000

Table HA-11 Minimum percentage of alignment with passing sight distance

COUNTRY	MINIMUM PERCENTAGE
SWITZERLAND, GERMANY	20%
FRANCE	25%
GREAT BRITAIN	15 - 40% (depending on the road category)

On two-lane roads, passing opportunities are influenced not only by the percentage of the alignment with the required sight distance but also by the availability of passing gaps between oncoming vehicles. Higher traffic volumes increase passing demand but reduce passing gaps, which may justify the construction of an additional lane.

How to detect problems

Accidents:

- head-on collisions, other accidents related to passing manoeuvres.

Traffic operation:

- vehicle queues, dangerous passing manoeuvres.

Road characteristics:

- compare available sight distances with ***passing sight distance***;
- check if pavement marking prohibit hazardous passing manoeuvres;
- check if passing opportunities are sufficient on the route.

Possibles measures

[3] Sight distance can be restricted not only by the presence of horizontal curves but also by features of the vertical alignment and by combinations of both (horizontal and vertical alignments).

WARNING SIGNS AND DEVICES

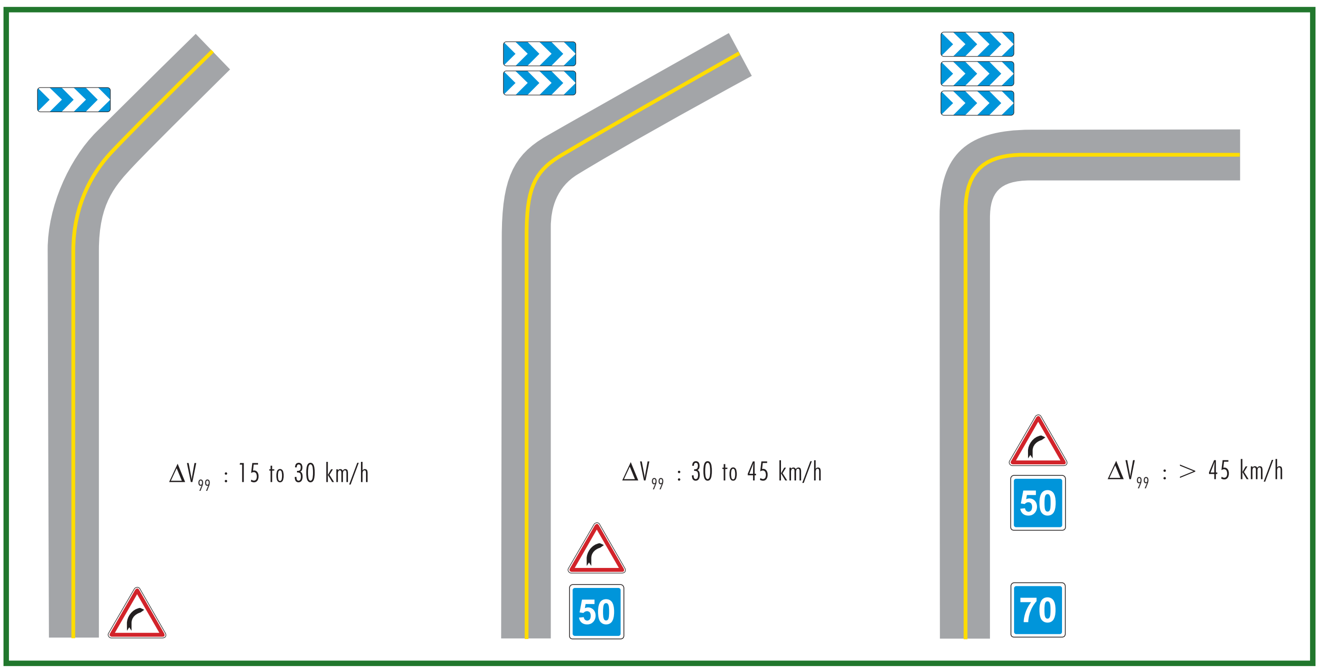
Description

When drivers have to slow down before entering a curve, they need adequate warning to be aware of the required speed modification. In addition to road signs indicating the presence of a curve (and possibly its recommended speed limit), several other types of warning devices can be used: marking, delineators (on road surface or poles), chevrons, rumble strips.

The nature and intensity of the message must be adapted to the conditions encountered: the road category, the required speed reduction, the unexpected nature of the curve, its visibility, and the traffic conflict risk. The use of the same warning measures for the same types of situations is highly recommended to reduce driving errors ***(driver expectancies*** and ***driving task)***.

Figure HA-26 Curve warnings adapted to the road environment

Figure HA-27 Curve warning signs – Spain



Safety

According to Tignor, curve warning signs can reduce accidents by 20% (ITE, 1999).

How to detect problems (road signs)

Accidents:

- run-off-the-road accidents.

Traffic operation:

- late braking, encroachments, excessive speeds.

Road characteristics:

Check for:

- existing road signs and compare with recommended standards (missing or superfluous equipment, size, location, height);
- visibility and conspicuity of roads signs;
- condition (worn, broken, clean, retroreflective);
- adequacy of the information provided for the situation (expectancy violations).

COMBINATION OF FEATURES

Description

Because of the inherent difficulties of the driving task in horizontal curves, drivers may have problems, at these locations, to deal with extraneous road or traffic features that require some of their attention. Consequently, one should avoid combining sharp horizontal curves with features that add to the driving complexity: potential sources of traffic conflicts (intersections, crossings, private accesses), sources of distraction (commercial signs, roadside activities, etc.), or other elements (hill, narrow bridge, end of lane, etc.).

Road narrowing and roadside commercial activity when approaching a tunnel in curve.

Accident at an intersection in a curve

Potential measures

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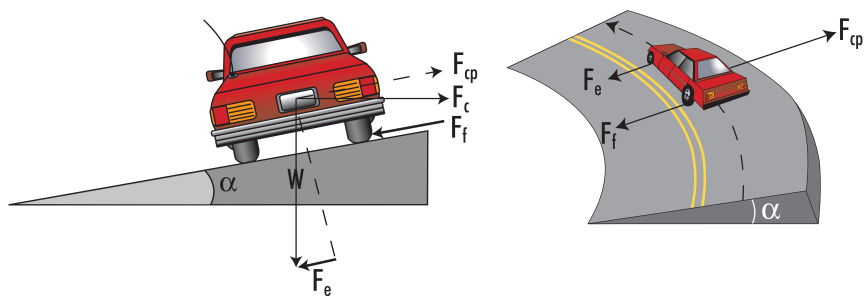
APPENDICES HORIZONTAL ALIGNMENT

APPENDIX HA-1: DYNAMICS IN HORIZONTAL CURVES

A vehicle travelling in a curve is pushed outwards the road by the centrifugal force. The friction between the tires and the road and the superelevation counteract this force.

Figure HA-A1 Forces acting on a vehicle in a curve



where:

- F_c = centrifugal force (N)
- F_{cp} = centrifugal force parallel to the road surface (N)
- F_f = force of transverse friction (N)
- F_e = superelevation force (N)
- W = weight of the vehicle (N)
- α = incline of the superelevation (°)

When in balance, the system of forces parallel to the road surface is:

$$F_{cp} = F_f + F_e$$

By developing each term and given than the centrifugal acceleration is equal to v^2/R, we obtain

$$\frac{Wv^2}{gR}\cos\alpha = W\cos\alpha \times f_t + W\sin\alpha$$

where:

- v = speed (m/s)
- R = curve radius (m)
- f_t = coefficient of transverse friction
- g = 9.81m/s²

By dividing each term by W cos α and since tan α = e, we obtain:

$$\frac{v^2}{gR} = f_t + e$$

The speed in a curve can therefore be computed as a function of R, e and f_t:

$$V = \sqrt{127R\,(e + f_t)}$$

where:

- V = speed (km/h)
- e = superelevation (m/m)

And the minimum curve radius can be computed as a function of V, e and f_t:

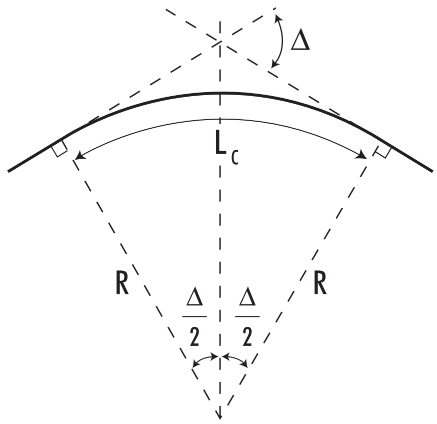
$$R = \frac{V^2}{127(e + f_t)}$$

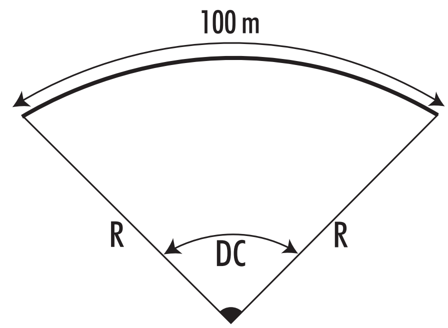
Calculators have been developed to compute V and R.

[HORIZONTAL CURVE - RADIUS] [HORIZONTAL CURVE - SPEED]

APPENDIX HA-2: GEOMETRY OF HORIZONTAL CIRCULAR CURVES

Figure HA-A2 Geometry of circular curves





A degree is equal to 1/360 circle (sexagesimal system) and a gon is equal to 1/400 circle (centesimal system).

	Sexagesimal system		Centesimal system	
Deflection angle (Δ)	$\Delta = \frac{L_c \times 180}{\pi R}$	(degrees)	$\Delta = \frac{L_c \times 200}{\pi R}$	(gons)
Length of the arc of the circle (L_c)	$L_c = \frac{\Delta \pi R}{180}$	(m)	$L_c = \frac{\Delta \pi R}{200}$	(m)
Radius (R) Radius of the arc of the circle	$R = \frac{L_c \times 180}{\Delta \pi}$	(m)	$R = \frac{L_c \times 200}{\Delta \pi}$	(m)
Degree of curve (DC) DC = Angle of deviation of a 100 m arc.	$DC = \frac{5{,}730}{R}$	$\left(\frac{\text{degrees}}{100\text{ m}}\right)$	$DC = \frac{6{,}370}{R}$	$\left(\frac{\text{gons}}{100\text{ m}}\right)$
Curvature change rate (CCR) CCR = Angle of deviation of a 1 km arc	$CCR = \frac{57{,}300}{R}$	$\left(\frac{\text{degrees}}{\text{km}}\right)$	$CCR = \frac{63{,}700}{R}$	$\left(\frac{\text{gons}}{\text{km}}\right)$

Relationships between degrees, radians and gons

$$\alpha_{rad} = \alpha^{\circ} \times \frac{\pi}{180^{\circ}}$$

$1^{\circ} = 0.0175$ radian

1 radian $= 57.3^{\circ}$

$$\alpha_{rad} = \alpha^{g} \times \frac{\pi}{200^{g}}$$

$1^{g} = 0.0157$ radian

1 radian $= 63.7^{g}$

$$\alpha^{\circ} = \alpha^{g} \times \frac{180}{200^{g}}$$

$1^{g} = 0.9^{\circ}$

$1^{\circ} = 1.11^{g}$

APPENDIX HA-3A: CALCULATION OF SPEED DIFFERENTIALS (Lamm et al., 1999)

2 lane rural roads

Main assumptions:

- the operating speed in a curve is deemed to be constant and calculated using a regression equation (Table HA-12 shows equations from several countries);
- a vehicle's speed in a tangent is calculated with the same equation, using CCR = 0;
- when approaching and exiting a curve, the recommended acceleration and deceleration rates are 0.85 m/s².

Table HA-A1 Regression models for operating speeds – Two-lane rural roads

COUNTRY	MODEL (km/h)	SPEED LIMIT (km/h)
Germany	$V_{85} = \dfrac{10^6}{8{,}270 + 8.01\ CCR}$	100
Australia	$V_{85} = 101.2 - 0.043\ CCR$	90
Canada	$V_{85} = e^{(4.561 - 5.27 \times 10^{-4}\ CCR)}$	90
United States	$V_{85} = 103.04 - 0.053\ CCR$	90
France	$V_{85} = \dfrac{102}{1 + 346(CCR/63700)^{1,5}}$	90
Greece	$V_{85} = \dfrac{10^6}{10{,}150.1 + 8.529\ CCR}$	90
Lebanon	$V_{85} = 91.03 - 0.056\ CCR$	80

Source: Lamm et al. in Highway design and traffic safety engineering handbook. Copyright 1999 by McGraw-Hill Compagnies, Inc.

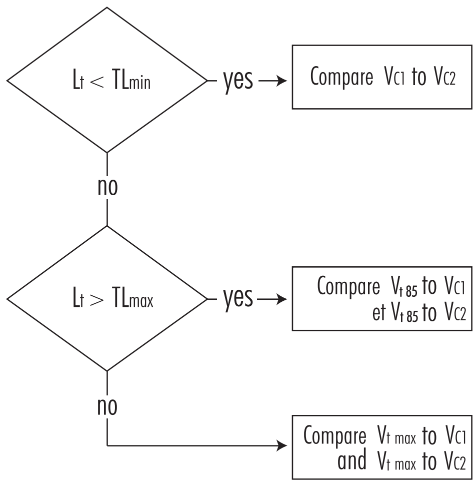
Procedure

Step 1 - Calculate the following parameters:

Table HA-A2 Definition of parameters

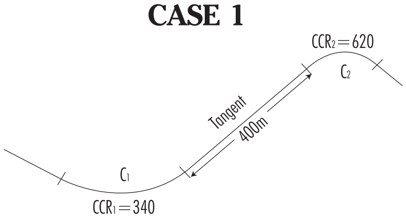
PARAMETERS	DESCRIPTION	SOURCE
V_{C1}	Operating speed in curve 1	Equations in Table HA-A1
V_{C2}	Operating speed in curve 2	Equations in Table HA-A1
L_t	Tangent length between two curves	Measurements from site / plans / data
$V_{t\ 85}$	Desired speed	Equations in Table HA-A1, CCR = 0
TL_{min}	Tangent length necessary for a vehicle to go from an initial speed (V_{C1}) to a final speed (V_{C2}) with an acceleration or deceleration rate of a or d.	$TL_{min} = \left\lvert \dfrac{V_{C1}^2 - V_{C2}^2}{25.92 \times a} \right\rvert$ or $TL_{min} = \left\lvert \dfrac{V_{C1}^2 - V_{C2}^2}{25.92 \times d} \right\rvert$
TL_{max}	Tangent length necessary for a vehicle to accelerate from an initial speed (V_{C1}) to a desired speed ($V_{t\ 85}$) and decelerate to a final speed (V_{C2}) with acceleration and deceleration rates of a and d.	$TL_{max} = \left\lvert \dfrac{V_{C1}^2 - V_{t85}^2}{25.92 \times a} \right\rvert + \left\lvert \dfrac{V_{t85}^2 - V_{C2}^2}{25.92 \times d} \right\rvert$
$V_{t\ max}$	Maximum speed reached when the length of the tangent does not allow the motorist to reach the desired speed.	$V_{t\ max} = \sqrt{\dfrac{V_{C1}^2 + V_{C2}^2 + 25.92 \times a \times L_t}{2}}$

Step 2 - Follow the algorithm below:



Examples

CASE 1



2 curves:

$CCR_1 = 340$
$CCR_2 = 620$

Separated by a 400 m tangent

French speed equation:

$V_{C1} = 90$ km/h
$V_{C2} = 77$ km/h
$L_t = 400$ m

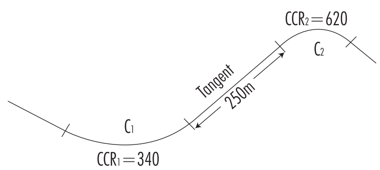
$V_{t\ 85} = 102$ km/h
$TL_{min} = 99$ m
$TL_{max} = 308$ m
$Vt_{max} = 106$ km/h
$L_t < TL_{min}$? no
$L_t > TL_{max}$? yes

Therefore, compare:
$V_{t\ 85}$ to V_{C1} ; $V_{t\ 85}$ to V_{C2}

102 km/h vs 90 km/h (acceptable)

102 km/h vs 77 km/h (poor)

CASE 2



2 curves:

$CCR_1 = 340$
$CCR_2 = 620$

Separated by a 250 m tangent

French speed equation:

$V_{C1} = 90$ km/h
$V_{C2} = 77$ km/h
$L_t = 250$ m

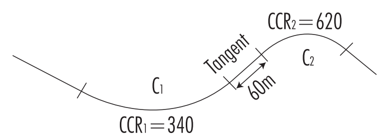
$V_{t\ 85} = 102$ km/h
$TL_{min} = 99$ m
$TL_{max} = 308$ m
$Vt_{max} = 99$ km/h
$L_t < TL_{min}$? no
$L_t > TL_{max}$? no

Therefore, compare:
$V_{t\ max}$ to V_{C1}; $V_{t\ max}$ to V_{C2}

99 km/h vs 90 km/h (good)

99 km/h vs 77 km/h (poor)

CASE 3



2 curves:

$CCR_1 = 340$
$CCR_2 = 620$

Separated by a 60 m tangent

French speed equation:

$V_{C1} = 90$ km/h
$V_{C2} = 77$ km/h
$L_t = 60$ m

$V_{t\ 85} = 102$ km/h
$TL_{min} = 99$ m
$TL_{max} = 308$ m
$Vt_{max} = 88$ km/h
$L_t < TL_{min}$? yes

Therefore, compare:
V_{C1} to V_{C2}

90 km/h vs 77 km/h (acceptable)

APPENDIX HA-3B: CALCULATION OF SPEED DIFFERENTIAL (SPAIN):

1. Determine V_{99} in curve, based on the following equation:

$$V_{99} = \sqrt{127R\,(0.25 + e)}$$

2. In preceding tangent, determine V_{99} which is a function of D_t, with

$$D_t = D + D_a + D_s$$

Where:

D = length of tangent (distance between 2 curves)

D_a = distance to accelerate from the V_{99} in the curve preceding the tangent (V_{99} computed with equation in 1. above). This distance is given by Figure HA-A4 below.

D_s = distance to decelerate to the V_{99} in the curve under study (V_{99} is computed with equation in 1. above). This distance is given by Figure HA-A5 below.

V_{99} in the preceding tangent is given by the Figure HA-A3.

3. Compare V_{99} in preceding tangent and V_{99} in curve (based on ***Table HA-2***).

Figure HA-A3 Operational speed in the preceding tangent (V_{99})

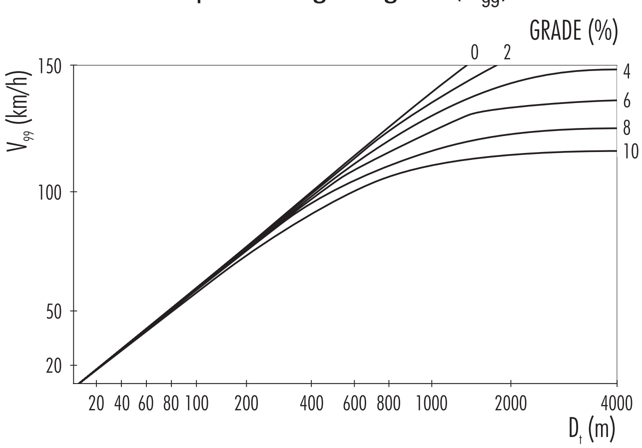


Figure HA-A4 Distance to accelerate from V_{99} in the curve preceding the tangent

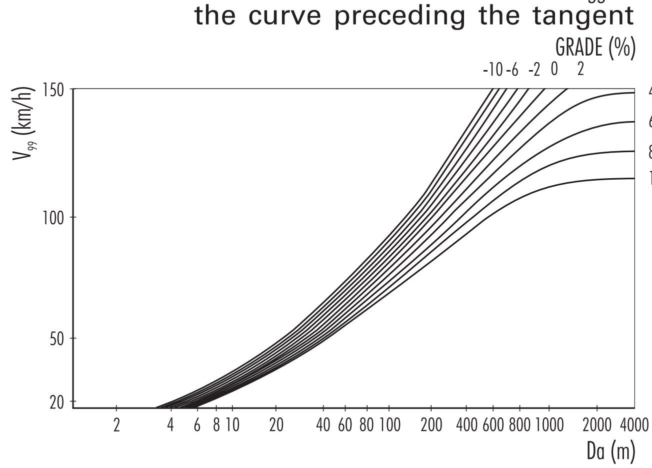
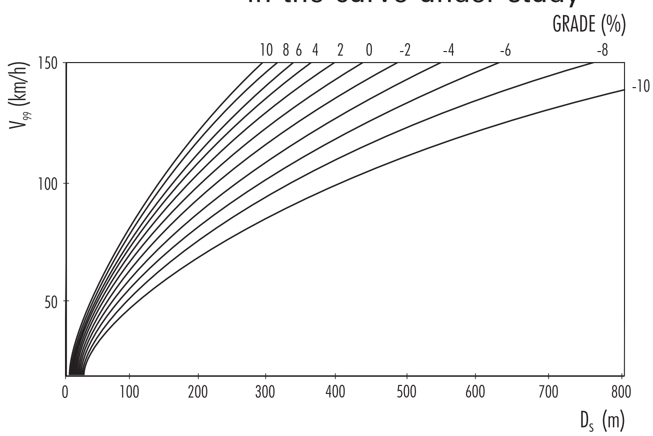


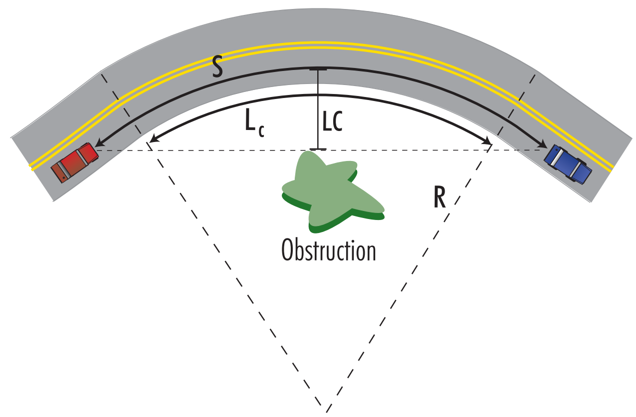
Figure HA-A5 Distance to decelerate to V_{99} in the curve under study



APPENDIX HA-4: HORIZONTAL CURVE GEOMETRY AND SIGHT DISTANCE

A mathematical relation exists between the distance without any visual obstruction (LC) on the interior side of horizontal curves and the available sight distance. Equations differ if the stopping sight distance (S) is less or more than the curve length (L_c).

Figure HA-A6 Sight distance in a horizontal curve



For $S < L_c$

$$LC = R \times \left(1 - \cos \frac{90 \times S}{\pi \times R}\right)$$

For $S > L_c$

$$LC = R \times \left(1 - \cos \frac{90 \times L_c}{\pi \times R}\right) + \left(\frac{S - L_c}{2}\right) \times \sin \frac{90 \times L_c}{\pi \times R}$$

where :

S = stopping sight distance
L_c = curve length
LC = lateral clearance
R = curve radius

VERTICAL ALIGNMENT

Technical sheet

Patrick Barber and Carl Bélanger

VERTICAL ALIGNMENT

Technical sheet

LIST OF FIGURES

LIST OF TABLES

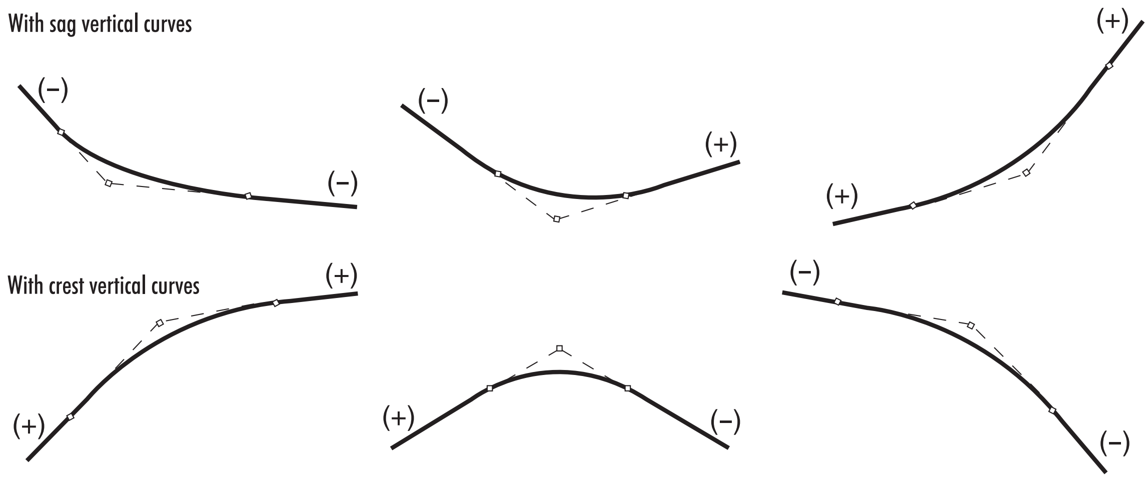
LIST OF ABBREVIATIONS		
a_c	=	coasting acceleration (ft/s^2)
a_p	=	horsepower limited acceleration (ft/s^2)
A	=	algebraic grade difference of consecutive straight segments $\|G1 – G2\|$
A_f	=	vehicle frontal area (ft^2)
C	=	overhead clearance (m)
C_{de}	=	correction factor for converting sea level aerodynamic drag to the local elevation
C_{pe}	=	correction factor for converting sea level net horsepower to local elevation
d	=	distance interval (m)
E	=	energy (J)
E_{kin}	=	kinetic energy (J)
E_{pot}	=	potential energy (J)
f_l	=	coefficient of longitudinal friction
F_a	=	air resistance (N)
F_g	=	grade resistance (N)
F_r	=	rolling resistance (N)
F_{tot}	=	total resistance (N)
F_w	=	tractive effort (N)
g	=	gravitational constant (9.8 m/s^2)
G	=	grade percent (%)
h_1	=	eye height of drivers (m)
h_2	=	object height (m)
h_3	=	height of head lamps (m)
K	=	horizontal distance needed to produce a 1% change in grade
k1, k2	=	constants
L	=	horizontal length of vertical curve (m)
m	=	vehicle mass (kg)
NHP	=	net power at sea level conditions (hp)
P_B	=	braking power (hp)
P_E	=	engine braking power (hp)
P_F	=	friction power (hp)
P_g	=	grade power (hp)
R	=	radius of the vertical curve (m)
S	=	sight distance (m)
S_p	=	+1 or -1, based on the sign of a_p
t	=	time (s)
t_r	=	reaction time (s)
T_a	=	ambient temperature (°F)
T_i	=	initial brake temperature (°F)
T(t)	=	brake temperature at time t (°F)
v	=	vehicle speed (m/s ou ft/s)
V	=	speed (mph)
V_f	=	final speed (km/h)
V_i	=	initial speed (km/h)
W	=	vehicle weight (lbs)
x	=	horizontal distance
y	=	height of slope (m)

SUMMARY

General Principles

The vertical alignment of a road consists of straight segments (levelled or inclined) connected by sag or crest vertical curves. Combinations of these elements create various shapes of road profiles (Figure VA-1).

Figure VA-1 Examples – Vertical alignments



The grade percent (G), height of slope (y) and K value characterize the vertical alignment (Figure VA-2). The maximum values of G and K that are recommended in several countries are shown in Appendix VA-1.

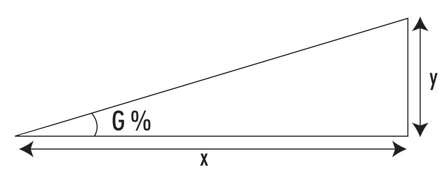
Figure VA-2 Definitions

STRAIGHT SEGMENTS

$$G = 100 \times \frac{y}{x} \qquad \text{[Eq. VA-1]}$$

where:

G = grade percent (%)
y = height of slope (m)
x = horizontal distance (m)

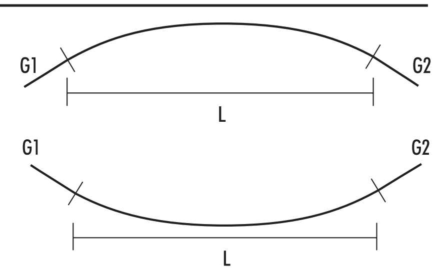


VERTICAL CURVES

$$K = L/A \qquad \text{[Eq. VA-2]}$$

where:

K = horizontal distance needed to produce a 1% change in grade
L = horizontal length of vertical curve (m)
A = algebraic grade difference of consecutive straight segments
= $|G1 - G2|$



Accidents

- Accidents occur more frequently on grades than on level sections. Accident frequency increases with grade percent, at a rate of 1.6% for each grade percentage (Harwood et al., 2000).
- Accident frequency and severity are higher on downhill grades than on uphill grades, with a high involvement of heavy vehicles.
- The difference in height between the top and bottom of a slope is seen as a better indicator of accident risk than the grade percentage (Service d'études techniques des routes et autoroutes, 1997).

Observations

The main elements to consider when conducting a safety analysis at a grade are:

- **on downhill grades:** increases in braking distances and possibility of heavy vehicle brake overheating;
- **on uphill grades:** speed differentials between passenger cars and heavy vehicles;
- **on crest curves:** restricted sight distances;
- **on sag curves:** water accumulation and accelerated erosion of shoulders due to water run-off.

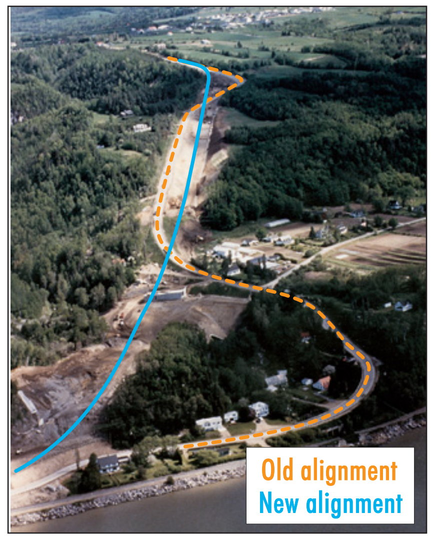
This technical sheet describes these various problems.

Combination of features

Vehicle acceleration on downhill grades, due to the action of the gravitational force, increases the difficulty of eventual slowdowns or complete stops. As a general principle, the presence of features that increase the probability of having to carry out such manoeuvres should be avoided, for example:

- intersection or other crossing (railway, crosswalk, bike path, etc.);
- sharp horizontal curve;
- narrow structures (bridge, tunnel, viaduct, etc.).

The risk is amplified when the feature is at the bottom of the grade, since speeds are higher and the probability of brake overheating is more significant.



Alignment modification to eliminate a sharp curve at the bottom of a steep grade

Possible solutions

Modifying a vertical alignment is often too costly to be considered. According to a U.S. synthesis report (Transportation Research Board, 1987), the reconstruction of a crest vertical curve should be considered when:

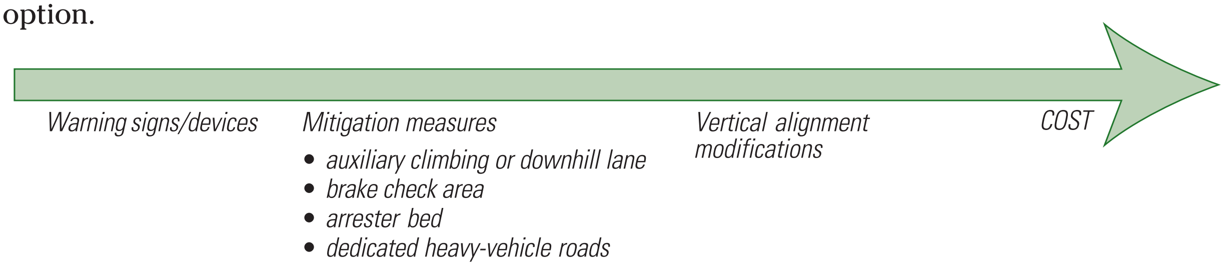
a) *the hill crest hides from view major hazards such as intersections, sharp horizontal curves, or narrow bridges;*

b) *the average daily traffic is greater than 1,500 vehicles per day;*

c) *and, the design speed of the hill crest (based on the minimum stopping sight distance provided) is more than 20 mph (32 km/h) below the running speeds of vehicles on the crest.*

In most cases, less costly mitigation measures are implemented (road sign, construction of brake check area, auxiliary climbing or downhill lane, arrester bed, etc.).

Since safety problems in grades primarily involve heavy vehicles, solutions aimed at limiting their presence at high-risk locations may also be considered, when permitted by the configuration of the road network (dedicated heavy-vehicle roads). Mandatory engine brakes for heavy vehicles is also an option.



DOWNHILL GRADES – GENERALITIES

From a safety perspective, the main elements that need to be considered in downhill grades are the increase in stopping distances and the possibility of brake overheating ***(Appendix VA-2)***.

Stopping distance

The increase in stopping distance can be significant. For example, Table VA-1 shows that with an initial speed of 100 km/h and a friction coefficient of 0.28, the braking distance increases by 37% (78 m) when comparing a 10% grade to a levelled road.

[BRAKING DISTANCE (TANGENT)] [1)]

Brake temperature (heavy vehicles)

The critical brake temperature is around 260°C. Above this point, the efficiency of braking systems is reduced, due to various physical phenomenons (expansion, deformation, etc.). Several mathematical models have been developed to estimate the brake temperature profile on downhill grades. The "***Grade-brake temperature***" calculator included in the CD-ROM version of this manual is based on the model developed by Myers et al. (1980), in which the brake temperature depends on the following factors:

- percentage and length of grade;
- engine compression, retarders;
- downhill speed;
- initial brake temperature;
- vehicle mass;
- emergency stop in descent.

Details are provided in ***Appendix VA-2***.

[GRADE ANALYSIS]

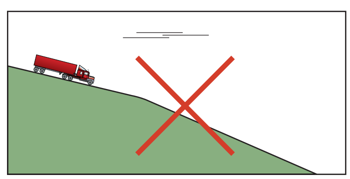
Table VA-1 Examples – Braking distances

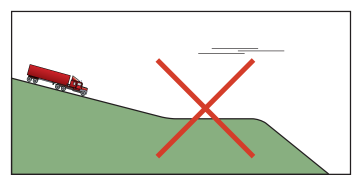
DOWNHILL GRADE (%)	BRAKING DISTANCE (m)
0	210
5	241
10	288

(Initial speed: 100 km/h, reaction time: 2.5 sec., friction coefficient: 0.28).

Compound Grades

Grades made up of segments having different grade percentages can mislead drivers about the upcoming vertical profile. Drivers of heavy vehicles who are not familiar with the area may then initiate their descent at speeds that are too high for conditions. The situation is exacerbated when a steep grade is preceded by a gentle slope on a flat segment.





How to detect problems

Accidents:
- accidents involving a heavy vehicle, out-of-control vehicle.

Traffic operation:
- high speed differentials between heavy vehicles and passenger cars;
- excessive speeds, queues of vehicles, hazardous passing manoeuvres.

Road characteristics:
- grade percentages higher than recommended values;
- unexpected characteristics (first steep grade, compound grades).

Possible measures

see: ***Vertical alignment summary – possible solutions***

[1)] The braking distance calculator yields the stopping distance when the final speed (V_f) is set to 0.

ROAD SIGNS

Description

Heavy vehicle drivers should have sufficient information about the profile of the grade before initiating their descent so that they can adjust their speed right from the top and avoid difficult deceleration manoeuvres midway down. General guidelines are provided in Table VA-2.

Signs must not be located too far from the beginning of the slope as to diminish their credibility. The recommended distances should be adapted to the operating speed. According to Baass (1993), warning signs should be located from 25 m (30 km/h) to 200 m (100 km/h), before the beginning of the descent.

How to detect problems

Accidents:

- accidents involving a heavy vehicle, (out of control vehicle).

Traffic operation:

- excessive speeds, late braking.

Road characteristics (road signs):

Check for:

- conformity with standards (missing or superfluous sign, size, location);
- visibility and conspicuity of signs and devices;
- condition of signs and devices (worn, broken, unclean, non-reflective);
- warning level adapted to road characteristics.

Table VA-2 Downhill warning signs
General guidelines

LONG HILL Indicate both percentage and length of grade Repeat signs at regular intervals	 (Europe)
COMPOUND GRADE Indicate respectives percentages	 (North America)
HAZARD AT BOTTOM Give advanced warning of the hazard (intersection, railroad crossing, sharp curve, etc.). Road sign at a brake check area (Québec). Vehicles are stopped outside traffic lanes and drivers have the time to decode this information.	

DRAINAGE

Description

Drainage facilities on grades should allow the rapid clearance of water from the road surface and prevent its accelerated erosion.

Drainage capacity needs to be suited to the heaviest rainfalls that may be reasonably expected in the area.

Deep and open drainage structures near the roadway must be avoided as they constitute rigid obstacles that may aggravate accident severity.

Drainage facilities must be regularly maintained to prevent clogging from accumulated debris.

see also: ***Vertical curves – drainage***

Hazardous drainage facility on a narrow and hilly road

How to detect problems (drainage)

Accidents:

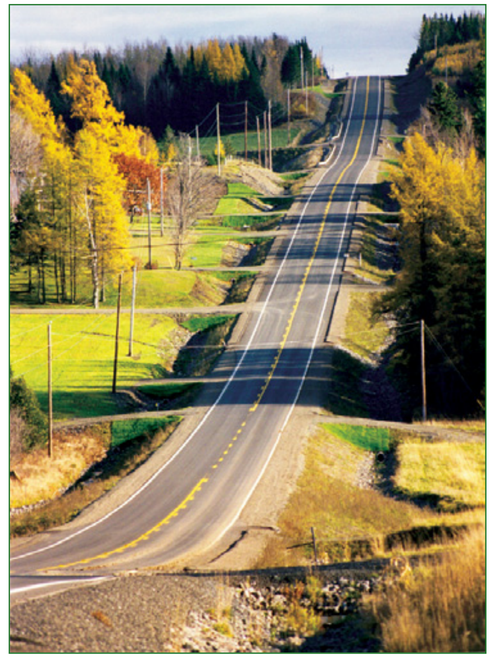
- wet-surface accidents.

Road characteristics:

- capacity of drainage facilities for rainfall conditions (water or debris accumulation, erosion);
- hazardous drainage structures (deep and opened structures close to traffic lanes).

Possible measures

- correction of surface defects;
- transverse grooving;
- improvement of drainage facilities (improve capacity, reduce hazard).



The combination of roadside accesses and deep opened drainage ditches increase the risk and potential severity of accidents

BRAKE CHECK AREAS

Description

Built at the top of some long and steep grades, brake check areas give heavy vehicle drivers an opportunity to stop and check the condition of their vehicle braking system away from traffic.

In addition to giving drivers a chance to detect some obvious mechanical problems (burning odor, smoke), brake check areas also provide the following benefits:

- heavy vehicle drivers are forced to start their downhill run from a stopped position, which eliminates the risk of excessive initial speeds;
- since they are away from traffic, heavy vehicle drivers can be provided with more detailed information on the configuration and difficulties of the grade (e.g. Figure VA-2);

For a brake check area to fully serve its purpose, stopping must be mandatory.

Figure VA-3 Brake check area

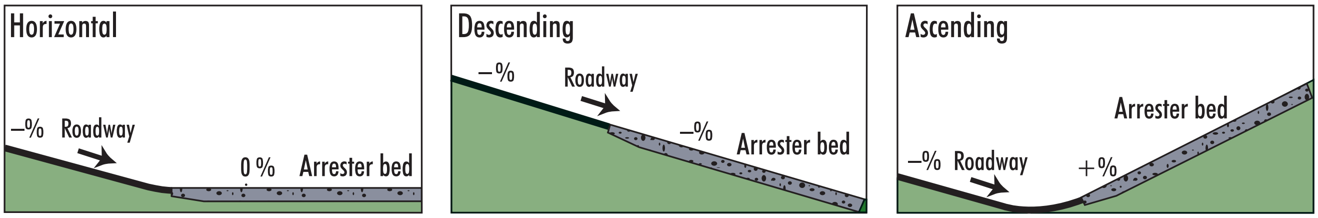
ARRESTER BEDS

Description

Arrester beds are roadside facilities designed to stop runaway heavy vehicles. Granular material is used (5-10 mm, rounded), as it provides more rolling resistance and reduces the length of the bed. Depending on the type of terrain, the arrester bed can be either horizontal, ascending, or descending (Figure VA-4). Ascending designs reduce stopping distances but it makes the use of granular material mandatory, to prevent rollbacks onto the roadway.

[**FILM - ARRESTER BEBS**]

Figure VA-4 Types of arrester beds



The construction of an arrester bed should be considered when:

- the probability of runaway vehicles is high (based on ***accident analyses*** and ***brake temperature profiles***);

[**GRADE ANALYSIS**]

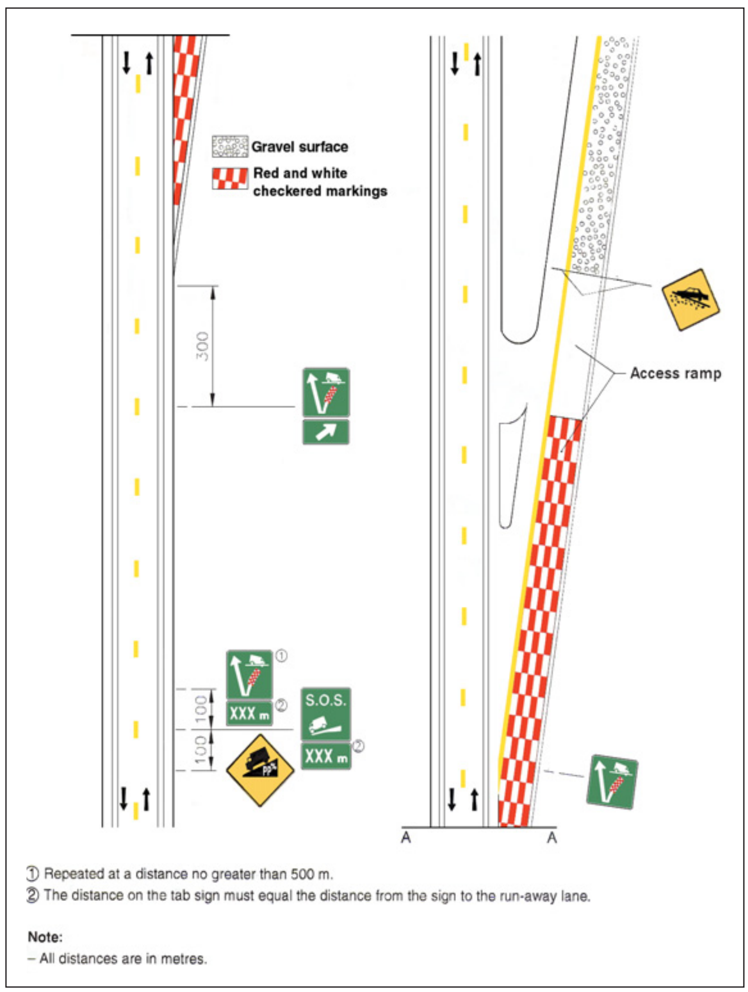
- out-of-control vehicles could cause catastrophic results (e.g. before a village entrance).

They should preferably be located on a tangent section since their location on curves would add to the manoeuvring difficulties facing the driver of a runaway truck.

Advance warning signs and distinctive markings should be used to identify the presence of the arrester bed and guide drivers of out-of-control vehicles. Signs should also be erected to discourage its use by other road users (arrester beds are often at locations offering a panoramic view of the surroundings – an attraction for tourists who are not necessarily familiar with this type of facility).

Due to their high construction costs, arrester beds are built only on a limited number of grades with a history of truck accidents, after the failure of other less costly measures.

Figure VA-5 Example – Road signs and markings at an arrester bed



Source: Ministère des transports du Québec, 1999

UPHILL GRADES – GENERALITIES

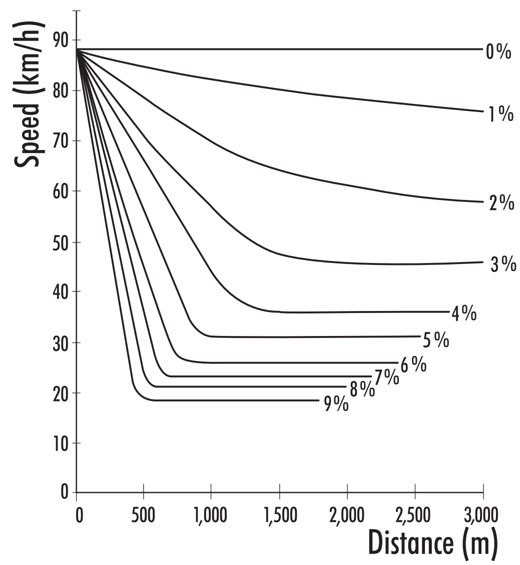
Description

The maximum speed of a vehicle on an uphill grade depends on its mass/power ratio. For passenger cars, this ratio is sufficiently small to maintain a constant speed on most uphill grades. However the much higher mass/power ratios of heavy vehicles may cause significant slowdowns on uphill grades.

Ratios of 180 kg/kW or 8.0 hp/ton are usually used at the design stage to estimate heavy vehicles' accelerations and decelerations on grades. An example of deceleration curves is shown in Figure VA-6. It indicates that even on a 1% uphill grade, a truck is slowed down. The deceleration rate and speed reduction rapidly increase with the steepness of the grade.

Mathematical models have been developed to estimate the speed profile of a vehicle based on its mass/power ratio. The "***Grade-Speed profile***" calculator can be used to determine speed profiles on grades, based on the methodology developed by Allen et al. (2000) (Figure VA-7) (details of the methodology are explained in ***Appendix VA-3***).

Figure VA-6 Deceleration curves



Source: A Policy on Geometric Design of Highways and Streets, Copyright 1994, by the American Association of State Highway and Transportation Officials, Washington, D.C. Used by permission.

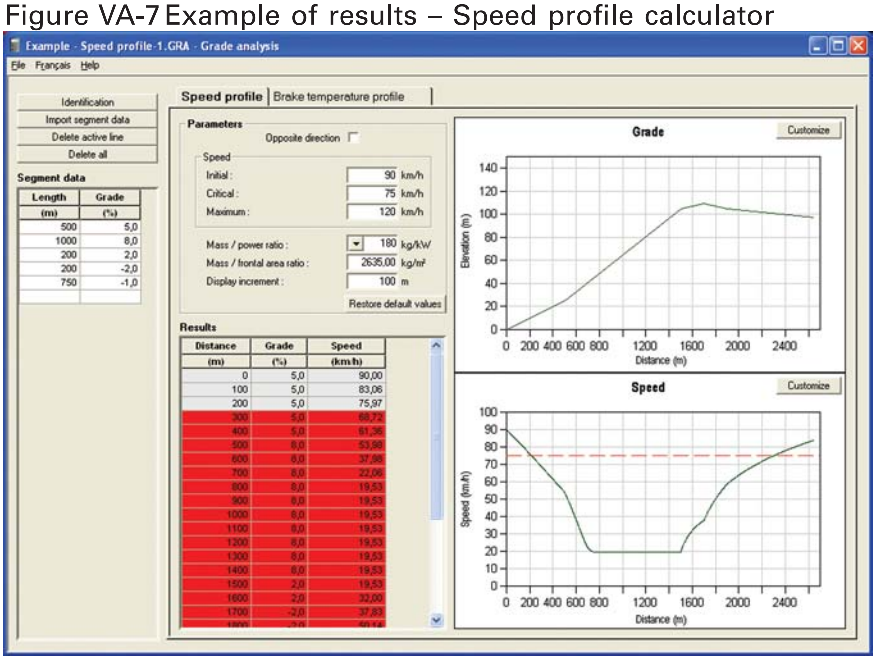
How to detect problems

- **Accidents:**
  - rear end collisions;
  - head on collisions.

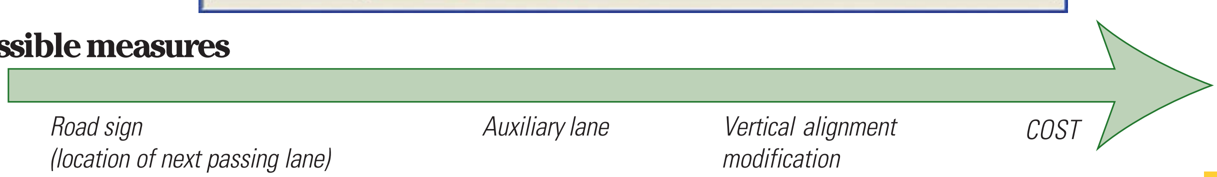
  [GRADE ANALYSIS]

- **Traffic operation:**
  - significant speed differentials;
  - platoons, dangerous passing manoeuvres;
  - calculate the speed profile of a typical heavy vehicle.

Figure VA-7 Example of results – Speed profile calculator



Possible measures



CLIMBING LANES

Description

Auxiliary lanes can be constructed on uphill grades to enable safe passing manoeuvres by slower vehicles.

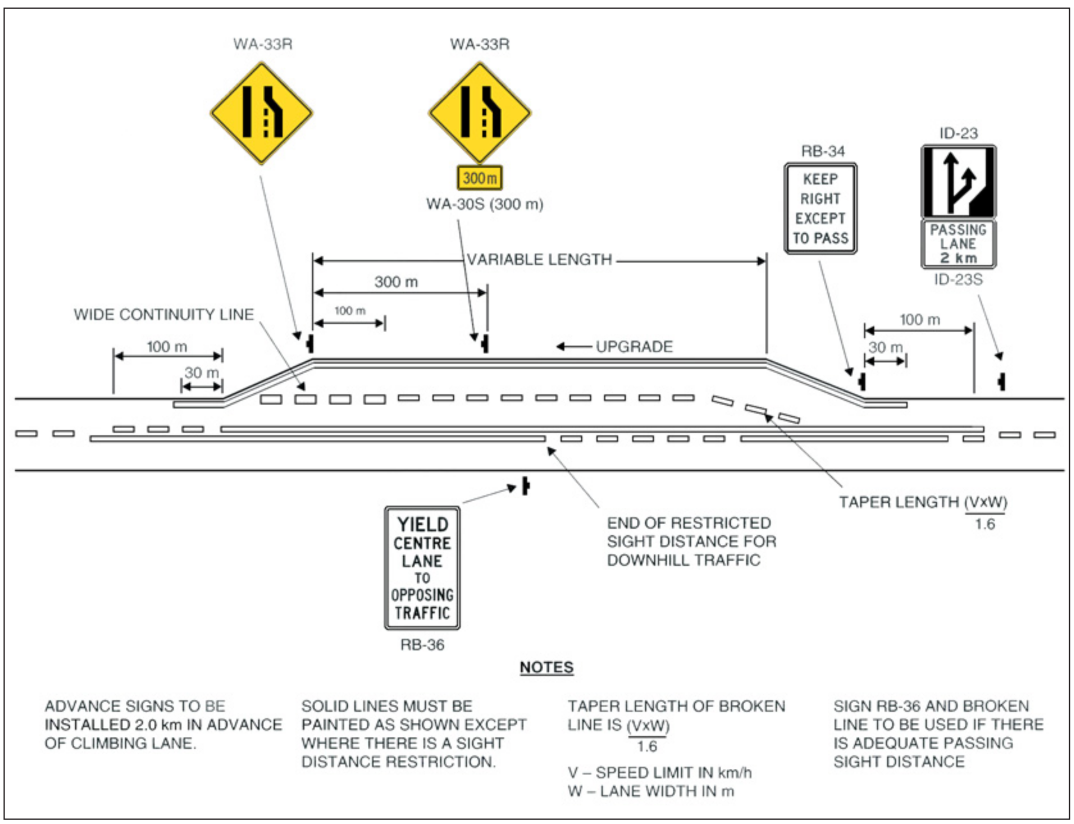
The criteria used to justify the construction of an auxiliary lane differ from one country to another; they are based on a comparison of a heavy vehicle climbing speed with either:

- an absolute minimum speed;
- the heavy vehicle's speed prior to uphill run;
- a passenger car's climbing speed.

In addition to the speed differentials, traffic volumes (total and heavy vehicles) are often considered.

Example – Climbing lane

Figure VA-8 Example – Signing and marking of a climbing lane



Source: Transportation Association of Canada, 1999

Combination of features

Auxiliary lanes encourage passing manoeuvres at relatively high speeds that are incompatible with the slower speeds of vehicles accessing and exiting the road. Therefore, auxiliary lanes should not be located in conjunction with intersections or other access points.

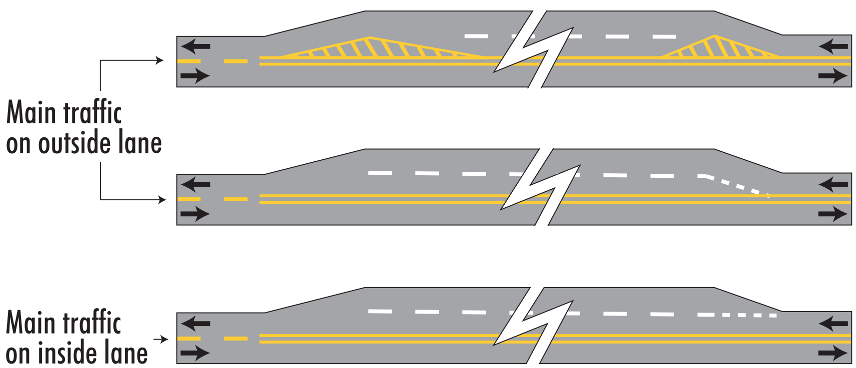
Avoid the combination of intersection and climbing lane on uphill grade.

Traffic Management (climbing lane)

There are two different ways of managing traffic flow at climbing lanes:

- main traffic on outside lanes (the inside lane is reserved for passing);
- main traffic on inside lane (the outside lane is reserved for slower vehicles).

Figure VA-9 Climbing lane – Traffic management



The main traffic on outside lane method is preferred as it is consistent with traffic management rules on the rest of the road network (vehicles stay on the outside lane except when passing) and it makes the climbing lane more effective.

To improve the efficiency and safety of climbing lanes, one must:

- inform drivers in advance of the upcoming climbing lane (e.g. Figure VA-8);
- provide advance warning of the end of the climbing lane (e.g. Figure VA-8);
- avoid ending the lane where available sight distance precludes the safe completion or abortion of passing manoeuvres.

Safety

According to available studies, auxiliary climbing lanes reduce accidents by 5% to 15% (Hauer et al., 1996, Lamm et al., 1999).

DRAINAGE

see: ***Downhill grades – drainage***

VERTICAL CURVES – GENERALITIES

Description

The straight segments of a vertical alignment (levelled or inclined) are connected by sag and crest curves *(Figure VA-1)*.

These curves are characterized by their K value[1]. As K decreases, the curve becomes sharper which reduces the available sight distance. The relation between geometry and sight distance at vertical curves is explained in *Appendix VA-4*.

Sight distance problems are more frequent on crest curves than on sag curves, where one should nevertheless verify that the visibility is not reduced by either the angle of a vehicle's headlight beam (at night) or the presence of overhead structures (viaduct, road sign, etc.). This latter case is particularly critical for heavy vehicles, since the driver's eye is higher than in passenger cars.

As anywhere else on the road network, the available sight distance should always be, at vertical crests, equal or larger than the required stopping distance. To fulfill this requirement, K values should be coherent with the road design speed. The *Appendix VA-1* shows the recommended K values in several countries.

Figure VA-10 Examples – K Values

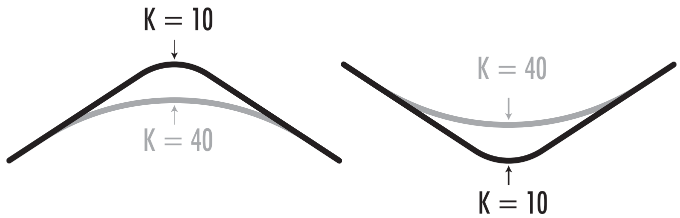
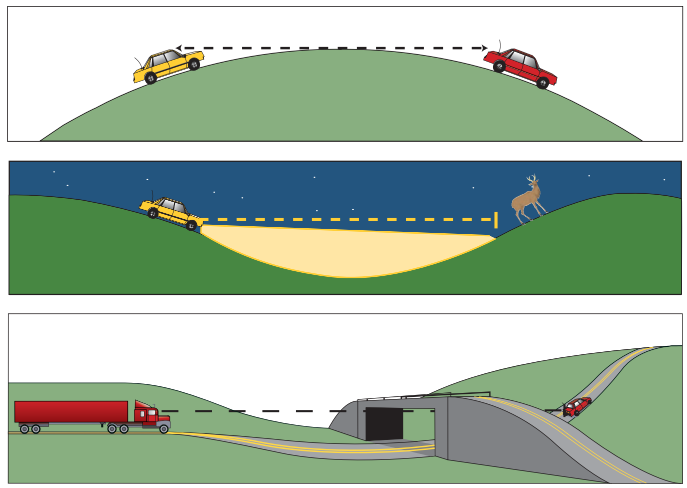


Figure VA-11 Sight distance restrictions on crest and sag curves



Safety

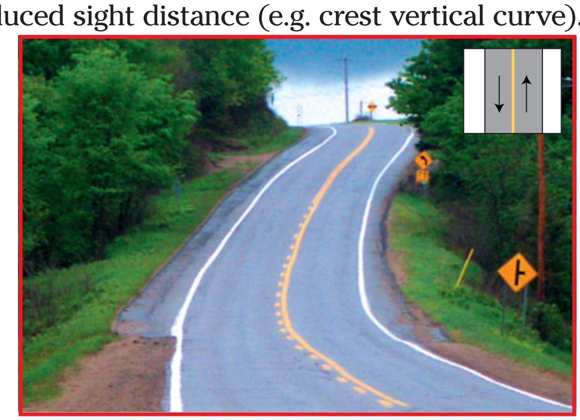
According to Olson et al. (1984), the accident frequency on crest curves with reduced sight distance is 52% higher than on curves with no reduction in sight distance.

Combination of features

With respect to sight distance in hills, the following problems are often encountered and should be detected:

- a combination of vertical and horizontal alignments causing a severe sight restriction;
- a source of traffic conflicts in a zone of reduced sight distance (e.g. crest vertical curve).

Combination of a downhill grade and sharp horizontal curve creating a sight distance restriction



Due to the vertical curve, drivers may be surprised by the presence of the intersection and horizontal curve ahead

[1] K = 100 x R (vertical curve radius).

How to detect problems (sight distance at vertical curves)

Accidents:

- rear end collisions, single vehicle accidents.

Traffic operation:

- traffic conflicts.

Road characteristics:

- compare the available sight distance with the required stopping sight distance;

  [BRAKING DISTANCE (TANGENT)]

- check for potential traffic conflict sources in zones of restricted sight distances (intersection, other crossing, driveway, end of climbing lane), brake marks.

Possible measures

Warning signs — *Relocation or elimination of traffic conflict sources* — *Vertical alignment modification* — *COST*

PASSING

Description

Pavement markings prohibiting passing manoeuvres must be clearly visible where the available sight distance makes passing manoeuvres unsafe. Situations in which the available sight distance is shorter than the required passing sight distance but sufficient to induce some drivers in dangerous passing manoeuvres should be avoided.

Passing opportunities should be assessed not only on crest curves, but also on a longer stretch of road on each side of the curve (see ***Horizontal alignment – passing***).

Marking prohibiting passing manoeuvres at a vertical crest curve.

Safety

According to a German study, 23% of accidents on rural crest vertical curves involve passing manoeuvres (Levin, 1995, cited by Lamm et al., 1999).

How to detect problems (passing)

Accidents:

- head-on collisions, sideswipes, single-vehicle accidents.

Traffic operation:

- platoons, dangerous passing manoeuvres.

Road characteristics:

- compare available sight distance with passing sight distance;
- pavement marking (passing manoeuvres prohibited when hazardous?);
- passing opportunities sufficient on the route

Possible measures

DRAINAGE

Description

One should verify that drainage conditions are appropriate to avoid water accumulations at sag vertical curves, particularly when these are located near a superelevation transition zone of an horizontal curve ***(Horizontal alignment - Superelevation)***.

see also: ***Downhill grades - drainage***

Wide paved shoulder and drainage facility on a downhill slope.

How to detect problems

Accidents:

- wet surface accidents.

Road characteristics:

- water or debris accumulation, erosion;
- hazardous drainage structures (deep and opened structures close to traffic lanes).

Potential measures

- increase of the roadway camber;
- improve drainage facilities (increase capacity, reduce hazards).

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APPENDICES VERTICAL ALIGNMENT

APPENDIX VA-1 VERTICAL ALIGNMENT DESIGN PARAMETERS

Table VA-A1 Maximum grades – Rural roads

	DESIGN SPEED (km/h)								
COUNTRY	40	50	60	70	80	90	100	110	120
AUSTRALIA									
Level	-	-	6 - 8	-	4 - 6	-	3 - 5	-	3 - 5
Rolling	-	-	7 - 9	-	5 - 7	-	4 - 6	-	4 - 6
Mountainous	-	-	9 - 10	-	7 - 9	-	6 - 8	-	-
CANADA	7	7	6 - 7	6	4 - 6	4 - 5	3 - 5	3	3
Secondary Roads	11	11	10 - 11	9	7 - 8	6 - 7	5 - 7	5 - 6	5
FRANCE	-	-	7	-	6	-	5	-	-
GERMANY	-	-	8	7	6	5	4.5	-	4
GREECE	-	11	10	9	8	7	5	4.5	4
ITALY	10	10	7	7	6	5	5	5	5
Secondary Roads	12	-	10	-	7	6	6	-	-
JAPAN	7	6	5	-	4	-	3	-	2
SOUTH AFRICA									
Level	-	-	-	5	4	3.5	3	3	3
Rolling	-	7	6	5.5	5	4.5	4	-	-
Mountainous	10	9	8	7	6	-	-	-	-
SWITZERLAND	12	-	10	-	8	-	6	-	4
UNITED STATES									
Level	-	-	5	5	4	4	3	3	3
Rolling	-	-	6	6	5	5	4	4	4
Mountainous	-	-	8	7	7	6	6	5	5

Source: Lamm et al. in Highway design and traffic safety engineering handbook. Copyright 1999 by McGraw-Hill Compagnies, Inc.

Table VA-A2 Minimum K values – Crest curves

	DESIGN SPEED (km/h)								
COUNTRY	40	50	60	70	80	90	100	110	120
AUSTRALIA	-	5	9	16	24	42	63	95	135
CANADA	4	7	15	22	35	55	70	85	105
FRANCE	-	-	15	-	30	-	60	-	100
GERMANY	-	-	27	35	50	70	100	-	200
GREECE	-	15	20	27	38	54	75	110	150
ITALY	5	-	10	-	30	-	70	-	140
JAPAN	-	8	14	-	30	-	65	-	110
SOUTH AFRICA	6	11	16	23	33	46	60	81	110
SWITZERLAND	15	21	30	42	60	85	125	200	-
UNITED STATES	5	10	18	31	49	71	105	151	202

Source: based on Krammes and Garnham, 1995

Table VA-A3 Minimum K values – Sag curves

	DESIGN SPEED (km/h)								
COUNTRY	40	50	60	70	80	90	100	110	120
CANADA	7	11	20	25	30	40	50	55	60
FRANCE	-	-	15	-	22	-	30	-	42
GERMANY	-	-	15	20	25	35	50	-	100
GREECE	-	14	19	25	33	42	52	63	75
ITALY	6	-	12	-	22	-	39	-	58
JAPAN	-	7	10	-	20	-	30	-	40
SOUTH AFRICA	8	12	16	20	25	31	36	43	52
SWITZERLAND	8	12	16	25	35	45	60	80	-
UNITED STATES	8	12	18	25	32	40	51	62	73

Source: based on Krammes and Garnham, 1995

APPENDIX VA-2 BRAKE TEMPERATURE ON DOWNHILL GRADES

The total energy of a vehicle arriving at the top of a downhill grade is equal to the sum of its kinetic and potential energy.

The kinetic energy is a function of the vehicle's mass (m) and speed (v) while its potential energy is a function of the height of the hill and the vehicle mass (eq. VA-4 and VA-5).

$$E_{kin} = \frac{m \times v^2}{2} \qquad \text{[Eq. VA-4]}$$

where:

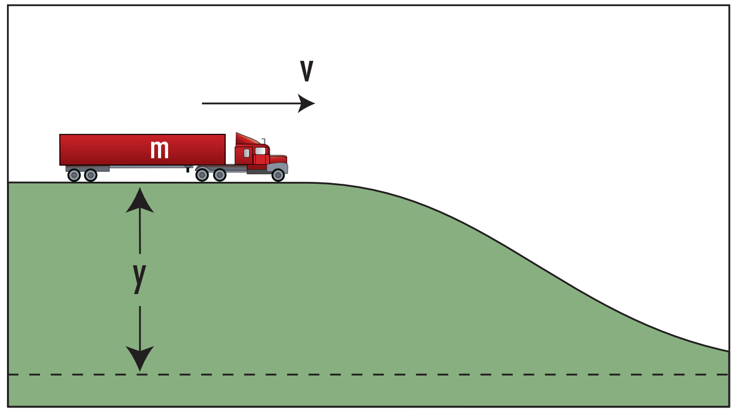
E_{kin} = kinetic energy (J)
m = vehicle mass (kg)
v = vehicle speed (m/s)

$$E_{pot} = m \times g \times y \qquad \text{[Eq. VA-5]}$$

where:

E_{pot} = potential energy (J)
m = vehicle mass (kg)
g = 9.8 m/s^2
y = height of slope (m)

Figure VA-A1 Vehicle travelling on a downhill grade



According to the law of energy conservation, this potential energy will be dissipated during the descent, through a mix of resistances (rolling, mechanical, air, engine, and braking)[2].

Braking systems transform some of this energy into heat by applying friction between two metal bodies. Intense or prolonged braking can therefore overheat brakes. This phenomenon is more likely to be a problem for heavy vehicles as their larger masses mean that a significantly higher quantity of energy needs to be transformed into heat (as compared with passenger vehicles).

Various mathematical models have been developed for estimating brake temperature profiles of heavy vehicles on downhill grades. The "Grade-brake temperature" calculator that is included in this manual is based on the model developed by Myers et al. (1980).

[GRADE ANALYSIS]

[2] If the vehicle accelerates during the descent, some of its potential energy is transformed into kinetic energy.

The model equation is (in English units):

$$T(t) = (T_i \times e^{-k1 \times t}) + T_a \times (1 - e^{-k1 \times t}) + k2 \times P_B \times (1 - e^{-k1 \times t}) \qquad \text{[Eq. VA-6]}$$

where:

T_i = initial brake temperature (suggested default value: 150°F)
T_a = ambient temperature (suggested default value: 90°F)
k1 = 1.23 + 0.0256*V
k2 = 0,1+ 0.00208*V
P_B = braking power (hp)

and:

$P_B = P_G - P_E - P_F$
P_G = grade power (hp)
P_E = engine braking power (hp) (default value is 73 hp)
P_f = friction power (hp)

$$P_G = \frac{W \times G \times V}{375} \qquad P_F = \frac{(450 + 17.25 \times V) \times V}{375}$$

where:

W = weight of vehicle (lbs)
G = grade percent (%)
V = speed (mph)

According to this model, brake overheating is therefore a function of the following:

- grade (percentage and length);
- downhill speed;
- engine compression (and retarder);
- vehicle weight.

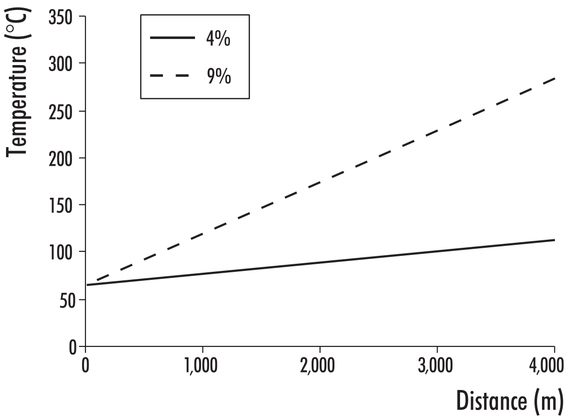
Other factors that need to be taken into consideration include:

- the initial brake temperature (which is related to the road's characteristics prior to the grade);
- the condition of the vehicle's braking system;
- the characteristics of heavy vehicle traffic;
- the probability of an emergency stop;
- driving strategy;
- etc.

The contribution of these factors is described below.

Figure VA-A2 Factors having an impact on brake temperature

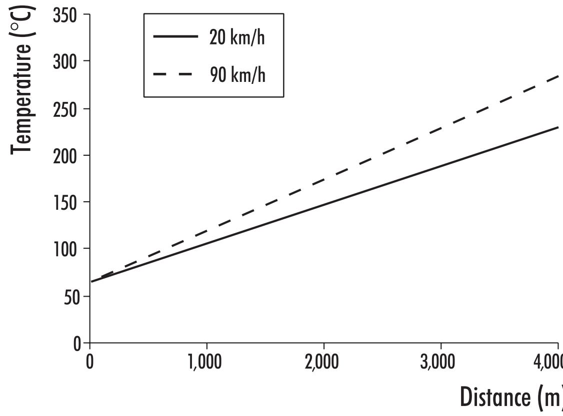
HEIGHT OF SLOPE



Engine compression: 54 kW, Mass: 36 287 kg, Speed: 50 km/h

The combination of grade percentage and lengths; which yields the height of the slope is an indicator of the potential for brake overheating. In France a 130 m drop is used as a risk indicator on freeways (Service d'études techniques des routes et autoroutes, 1997). A 200 m drop may be sufficient to increase the temperature to a critical level.

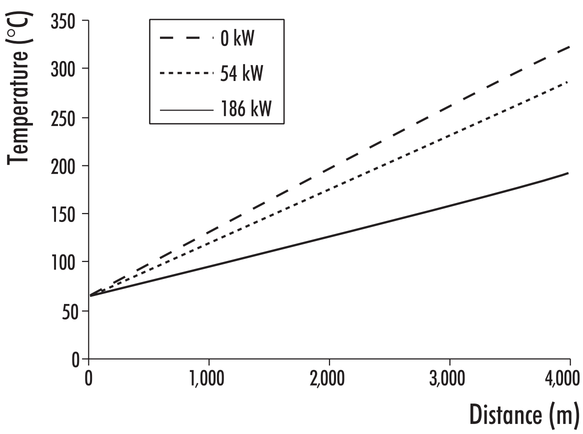
SPEED



Grade: 9%, Engine compression: 54 kw, Mass: 36 287 kg

Brake temperatures increase more rapidly at high speeds.

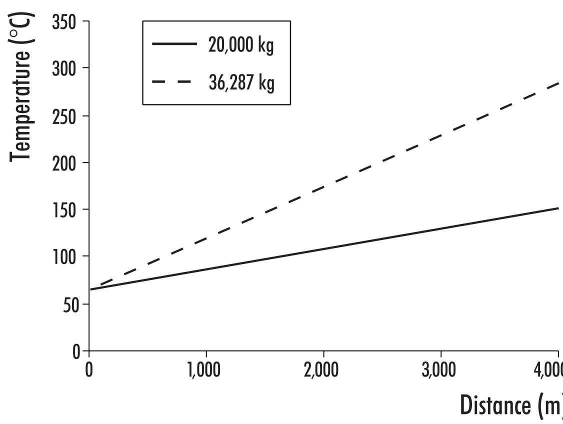
ENGINE COMPRESSION



Grade: 9%, Speed: 50 km/h, Mass: 36 287 kg

Engine compression helps slow down vehicles in their descent. Without a retarder, the compression can reach up to 30% of the rated engine power. With retarders the available compression can be as high as the rated engine power.

MASS OF VEHICLE



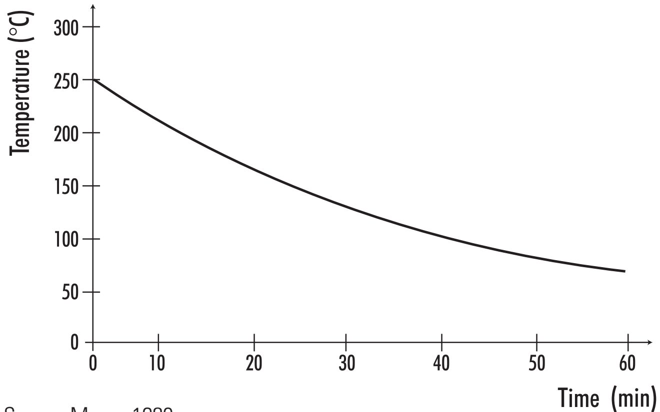
Grade: 9%, Speed: 50 km/h, Engine compression: 54 kw

Brake temperatures increases at a higher rate for heavier vehicles.

Other factors affecting the rate of increase of brake temperature:

INITIAL BRAKE TEMPERATURE

Figure VA-A3 Brake cooling time



Source: Myers, 1980

Since brakes cool slowly, the initial brake temperature at the start of a descent must be estimated by taking into account a sufficiently long stretch of road prior to the top of the grade. (Check for downhill grades, sharp curves, mandatory stops, etc.).

MECHANICAL STATE OF THE VEHICLE

- mechanical defects in the braking system can significantly increase the rate at which brake temperature rises.

CHARACTERISTICS OF HEAVY VEHICLE TRAFFIC

- number of heavy vehicles
- type of goods transported (mineral products, lumber, etc.)

DRIVING STRATEGY

- initial speed at hilltop
- descent speed
- braking strategy

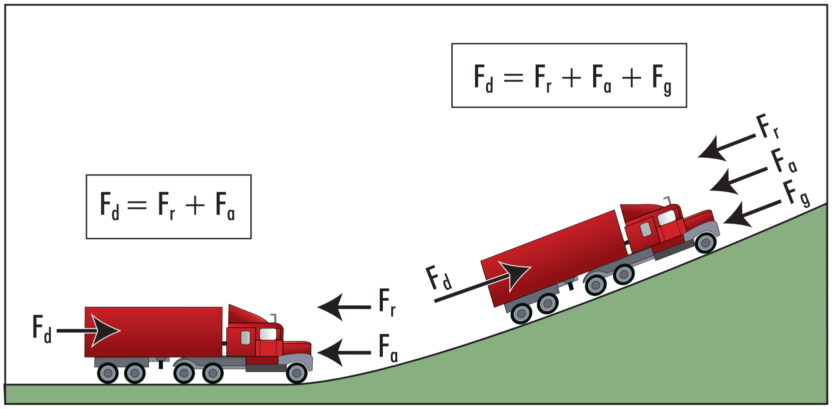
PROBABILITY OF A SPEED REDUCTION OR A STOP

- mandatory stop
- intersection or other crossing (railway, crosswalk, bike path, etc.
- sharp curve

APPENDIX VA-3 HEAVY VEHICLE SPEED ON UPHILL GRADES

To maintain a constant speed, a vehicle's engine must develop a tractive effort equal to the rolling and air resistance. When climbing a hill, the engine also has to overcome the resistance due the force of gravity.

Figure VA-A4 Force system – Climbing vehicle



where:

Fd = engine tractive force (N)
Fr = rolling resistance force (N)
Fa = aerodynamic drag force (N)
Fg = grade resistance force (N)

If the tractive force of the engine is smaller than the sum of these resistances, the vehicle decelerates.

Several models have been developed to estimate vehicle speed on grades. The ***"Grade analysis"*** calculator uses the semi-empirical model formulated by Allen et al. (2000). A vehicle's acceleration or deceleration is estimated as a function of its speed, power, mass, frontal area and grade percentage.

The speed profile of a vehicle is calculated over short distance intervals using the following algorithm:

1. select the distance interval (d) (the default value used by the calculator is 3.28 pi or 1 m);
2. select the vehicle's initial climbing speed (v_i);
3. calculate a_c (coasting acceleration), a_p (power limited acceleration) and a_e (effective acceleration), using the following equations:

$$a_C = -0.2445 - 0.0004v_i - \frac{0.021C_{de}v_i^2}{(W/A)} - \frac{222.6C_{pe}}{(W/NHP)v_i} - g \times \frac{G}{100} \qquad \text{[Eq. VA-7]}$$

where:

a_c = coasting acceleration (ft/s^2)
v_i = vehicle speed (ft/s)
C_{de} = correction factor converting sea level aerodynamic drag to the local elevation of E (pi)
C_{de} = $(1-0.00000688\ E)^{4.255}$
W = vehicle gross weight (lbs)
A_f = vehicle frontal area (ft^2)
C_{pe} = correction factor for converting sea level net horsepower to local elevation of E (pi) (gasoline engines)
C_{pe} = 1-0.00004 E
NHP = net power at sea level conditions (hp)
g = acceleration due to gravity (32.2 ft/s^2)
G = percent grade (%)

$$a_p = \left[a_c + \frac{15{,}368C_{pe}}{(W/NHP)v_i}\right] \bigg/ \left[1 + \frac{14{,}080}{(W/NHP)v_i^2}\right] \quad \text{[Eq. VA-8]}$$

where:

a_p = horsepower limited accelerations (ft/s²)

$$a_e = \left[\frac{0.4v_i}{0.4v_i + 1.5S_p(a_p - a_c)}\right] \times a_p \quad \text{[Eq. VA-9]}$$

where:

S_p = +1 or -1, based on the sign of a_p

4. Calculate vehicle speed at the end of the interval (v_f) using the following equation:

$$v_f = \sqrt{v_i^2 + 2a_e d}$$

where:

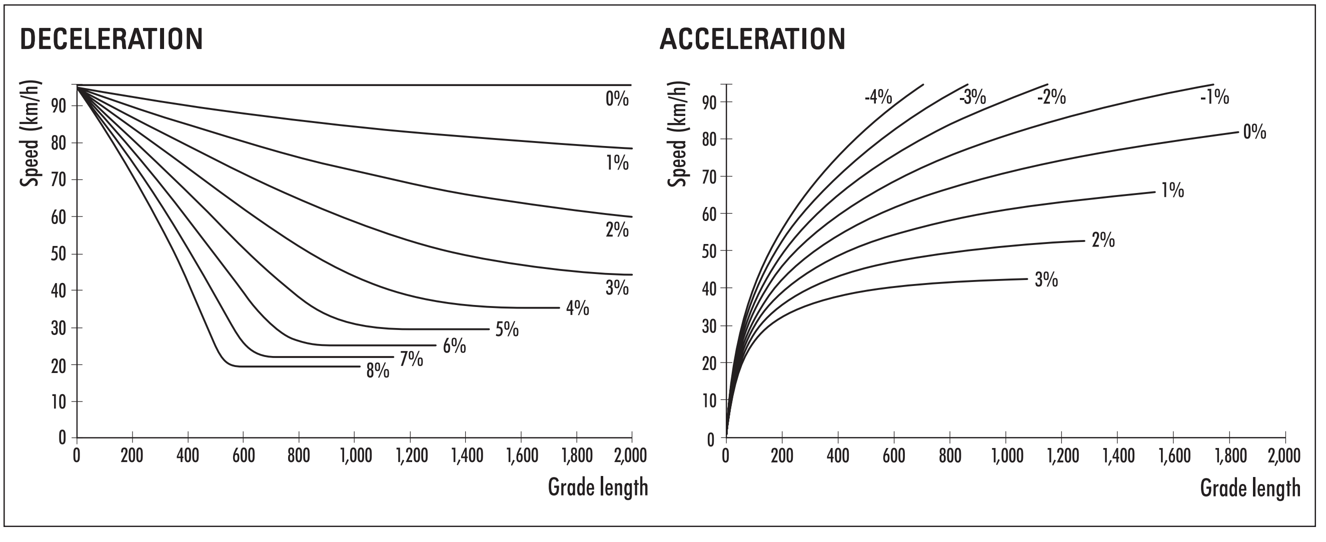
d = distance interval (m)

5. The final speed becomes the initial speed of the following interval and steps 2 to 5 are repeated until the end of the grade.

(If $v_i < 10$ ft/s, the term $0.4\ v_i = 10$)

This algorithm can be used to obtain deceleration and acceleration curves of heavy vehicles on grades, as shown in Figure VA-A5.

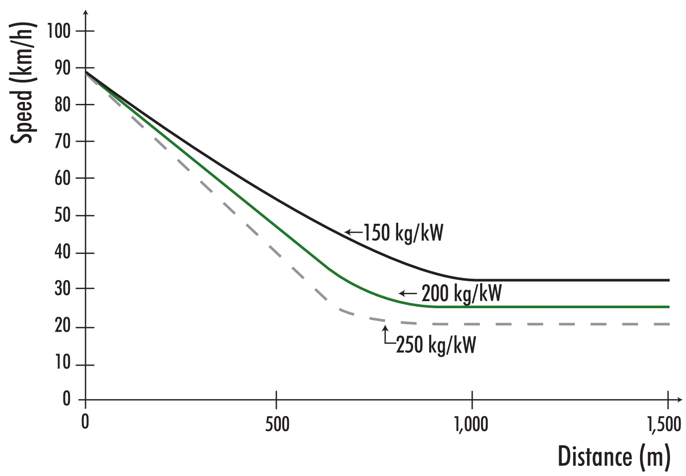
Figure VA-A5 Deceleration and acceleration curves (180 kg/kW truck)



Mass/power ratio (M/P)

The mass/power ratio is often used to characterize the acceleration and deceleration capabilities of heavy vehicles on grades, as there is a good correlation between a vehicle's mass and the resistance forces acting on it. The maximum speed that can be sustained on a grade decreases as the M/P ratio increases.

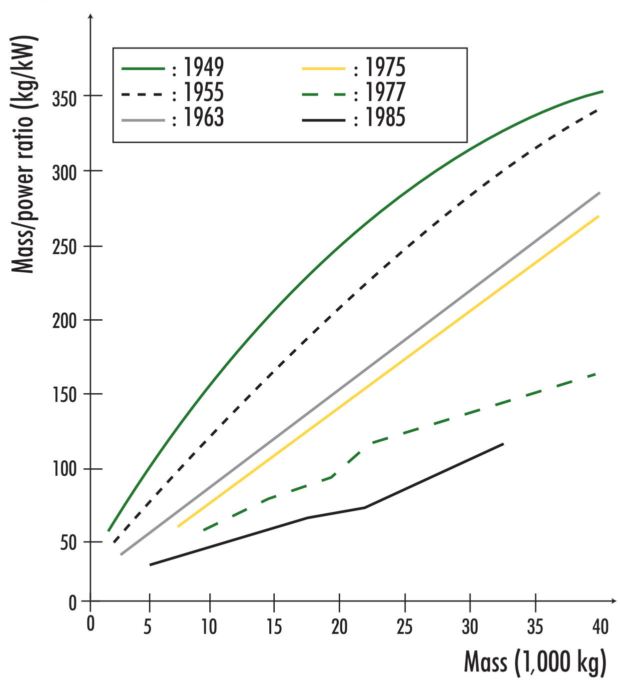
Figure PL-A6 Deceleration curves based on mass/power ratios



In North America, a mass/power ratio of 180 kg/kW is used, whereas in Europe the power/mass ratio is used. (many countries use a value of 7.5 to 8.0 hp/ton, which is equivalent to 180 kg/kW).

It should be noted that the power of heavy vehicles has improved significantly since the 1950s. The typical age for a country fleet of heavy vehicles should therefore be taken into account when estimating deceleration rates.

Figure PL-A7 Evolution – Mass/power ratios



Source: American Association of State Highway and Transportation Officials, 1994

APPENDIX VA-4 SIGHT DISTANCES AT VERTICAL CURVES

Sight distances in vertical curves can be calculated using mathematical equations.

Three different cases need to be distinguished:

- crest vertical curves
- sag vertical curves (headlight beams)
- sag vertical curves (structure overhanging the road)

The equations differ if the sight distance is smaller or larger than the curve length.

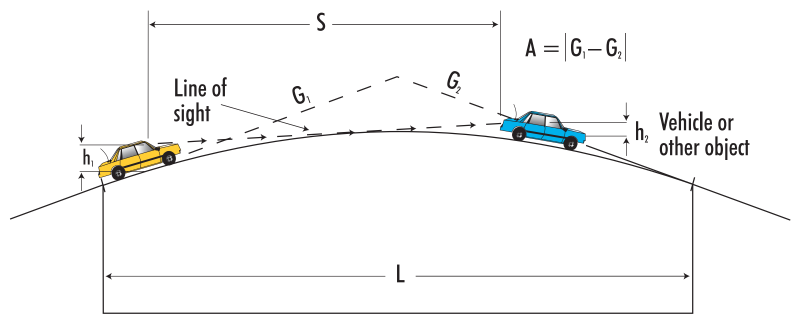
Crest vertical curve

For $S < L$

$$L = \frac{A \times S^2}{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}$$

For $S > L$

$$L = 2S - \frac{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}{A}$$



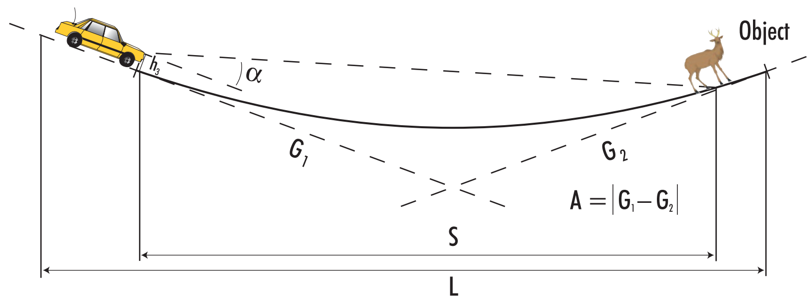
Sag vertical curves (headlight beams)

For $S < L$

$$L = \frac{A \times S^2}{200\left(h_3 + S \tan \alpha\right)}$$

For $S > L$

$$L = 2S - \frac{200\left(h_3 + S \tan \alpha\right)}{A}$$



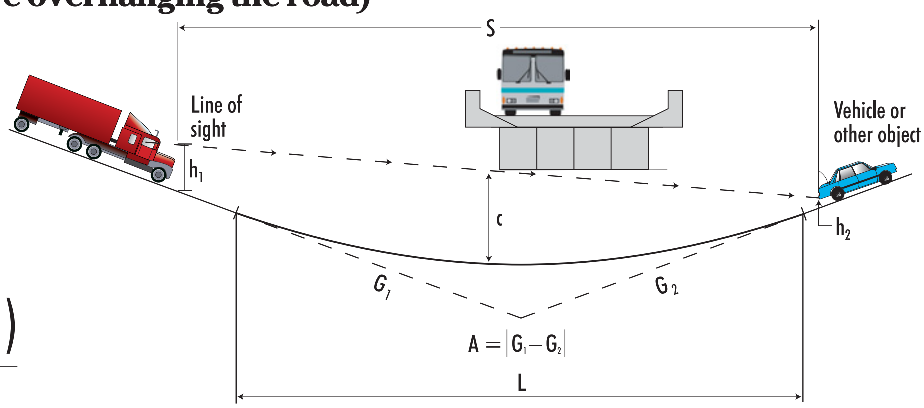
Sag vertical curve (structure overhanging the road)

For $S < L$

$$L = \frac{A \times S^2}{800\left(c - \frac{h_1 + h_2}{2}\right)}$$

For $S > L$

$$L = 2S - \frac{800\left(c - \frac{h_1 + h_2}{2}\right)}{A}$$



L	=	length of vertical curve (m)
S	=	sight distance (m)
h3	=	height of head lamps (m)
h2	=	height of object (m)
h1	=	height of the driver's eyes (m)
α	=	angle of light beam upward from plane vehicle
A	=	algebraic difference in grades (percent)
c	=	vertical clearance (m)
G_1, G_2	=	percentage of slopes (%)

SIGHT DISTANCE

Technical sheet

Patrick Barber and Carl Bélanger

SIGHT DISTANCE

Technical sheet

LIST OF FIGURES

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SUMMARY

General principles

At any point on a road, the available sight distance must be sufficient for a driver travelling at a reasonable speed (V_{85}) to stop his vehicle safely without hitting a stationary object located on his path ***(stopping sight distance)***.

At intersections, other sight distance criteria need to be satisfied to ensure drivers' safety. These criteria vary according to the type of intersection, the right-of-way rules and the allowed manoeuvres.

Table SD-1 Sight distance criteria at intersections

TYPE OF INTERSECTION AND RIGHT-OF-WAY RULES	SIGHT DISTANCE CRITERIA			
	STOPPING	MANOEUVRE	TRIANGLE	DECISION
		Crossing from minor Turning from minor Turning from major		
Conventional intersections				
Uncontrolled	X	X	X	Complex or unexpected situations
Yield	X	X	X	
Stops on minor road	X	X		
All-way stop	X			
Traffic signals	X	X		
Roundabouts	X		X	

On road sections, passing, decision and meeting sight distances need to be available in some circumstances.

Table SD-2 Sight distance criteria on road sections

SIGHT DISTANCE CRITERION	CIRCUMSTANCES
Stopping	throughout the network
Passing	locations where passing in opposing lane is allowed
Decision	complex or unexpected situations
Meeting	narrow roads (two-way traffic allowed but road width is insufficient for vehicles to meet safely)

Observations

In a safety study, analysts must determine the **available sight distances** and compare them with the **required sight distances**.

Available sight distances are measured at the site itself[1]. These distances may vary significantly according to the selected driver eye height and the height of the object to be perceived. The ***Sight distance*** technical study describes how to measure available sight distances; it also indicates the object and eye heights that are recommended in several countries.

[1] At the design stage, available sight distances may be calculated using graphic or mathematical methods. For existing roads, however, field measurements are recommended as they may reveal sight obstructions that are not shown on plans.

Required sight distances are determined using mathematical equations that take into account the vehicle speed and a number of other factors, which vary according to the criterion being considered (drivers' reaction time, coefficient of available friction, vehicle acceleration and deceleration performance, etc.). This technical sheet describes the underlying principles for determining the required sight distances under the various criteria listed in tables ***SD-1*** and ***SD-2***.

Warning

- this technical sheet describes two equations to calculate stopping sight distances and a calculator is provided to facilitate their use. It should be recognized that distances obtained using this calculator may differ from values that are recommended in a country's design standards. These latter values have precedence;

  [BRAKING DISTANCE (TANGENT)]

- the same remark applies to manoeuvring distances: a simple equation is proposed in this technical sheet but a country's recommended distances may be different. Once again, national standards have precedence;
- with respect to the other sight criteria listed in tables ***SD-1*** and ***SD-2***, only the general principles are described in this technical sheet.

Accidents

The accident risk increases as sight distance decreases, at a rate that is also influenced by:

- the traffic volumes;
- the possibility of traffic conflicts in the zone with the sight restriction (intersection, access, etc.).

Some accident types may be indicative of sight distance problems.

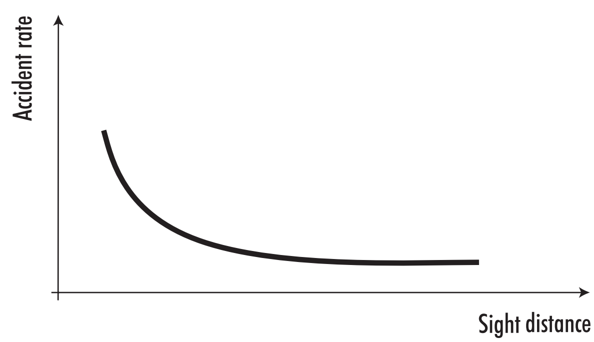
Table SD-3 Accident types that may be indicative of sight distance problems

TYPE OF SITE	ACCIDENT TYPE
Intersection	Right angle, rear-end, opposing direction with turning manoeuvre
Section	Run-off-the-road, head-on collision, rear-end collision and right angle collision

The relationship between accident rate and sight distance is not linear since the rate is seen to increase rapidly after a certain critical distance (Fambro et al., 1997).

- on rural roads, the critical sight distance is in the order of 90 m to 100 m;
- accidents related to passing manoeuvres increase when the sight distance is less than 400 m to 600 m (Lamm et al., 1999);
- at unsignalized intersections, right-angle accidents increase when the sight distance is restricted on an approach, (especially for right-angle accidents at rural intersections).

Figure SD-1 Sight distance and accident rate



Some traffic problems or hazardous behaviour may be attributed to sight distance defects: traffic conflicts, late braking, hazardous passing manoeuvres, etc. Site observations should allow the detection of those situations.

Possible solutions

In sections, definitive improvements to sight distance problems generally entail changes to a road's horizontal or vertical profile. When the cost of such interventions is prohibitive, mitigation measures need to be considered; possible actions are:

- improvement of warning measures (road signs and others);
- improvement of roadside conditions (removal of visual obstructions on the interior side of horizontal curves, removal of rigid obstacles);
- elimination of potential conflicts in zones with restricted sight distances (e.g. relocate a road access);
- use of speed reducing devices (when compatible with the road environment).

At intersections, the available sight distances must be sufficient to allow users to safely complete each permitted but non-priority manoeuvre. Again, the horizontal or vertical profile may need to be improved.

The removal of objects that are located in an intersection quadrant and impede visibility is also a beneficial measure (street parking nearby the intersection, billboards, commercial stands, vegetation, etc.).

Stop signs must be clearly visible at all times and on all approaches where this manoeuvre is mandatory.

When a sight distance problem cannot be corrected, alternative measures should be considered:

- improvement of warning measures (road signs and others);
- movement prohibition;
- changes to traffic priorities, using a more restrictive mode (e.g. traffic signals);
- geometric improvements aimed at reducing speeds or conflicts (e.g. roundabouts, traffic-calming measures, channelization).

In both cases, the stop signs is hardly visible

INTERSECTIONS

Stopping sight distance

Conventional intersections and roundabouts
All right-of-way rules
All approaches

As anywhere else in the network, the available sight distance when approaching an intersection must be sufficient to enable a driver travelling at a reasonable speed (V_{85}) to stop his vehicle safely before hitting a stationary object in his path.

At conventional intersections, the stopping sight distance should be checked on each of the intersection's upstream and downstream approaches. At a roundabout, the stopping sight distance should be checked on each approach, in the ring lane and in each of the roundabout's exit (Figure SD-2). Specific attention should be paid to the sight distance of pedestrian crosswalks in the roundabout's exits.

The two following equations, which use either the coefficient of longitudinal friction or the deceleration rate, may be used to calculate the required stopping sight distance. The first term of these equations represents the distance travelled by a vehicle during the driver's reaction time whereas the second term represents the distance travelled during the mechanical braking of the vehicle. Typical values for each parameter of these equations are shown in Table SD-4

$$SSD = \frac{V_i \times t}{3.6} + \frac{V_i^2}{254\left(f_l \pm \frac{G}{100}\right)} \qquad \text{[Eq. SD-1]}$$

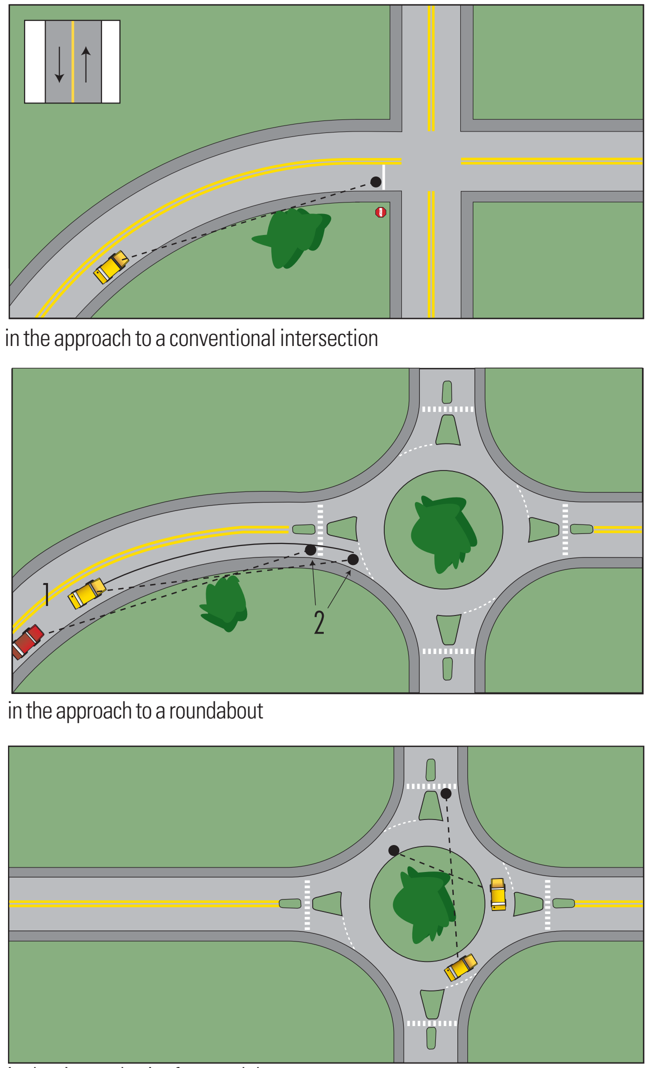
$$SSD = \frac{V_i \times t}{3.6} + \frac{V_i^2}{254\left(\frac{a}{g} \pm \frac{G}{100}\right)} \qquad \text{[Eq. SD-2]}$$

where:

- SSD = (required) stopping sight distance (m)
- t = reaction time (s)
- V_i = initial speed (km/h)
- f_l = coefficient of longitudinal friction
- a = deceleration rate (m/s^2)
- g = acceleration due to gravity (9.8 m/s^2)
- G = grade percent (%)

[BRAKING DISTANCE (TANGENT)]

Figure SD-2 Stopping sight distance



in the approach to a conventional intersection

in the approach to a roundabout

in the ring and exit of a roundabout

When measuring available sight distances, lines of sight should not encroach on roadside areas that are not permanently free of visual obstructions. One needs to take into account temporary or seasonal obstructions that may not be present during the site visit (vegetation, commercial stand, snow, etc.) ***(Sight distance – Technical study)***.

Table SD-4 Typical values for stopping sight distance calculations

PARAMETER	TYPICAL VALUES
Reaction time (t)[a]	1.0 to 2.5 s
Coefficient of longitudinal friction (f_l)[b]	0.15 to 0.5
Deceleration rate (a)	3.4 m/s^2

[a] based on the surrounding environment (urban or rural).

[b] based on speed.

The "braking distance" calculator can be used to calculate either the braking distance (i.e. from an initial speed V_i to a final speed $V_f \neq 0$) or the stopping sight distance (with $V_f = 0$).

Figure SD-3 Examples – Stopping distances (based on equation SD-1)

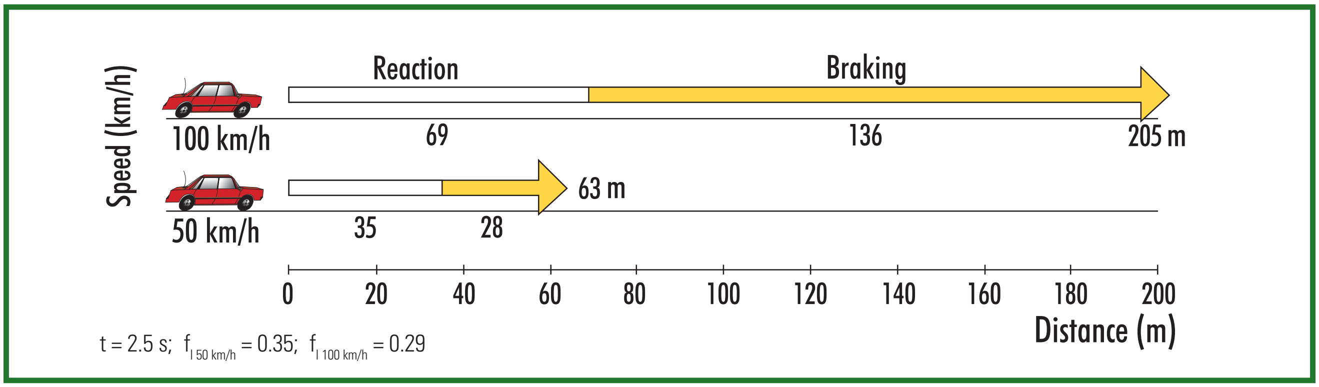


Table SD-5 shows the recommended stopping sight distances in several countries.

Table SD-5 Recommended stopping sight distances

COUNTRY	TIME (s)	SPEED (km/h)											
		30	40	50	60	70	80	90	100	110	120	130	140
		STOPPING SIGHT DISTANCE (m)											
Austria	2.0	-	35	50	70	90	120	-	185	-	275	-	380
Canada	2.5	-	45	65	85	110	140	170	210	250	290	330	-
France	2.0	25	35	50	65	85	105	130	160	-	-	-	-
Germany	2.0	-	-	65	85	110	140	170	210	255	-	-	
Great Britain	2.0	-	-	70	90	120	-	-	215	-	295	-	-
Greece	2.0	-	-	-	65	85	110	140	170	205	245	-	-
South Africa	2.5	-	50	65	80	95	115	135	155	180	210	-	-
Sweden	2.0	35	-	70	-	165	-	-	-	195	-	-	-
Switzerland	2.0	35	-	50	70	95	120	150	195	230	280	-	-
USA	2.5	35	50	65	85	105	130	160	185	220	250	285	-

Adapted from: Harwood et al., 1995

Manoeuvring sight distance

Conventional intersections

Non-priority manoeuvres

A driver who is stopped at an intersection should have sufficient sight distance to complete safely all permitted but non-priority manoeuvres ***(Figure SD-4)***:

- left turn, crossing, right turn from a minor road;
- left turn from a major road.

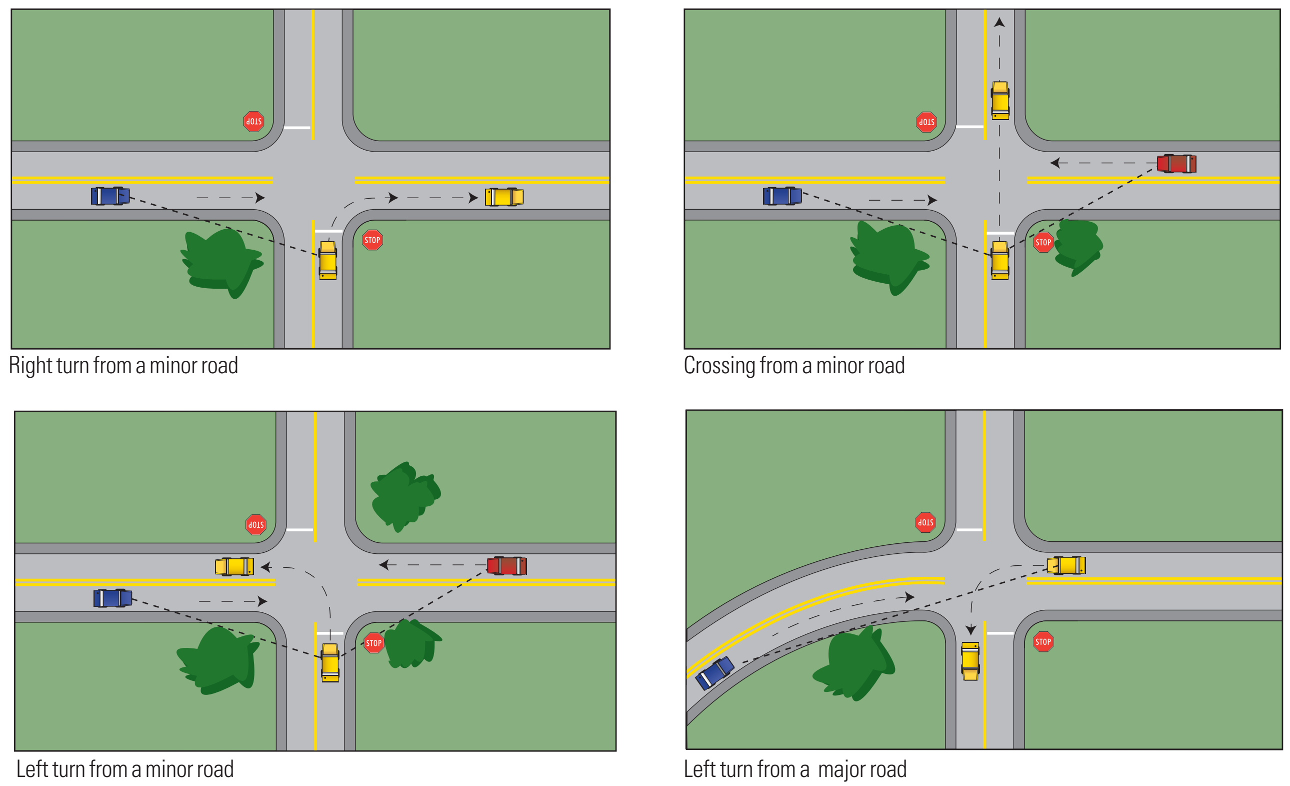
A number of methods, that vary greatly in their complexity, have been developed to calculate the required manoeuvring sight distances. A simple equation calculates this distance based on the speed of vehicles with the right of way and the gap required to complete non-priority manoeuvres. This gap may vary from one country to another, as shown in ***Table SD-6***.

$$D = \frac{V_{85} \times t}{3.6} \qquad \text{[Eq. SD-3]}$$

where:

D = manoeuvring distance (m)
V_{85} = 85th percentile of speed on major road (km/h)
t = manoeuvring gap(s)

Figure SD-4 Manoeuvring sight distances at an intersection



Right turn from a minor road

Crossing from a minor road

Left turn from a minor road

Left turn from a major road

Table SD-6 Manoeuvring gaps at an intersection (passenger vehicles)

FRANCE	ENGLAND	SPAIN	USA
6 - 8 s	5 - 8 s	6 - 8 s	6.5 - 7.5 s

Heavy vehicles

When the volume of heavy vehicles is high, it may necessary to extend manoeuvring gaps to take into account the characteristics of these vehicles (slower acceleration and deceleration rates, larger sizes). As a result, the required sight distances may then be increased significantly, as illustrated in Table SD-7.

Table SD-7 Required sight distance (left turn from minor road)

V_{85} MAJOR ROAD (km/h)	REQUIRED SIGHT DISTANCE (m)		
	PASSENGER VEHICLE	TRUCK	SEMI-TRAILER
50	95	150	195
60	115	180	235
70	135	210	275
80	150	240	315
90	170	270	355
100	190	300	395

Source: Transportation Association of Canada, 1999

Sight triangle

Conventional intersections and roundabouts

NO CONTROL, YIELD

All approaches

At these locations, the available sight distance must be sufficient to enable drivers to detect in advance vehicles approaching on adjacent legs with which they could be in conflict. The roadsides of these intersections should be permanently free of any sight obstruction. At a conventional intersection, the area that needs to be free forms a "sight triangle".

The dimensions of this triangle vary according to:

- the type of intersection (conventional or roundabout);
- the type of traffic control (none or yield);
- the vehicles approach speed;
- the assumptions relating to drivers behaviour (reaction time, deceleration rate).

Conventional intersections:

At uncontrolled conventional intersections, the required size of the sight triangle for the vehicle 1 driver is defined by the lengths of D1 - D2 and D1 - D3, as shown in Figure SD-5. In Spain, these lengths must be at least equivalent to the distance covered in 3 s at a speed of V_{85} on the adjacent legs under consideration.

Roundabouts:

At roundabouts, the dimensions of the pseudo-sight triangle are determined by the D1, D2 and D3 distances, as shown in Figure SD-5:

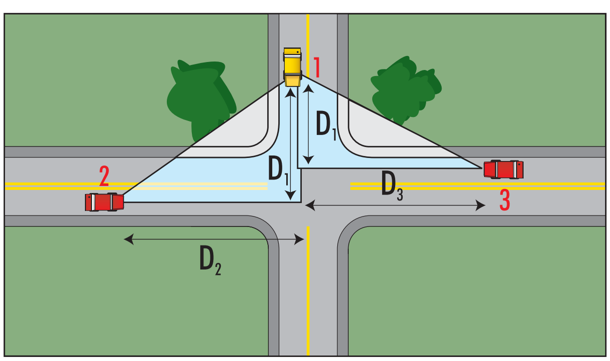
D1: distance on the leg considered; 15 m is generally recommended to avoid excessive approach speeds.

D2: required distance between vehicle 1 and a vehicle 2 approaching from the adjacent upstream leg.

D3: required distance between vehicle 1 and a vehicle 3 approaching from the ring lane.

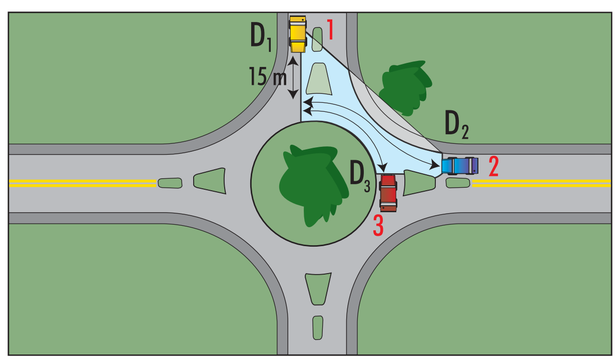
Distances that are recommended in U.S.A for uncontrolled conventional intersections and roundabouts are indicated in Tables ***SD-8*** and ***SD-9***.

Figure SD-5 Sight triangles[a]



Conventional intersection:

The driver of vehicle 1 should see vehicles approaching the intersection in both adjacent legs (vehicles 2 and 3) sufficiently in advance.



Roundabout:

The driver of vehicle 1 must see the vehicles approaching from the left adjacent leg (vehicle 2) and the vehicles traveling in the circle (vehicle 3) sufficiently in advance.

[a] right hand side driving

Table SD-8 Sight triangle
Uncontrolled intersections

DESIGN SPEED OF THE APPROACH (km/h)	DISTANCES D_1, D_2 AND D_3 (m)
30	25
50	45
70	65
90	90
100	105
120	135

Source: A Policy on Geometric Design of Highways and Streets, Copyright 2001, by the American Association of State Highway and Transportation Officials, Washington, D.C. Used by permission.

Table SD-9 Sight triangle
Roundabouts

CONFLICTING APPROACH SPEED (km/h)	DISTANCE D_1 (m)	DISTANCES D_2 AND D_3 (m)
20	15	36
25	15	45
30	15	54
35	15	63
40	15	72

Source: Federal Highway Administration, 2000

Visual obstruction in the corner of a conventional intersection.

Decision sight distance (intersections and sections)

Some countries use the decision sight distance criteria in more complex or unexpected driving situations. This criterion provides for an additional safety margin over and above the stopping sight distance (Table SD-10).

For example, Canadian standards recommend using the decision sight distance in the following situations (Transportation Association of Canada, 1999):

- complex intersections or interchanges;
- locations requiring unusual or unexpected manœuvres;
- major changes in cross-section;
- roadwork areas.

Table SD-10 Comparison of stopping sight distances and decision sight distances

	DESIGN SPEED (km/h)				
	70	80	90	100	110
Stopping sight distance (m)	110	140	170	210	250
Decision sight distance (m)	200	230	275	315	335

Source: Transportation Association of Canada, 1999

SECTIONS

In sections, most sight distance problems are related to the presence of horizontal or vertical curves. These issues are covered in the corresponding technical sheets:

sight distance in horizontal curves (lateral clearance)
sight distance in vertical curves

Stopping sight distance or decision sight distance

As mentioned in introduction, the sight distance, at any point of a road network, must be sufficient to enable a driver travelling at a reasonable speed (V_{85}) to stop his vehicle safely before hitting a stationary object in his path (***stopping sight distance*** and ***decision sight distance***).

Passing sight distance

The passing sight distance is the distance a driver has to see ahead of him in the incoming lane to be able to complete a safe passing manoeuvre. This distance is required on two-way, two-lane roads, where the pavement marking allows passing. The manoeuvre can be broken down into four stages, as shown in Figure SD-6: perception and reaction (the driver decide to initiate a passing manoeuvre), passing manoeuvre, safety margin and distance travelled by the incoming vehicle. The required passing sight distance may vary significantly depending on the assumptions made at each stage ***(Table SD-11)***.

Passing manoeuvres are rarely possible in horizontal and vertical curves ***(horizontal alignment – passing and vertical alignment – passing)*** and one should ensure that the manoeuvre is clearly prohibited at all times where it would be unsafe (marking, median separation).

It is also necessary to verify that passing opportunities are sufficient on the route, based on its geometric characteristics and traffic conditions ***(horizontal alignment – passing)***.

Figure SD-6 Passing manoeuvre

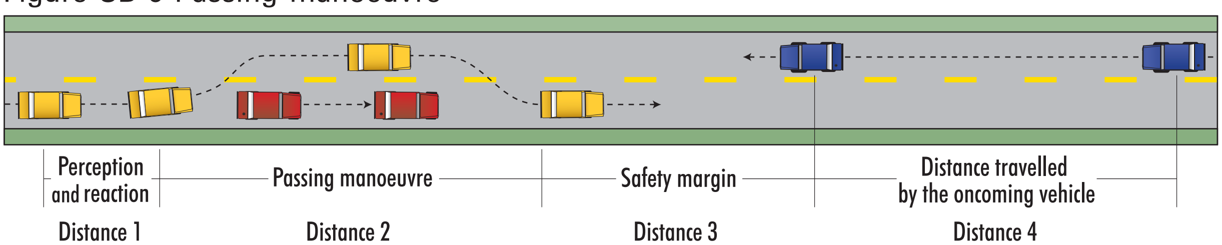


Table SD-11 Recommended passing sight distances (m)

	SPEED (km/h)								
Country	50	60	70	80	90	100	110	120	130
Australia	330	420	520	640	770	920	1100	1300	1500
Austria	-	400	-	525	-	650	-	-	-
Canada	340	420	480	560	620	680	740	800	-
Germany	-	475	500	525	575	625	-	-	-
Greece	-	475	500	525	575	625	-	-	-
South Africa	340	420	490	560	620	680	740	800	-
United Kingdom	290	345	410	-	-	580	-	-	-
USA	345	407	482	541	605	670	728	792	-

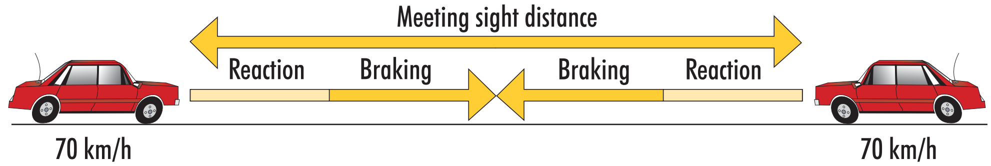
Source: Harwood et al., 1995

Meeting sight distance

Some countries use the meeting sight distance as a criterion. This is the distance required for two vehicles coming towards each other to stop without colliding. This sight distance should be considered when two-way traffic is allowed but the road is too narrow for cars to meet safely (e.g. narrow bridge).

The required meeting sight distance is calculated by adding together the stopping sight distances of both vehicles (Figure SD-7).

Figure SD-7 Meeting sight distance



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ROAD SURFACE CONDITIONS

Technical sheet

Carl Bélanger and Patrick Barber

ROAD SURFACE CONDITIONS

Technical sheet

LIST OF FIGURES

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SUMMARY

General principles

This technical sheet describes the relationship between safety and two characteristics of the road surface - friction and roughness.

In its broad sense, friction is defined as a resistance to motion between two surfaces in contact with each other. In the case of road transport, the surfaces considered are the tires and the road surface. A distinction is made between the ***longitudinal friction*** component (which affects acceleration and deceleration) and the ***transverse friction*** component (which allows changes of direction). There is a strong relationship between friction and safety.

The road evenness is a measure of the regularity of the road surface. It is affected by various types of cracks, deformations or disintegration problems. The longitudinal and transverse components of the evenness of a road surface are distinguished. Longitudinal evenness is generally measured using the IRI (International Roughness Index), which is based on the vertical motions in the suspension of a vehicle moving along a road, under standardized conditions. The analysis of the transverse evenness allows the detection of different types of problems, including rutting. Pavement roughness has a direct impact on passenger comfort and vehicle operating costs. Under some circumstances, it may also affect safety.

Multi-fonctions vehicle

Multi-function vehicles that are instrumented to make simultaneous measurements of several road surface characteristics are now available.

Accidents

Friction

The accident rate increases as the **skid resistance**[1] of a road surface decreases. The problem is amplified when the pavement is wet because the contact between the tires and the road is then reduced. A concentration of accidents on a wet surface can therefore be an indicator of friction deficiency. The following conditions increase the risk of accidents even more:

- the problem is at a location where the friction requirement is high (e.g. approach to an intersection, horizontal curve, downhill slope);
- the problem is isolated (e.g. road surface contamination).

Drivers may have difficulty in recognizing sites with skid resistance problems and as such, they may not reduce their speed at those locations, as would be necessary to maintain their risk at a level they consider acceptable.

Evenness

The existing literature does not allow a clear relationship to be established between safety and evenness. This seems to be partly due to the fact that a number of the available studies included substantial proportions of sites where pavement roughness was minor.

[1] Skid resistance is defined as the retarding force generated by the interaction between a pavement and a tire under a locked, non-rotating wheel condition (ASTM - E867). It is related to the magnitude of the coefficient of friction.

However, the risk of accident can be expected to increase when pavement roughness is sufficiently severe to either reduce the tire-pavement contact or cause hazardous avoidance manoeuvres, losses of control, mechanical failures or water accumulations (e.g. in deformations, ruts).

Impact of resurfacing

A number of studies have tried to determine the safety impacts of resurfacing.

In 1987, Cleveland concluded that:

> *"Rural resurfacing projects selected because of their pavement structural or riding condition have a small, immediate increase in overall accident experience, averaging 2%, and probably less than 5%. This is made up of a 10% increase in dry pavement accidents and a similar decrease in wet pavement accidents."*
>
> *"Rural projects resurfaced because of a large number of wet pavement accidents; for example, more than 25% of the total, have an immediate reduction in wet pavement accidents of from 15% to 70%, probably averaging 20% over the life of the project."*
>
> *"Urban resurfacing projects should have an average accident reduction of about 25% over the life of the resurfaced pavement."*

The conclusions of Schandersson (1994) were similar.

Some studies have also tried to compare the safety impact of projects consisting only of resurfacing with those that include additional improvements:

- Hauer et al (1994) concluded that in projects involving resurfacing only, safety was initially reduced, while in projects involving resurfacing and other roadway improvements[2], it improved. They also concluded that within the first 6-7 years of pavement life, safety improves as the pavement age.
- However, a more recent study aimed at assessing the safety impact of resurfacing, with or without additional action, was unable to reach clear conclusions on the subject and recommends additional research (Hughes et al., 2001).

Observations

- ***friction***
- ***evenness***

Possible solutions

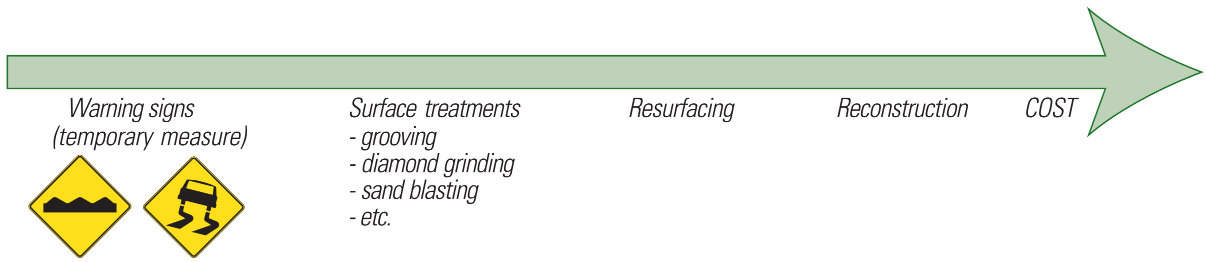
The most common solution for road surface defects consists of resurfacing, which can correct different types of friction or evenness problems.

However, when the problems result from structural defects, more expensive measures involving the treatment of road foundations may prove necessary.

Conversely, less expensive superficial treatments may also be considered in some cases.

[2] Road elements that were most often included in those improvements were: superelevation, shoulder, drainage and roadsides (slope flattening, removal or relocation of fixed objects, guardrails).

When road surface deficiencies are likely to increase the risk of accident and corrective measures cannot be immediately implemented, warning signs must be installed as a temporary measure, in order to warn approaching road users.



FRICTION

Description

Friction is defined as the resistance to motion between two surfaces in contact. Its magnitude is expressed by the coefficient of friction (f) which is a ratio of 2 forces, one parallel to the surface of contact between two bodies and opposed to their motion (the friction force) and the other perpendicular to this surface of contact (the normal force) (Figure SC-1). In the context of road transportation, the surface of contact is the road-tire interface and the normal force is the wheel load.

The coefficient of friction ranges from nearly 0 under icy conditions up to above 1.0 under the best surface conditions (Table SC-1).

Figure SC-1 Coefficient of friction

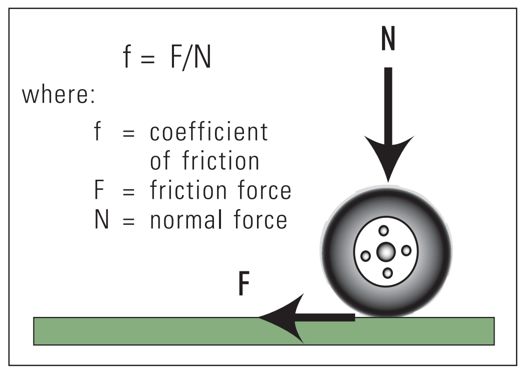


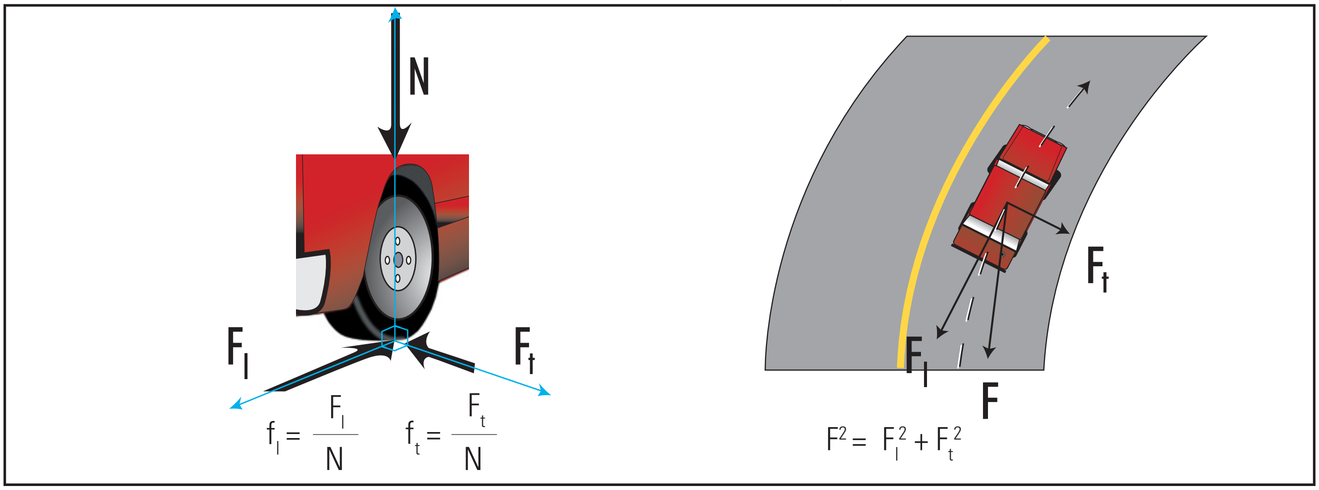
Table SC-1 Coefficients of friction of various roadway surfaces

TYPE OF ROAD SURFACE	DRY				WET			
	LESS THAN 50 km/h		MORE THAN 50 km/h		LESS THAN 50 km/h		MORE THAN 50 km/h	
	FROM	TO	FROM	TO	FROM	TO	FROM	TO
Portland Cement								
New, sharp	0.80	1.20	0.70	1.00	0.50	0.80	0.40	0.75
Travelled	0.60	0.80	0.60	0.75	0.45	0.70	0.45	0.65
Traffic polished	0.55	0.75	0.50	0.65	0.45	0.65	0.45	0.60
Asphalt or Tar								
New, sharp	0.80	1.20	0.65	1.00	0.50	0.80	0.45	0.75
Travelled	0.60	0.80	0.55	0.70	0.45	0.70	0.40	0.65
Traffic polished	0.55	0.75	0.45	0.65	0.45	0.65	0.40	0.60
Excess Tar	0.50	0.60	0.35	0.60	0.30	0.60	0.25	0.55
Gravel								
Packed, oiled	0.55	0.85	0.50	0.80	0.40	0.80	0.40	0.60
Loose	0.40	0.70	0.40	0.70	0.45	0.75	0.45	0.75
Cinders								
Packed	0.50	0.70	0.50	0.70	0.65	0.75	0.65	0.75
Rocks								
Crushed	0.55	075	0.55	0.75	0.55	0.75	0.55	0.75
Ice								
Smooth	0.10	0.25	0.07	0.20	0.05	0.10	0.05	0.10
Snow								
Packed	0.30	0.55	0.35	0.55	0.30	0.60	0.30	0.60
Loose	0.10	0.25	0.10	0.20	0.30	0.60	0.30	0.60

Source: Fricke, 1990

The friction is analyzed using its longitudinal and transverse components.

Figure SC-2 Longitudinal friction (f_l) and transverse friction (f_t)



Longitudinal friction (f_l)

The coefficient of longitudinal friction (f_l) is a measure of friction in the direction the vehicle is moving (Figure SC-2); the smaller the f_l values, the longer the acceleration and deceleration distances.

Braking distances can be computed from equation SC-1 or SC-2:

- equation SC-1 assumes a constant value of f_l over speed which is a simplification of reality that is often used in practice ***(friction - speed adjustment)***;
- equation SC-2 is more accurate as it takes into account the fact that friction decreases as speed increases. In order to use this equation, the relationship between speed and friction needs to be known.

Differences in results from both equations depend upon the characteristics of the road surface.

A similar equation calculates the braking distance based on deceleration rates rather than friction ***(Equation SD-2)***.

A calculator is provided to compute braking distances based on either of these equations. When V_f

$$\text{Braking distance} = \frac{V_i t}{3.6} + \frac{V_i^2 - V_f^2}{254\,(f_l \pm G)} \qquad \text{[Eq. SC-1]}$$

or

$$\text{Braking distance} = \frac{V_i t}{3.6} + \int_{V_i}^{V_f} \frac{V}{127\,(f_{lv} \pm G)}\, dV \qquad \text{[Eq. SC-2]}$$

where:

V_i = initial speed (km/h)
V_f = final speed (km/h)
t = reaction time (s)
f_l = coefficient of longitudinal friction
f_{lv} = coefficient of longitudinal friction at speed V
G = grade (%/100)

[BRAKING DISTANCE (TANGENT)]

Transverse friction (f_t)

The coefficient of transverse friction (f_t) is a measure of the available skid resistance in a direction perpendicular to the vehicle's direction of travel (Figure SC-2). It allows changes of direction.

Appendix HA-1 of the technical sheet on horizontal alignment explains the relationship between various components of a curve. It describes how to calculate the (theoretical) maximum speed at which a vehicle can travel in a horizontal curve, based on its curvature radius, superelevation and coefficient of transverse friction. Alternately, one can also compute the required coefficient of transverse friction based on a combination of speed, curve radius and superelevation. A calculator is provided to perform those computations.

[BASIC EQUATIONS]

Values of longitudinal and transverse friction are in general closely related except at sites where local conditions have caused an accelerated aging of the road surface in a specific direction.

Combination of f_l and f_t - Steering and braking simultaneously

When both steering and braking need to be accomplished simultaneously (e.g. braking in a horizontal curve), the available friction at the site is shared between its longitudinal and transverse components. Consequently, the braking distance is increased (eq. SC-3).

$$bd_{curve} = \frac{V_i t}{3.6} + \frac{V_i^2 - V_f^2}{254\left(\sqrt{f^2 - \left(\frac{V_i^2}{127R} - e\right)^2} \pm G\right)} \qquad \text{[Eq. SC-3]}$$

where:

bd_{curve} = braking distance in curve (m)
f = friction coefficient
R = curve radius (m)
e = superelevation

[BRAKING DISTANCE (CURVE)]

Friction - Road design

Roads need to be designed to allow safe traffic operations even when prevailing conditions are not ideal. As such, the values of the coefficient of longitudinal friction that are used at the design stage assume poor conditions, namely wet surface and worn tires[3]. *Appendix SC-1* shows the f_l design values that are recommended in several countries. They range from around 0.45 at 30 km/h to less than 0.3 at high speeds.

Values of transverse friction that are used at the design stage are based on a criterion of comfort rather than safety, namely on the speed at which the effect of the centrifugal force is sufficiently uncomfortable to cause drivers to decelerate. *Appendix SC-1* shows recommended f_t values in several countries. They generally range between 0.07 and 0.18. By using such low f_t values at the design stage, around 90% of the total friction remains available for braking manoeuvres in curves, hence preventing excessive increases of stopping distances (Table SC-2).

Table SC-2 Examples – Longitudinal friction available in curves (design)

DESIGN SPEED (km/h)	f	f_t	f_l[1]	f_l/f
50	0.40	0.16	0.37	92%
100	0.28	0.11	0.26	92%

[1] f_l available in curve is computed from: $f_{tot}^2 - f_t^2 = f_l^2$

[3] However, they do not assume extreme conditions such as icy, snowy or flooded road surfaces in which a “reasonable” driver is expected to reduce speed.

Friction – Existing roads

Friction values that are used in design are absolute minimal. Existing road surfaces that do not meet these thresholds have obvious skid resistance problems and require improvement. At locations with higher friction needs (e.g. approach to intersection, horizontal curve, downhill grade), much higher friction values must be provided.

In the United Kingdom, the network is divided into 13 site categories, each having a specific site investigation threshold.

Table SC-3 Investigatory skidding resistance levels for different site categories (UK)

SITE CATEGORY	SITE DEFINITION	INVESTIGATORY LEVELS OF MEAN SUMMER SIDEWAY-FORCE COEFFICIENT (MSSC) AT 50 KM/H							
		0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65
A	MOTORWAY (MAINLINE)								
B	DUAL CARRIAGEWAY (ALL PURPOSE) NON EVENT SECTIONS								
C	SINGLE CARRIAGEWAY NON EVENT SECTIONS								
D	DUAL CARRIAGEWAY (ALL PURPOSE) MINOR JUNCTIONS								
E	SINGLE CARRIAGEWAY MINOR JUNCTIONS								
F	APPROACHES TO AND ACROSS MAJOR JUNCTIONS (ALL LIMBS)								
G1	GRADIENT 5% TO 10% LONGER THAN 50 m – DUAL (DOWNHILL ONLY) – SINGLE (UPHILL AND DOWNHILL)								
G2	GRADIENT STEEPER THAN 10% AND LONGER THAN 50 m – DUAL (DOWNHILL ONLY) – SINGLE (UPHILL AND DOWNHILL)								
H1	BEND (NOT SUBJECT TO 40MPH OR LOWER SPEED LIMIT) RADIUS < 250 m								
J	APPROACH TO ROUNDABOUT								
K	APPROACH TO TRAFFIC SIGNALS, PEDESTRIAN CROSSING, RAILWAY LEVEL CROSSINGS OR SIMILAR								
		INVESTIGATORY LEVELS MSSC AT 20 KM/H							
		0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75
H2	BEND (NOT SUBJECT TO 40MPH OR LOWER SPEED LIMIT) RADIUS < 100 m								
L	ROUNDABOUT								

1. Investigatory levels are for the mean skidding resistance within the appropriate section length.
2. Investigatory levels for categories A, B and C are based on 100 meter section lengths.
3. Investigatory levels for site categories D, E, F, J and K are based on the 50 meter approach to the feature.
4. Investigatory levels for the site categories G and H are based on 50 meter section lengths, or for H the length of the curve if shorter.
5. The investigatory level for site category L is based on 10 meter section lengths.
6. Residual section lengths less than 50% of a complete section should be attached to the penultimate section.
7. Individual values within each section should be examined and the significance of any values which are substantially lower than the mean value assessed.

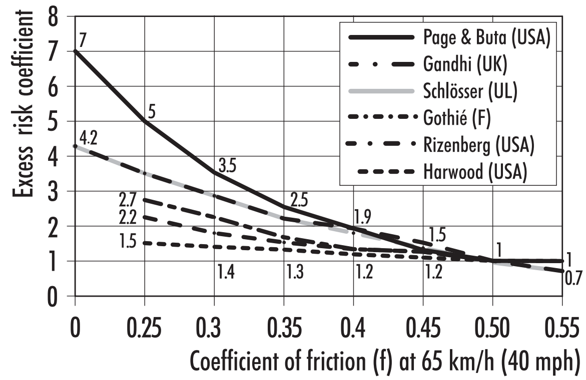
Source: Design manual for roads and bridges (***http://www.official-documents.co.uk/document/deps/ha/dmrb/index.htm***).

Safety

The accident risk is higher when the skid resistance is low (Figure SC-3). As mentioned in the introduction, accidents that are related to friction deficiencies occur mostly under wet surface conditions because the available friction is then reduced. These concentrations of wet surface accidents are worst at road locations having both a poor skid resistance and a high friction demand:

- Page and Butas (1986) found that accident rates on wet pavement were highest in horizontal curves, especially when **skid number**[4] were less than 25. Wet pavement accident rates were also higher for both uphill and downhill slopes (steeper than 3%) than for flatter terrain.
- Farber et al (1974) report that only 2.3% of wet surface accidents occurred on tangent sections of roads, where the friction demand is low.
- Parry et al (2001) concludes that amongst the most potentially dangerous driving conditions are those caused by low friction due to heavy rainfall combined with poor road geometry, or those where there is a sudden change in friction, perhaps due to contamination, localized deterioration of the surface or first snowfall.

Figure SC-3 Excess risk coefficient (C_{ar})



Source: Delanne and Travert, 1997

In England, the installation of anti-skid surfacing has been found to be the single most effective accident counter-measure at urban major road intersections, in the absence of speed reducing measures (DOT London, 2001).

How to detect problems

Accidents: wet surface accidents

Traffic operation: skidding

Physical features:

- aging of aggregates;
- bleeding;
- water/debris accumulations (check drainage facilities);
- presence of features that require a high friction level (intersection, horizontal curve, downhill grade, etc.).

Bleeding

These various problems are described in the ***friction test*** technical study.

[4] Skid number = 100 f_l

EVENNESS

Description

Evenness is a measure of the regularity of a road surface. All types of road surfaces (rigid, flexible, gravel, etc.) deteriorate at a rate which varies according to the combined action of several factors:

- axial load of vehicles;
- traffic volumes;
- weather conditions;
- quality of materials;
- construction techniques.

These deteriorations have an impact on the road surface roughness by causing either cracking, deformation or disintegration.

Longitudinal evenness

Various indicators can serve to estimate the quality of the longitudinal evenness of a road surface, but the International roughness index (IRI), developed by the World Bank in the 1980's, is the one most used today.

The IRI measures the vertical motion of the suspension of a vehicle travelling on a road under standardized testing conditions (meters of vertical displacement per kilometer driven).

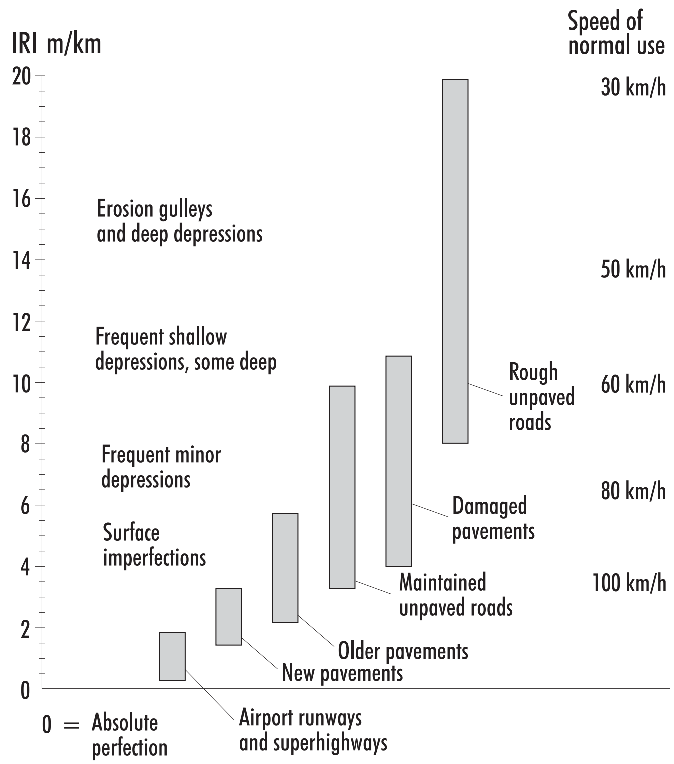
One of the main advantages of the IRI over older measurement methods is its reliability. The standardized testing conditions facilitate both repeatability and comparisons of results.

Typical IRI values range between 0 m/km and 20 m/km ("0" representing perfect conditions, (Table SC-4 and Figure SC-4).

Table SC-4 Examples of critical IRI values Main rural roads (Spain)

IRI VALUE	MINIMUM % OF LENGTH WITH IRI BELOW LIMIT
1.5	50
2.0	80
2.5	100

Figure SC-4 IRI scale



Source: Sayers, Gillespie et Paterson, 1986

Severe deterioration of a road surface (combination of problems: cracking, potholes, depressions)

Transversal evenness

The measurement of the transverse profile of the pavement allows the detection of various types of problems: inadequate camber, lane/shoulder drop-off, rutting, etc.

A number of road administrations use rut depths as a trigger to road surface remedial actions. The presence of ruts makes lateral shifts more difficult and increases discomfort and manoeuvre difficulties. Moreover, the presence of ruts can cause water accumulations, thereby increasing the risk of aquaplaning. The situation is particularly hazardous for two-wheeled vehicles. A rut depth of 20 mm to 25 mm is often considered critical. It can be measured manually or with laser devices.


Heaving


Rut

Safety

When the evenness of a whole road section has sharply deteriorated, users tend to reduce their speed in order to maintain their comfort at an acceptable level, thus minimizing potential safety impacts.

Pavement roughness can however be more detrimental to safety when problems are localized, unexpected and significant. Such situations can generate dangerous avoidance manoeuvres, losses of control or mechanical breakdowns of vehicles, thereby increasing the risk of accidents.

Reductions in skid resistance caused by vertical oscillations of vehicles on uneven road surfaces can prove problematic, especially for heavy vehicles and when the problems are isolated.

According to Al-Masaeid (1997), the safety impact of pavement roughness varies according to the type of accident considered:

- the single-vehicle accident rate decreases as the IRI increases, due to reduced speeds;
- the multi-vehicle accident rate increases, due to lateral shifts and speed differentials between road users.

However, one should also be aware that an improvement in the evenness quality associated with resurfacing may result in speed increases, thereby having a slightly negative safety effect ***(impacts of resurfacing on safety)***.

With respect to ruts, some studies mention an increase in accidents with rut depth, under wet surface conditions (Schandersson, 1994; Start et al., 1995).

How to detect problems (evenness)

Traffic operation:

- hazardous manoeuvres or unsafe lateral positioning of vehicles (to avoid surface defects).

Physical features:

- excessive surface defects (potholes, cracks, waves, rutting, other deformations);
- isolated or unexpected road surface defects that may surprise drivers;
- water/debris accumulation on the road, due to road surface deformations.

If needed, measure rut depth.

Possible measures

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APPENDIX SC-1

Friction coefficients (design)

Table SC-A1 Coefficients of longitudinal friction (f_l)

	DESIGN OR OPERATING SPEED (km/h)									
Country	30	40	50	60	70	80	90	100	110	120
Australia	-	-	0.52	0.48	0.45	0.43	0.41	0.39	0.37	0.35
Austria	0.44	0.39	0.35	0.31	0.27	0.24	0.21	0.19	0.17	0.16
France	-	0.37	-	0.37	-	0.33	-	0.30	-	0.27
Germany	0.51	0.46	0.41	0.36	0.32	0.29	0.25	0.23	0.21	0.19
Greece	0.46	0.42	0.39	0.35	0.32	0.30	0.28	0.26	0.24	0.23
South Africa – passenger cars	0.42	0.38	0.35	0.32	-	0.30	-	0.29	-	0.28
South Africa – heavy vehicles	0.28	0.25	0.23	0.23	-	-	-	-	-	-
Sweeden	0.46	0.45	0.42	0.40	0.37	0.35	0.33	0.32	0.30	-
Switzerland	-	0.43	0.37	0.33	0.29	0.27	0.25	0.24	0.23	0.22
USA	0.40	0.38	0.35	0.33	0.31	0.30	0.30	0.29	0.28	0.28

Source: Harwood et al., 1995

Table SC-A2 Coefficients of transverse friction (f_t)

	DESIGN SPEED (km/h)							
Country	50	60	70	80	90	100	110	120
Australia	0.35	0.33	0.31	0.26	0.18	0.12	0.12	0.11
Austria	-	0.16	0.14	0.14	0.13	0.12	0.11	0.10
Belgium	-	0.14	-	-	0.10	-	-	0.07
Canada	0.16	0.15	0.15	0.14	0.13	0.12	0.10	0.09
France	-	0.17	-	0.14	-	0.12	-	-
Germany	-	0.14	0.12	0.11	0.10	0.09	-	0.07
Greece	0.16	0.15	0.14	0.13	0.12	0.11	0.10	0.09
Italy	-	0.17	-	-	-	0.13	-	0.10
Japan	0.10	0.09	-	0.08	-	0.07	-	0.06
Luxembourg	-	0.17	0.16	0.17	0.13	0.15	0.12	0.12
Norway	0.20	0.18	0.16	0.14	0.12	0.10	0.08	0.07
The Netherlands	-	0.15	0.08	-	-	0.10	-	0.08
Portugal	-	0.16	0.13	0.12	-	0.09	-	0.08
South Africa	0.16	0.15	0.15	0.14	0.13	0.13	0.12	0.11
Spain	-	-	0.08	-	-	0.10	-	0.10
Sweeden	0.18	-	0.15	-	0.12	-	0.10	-
Switzerland	0.19	0.17	0.15	0.14	0.13	0.12	0.11	0.10
U.K.	0.10	0.10	0.10	-	-	0.10	-	0.10
USA	0.16	0.15	0.14	0.14	0.13	0.12	0.11	0.09

Source: Krammes and Garnham, 1995

HUMAN FACTORS

Technical sheet

H.-J. Vollpracht and Dr. S. Birth

HUMAN FACTORS

Technical sheet

LIST OF FIGURES

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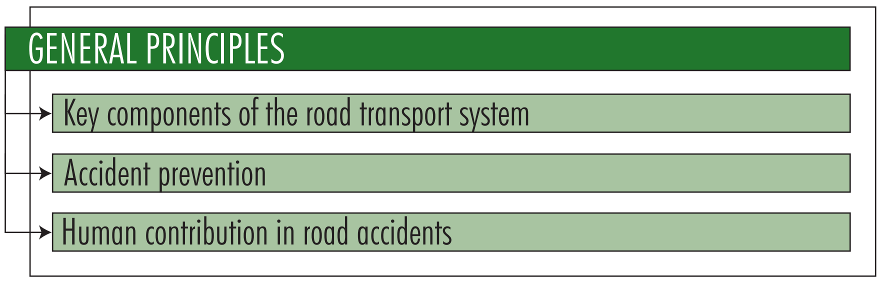
INTRODUCTION

This technical sheet has been prepared by members of the PIARC Road Safety Committee who, with the support of German psychologists, have analyzed 470 experimental studies about perception, information processing and other mental processes, which all have an impact on drivers' performance.

The first section presents some background information on human factors and road design. The second section describes in more detail the contribution of 5 human factors that influence driving behaviour.

GENERAL PRINCIPLES



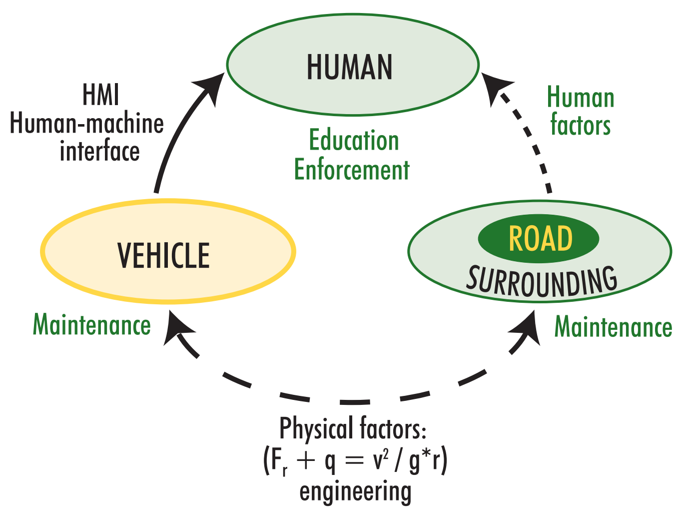
KEY COMPONENTS OF THE ROAD TRANSPORT SYSTEM

The road transport system can be described as a triangle made of three key components, namely the road user (human), the vehicle and the road characteristics (Figure HF-1). Each of these components can contribute individually to traffic accidents. However, these are most often the result of complex combinations and interactions between these components:

- interactions between vehicles and roads, which are described in several technical guidelines used by road engineers;
- interactions between road users and vehicles (human-machine interface). The ergonomic needs of drivers and passengers are taken into consideration by the car industry;
- interactions between road users and roads, which is the field of human factor specialists. These interactions are not very well described in existing technical guidelines.

A desirable approach would be to start with human physiological and psychological capabilities and limitations, and to use these as a basis in road and traffic engineering.

Figure HF-1 Key components of the road transportation system



Source: Vollpracht and Birth, 2002

Road designers should ask themselves why new blackspots sometimes appear after the construction of road projects that conform to existing standards. They have to realize that humans are not infallible but, rather, that they make errors for a variety of reasons, some of which are linked to the application of design principles that interfere with drivers' perceptions.

ACCIDENT PREVENTION

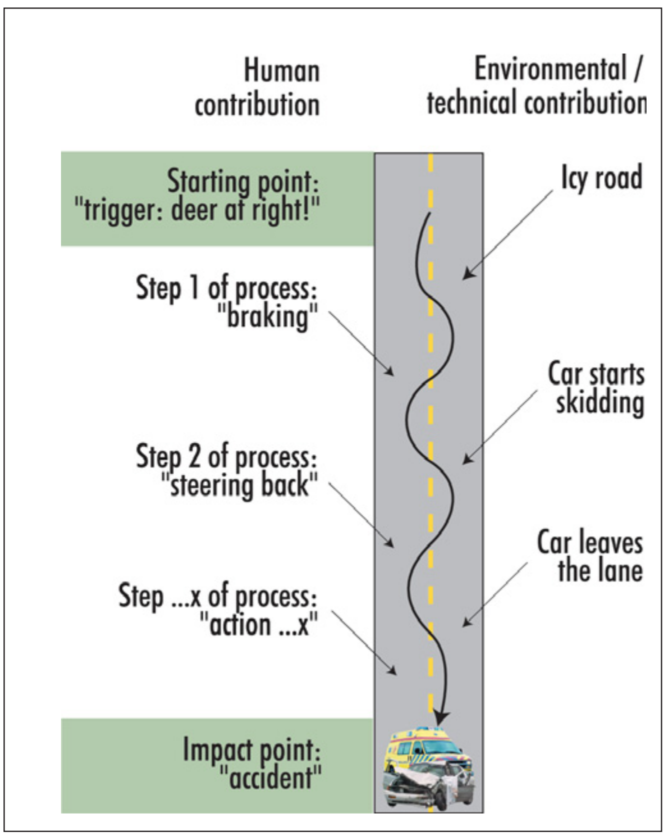
It is well known that human factors have an enormous impact on the safe handling of technical systems. Since 1970 several design standards have been developed to prevent human errors in many technical fields such as household appliances, industries, aviation and vehicle manufacturers. But do road designers know what is going on in people's minds while driving a car?

Building roads is the domain of engineers. Defining the needs of road users is the domain of psychologists. There is actually a gap between these two professions that needs to be bridged in order to develop better self-explained roads that will have the necessary features to efficiently reduce drivers' errors and accidents. Road engineering standards should be based on human behaviour, needs, capabilities and limitations.

HUMAN CONTRIBUTION IN ROAD ACCIDENTS

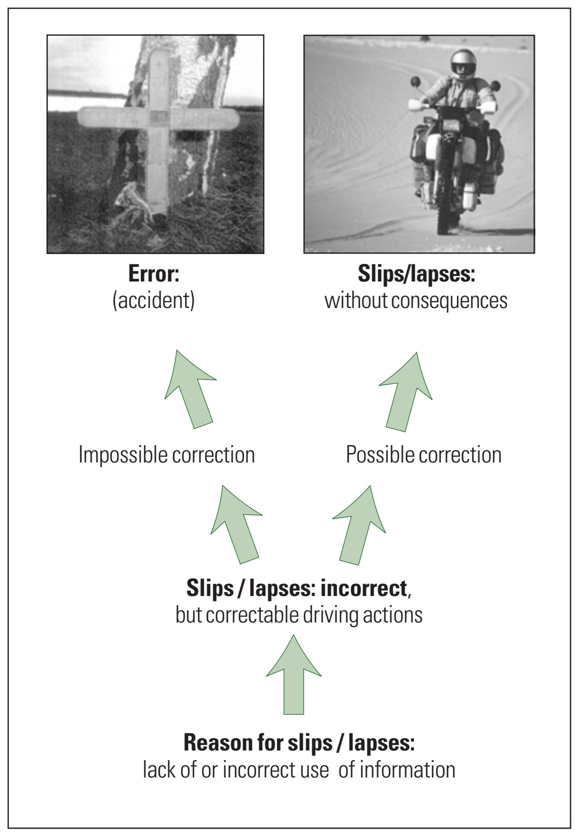
A road accident is generally the end-result of a multi-step process (Figure HF-2). By changing actions that are taken at any of these steps, an accident may or may not be avoided (Figure HF-3). Human factor specialists seek to understand the contribution of humans in road accidents, in order to propose solutions that will break the chain leading to accidents. Analysis has to begin at the starting point (not just at the impact point) to better understand how these events occur.

Figure HF-2 Example – Multi-step process leading to an accident



Source: Sporbeck et al., 2002

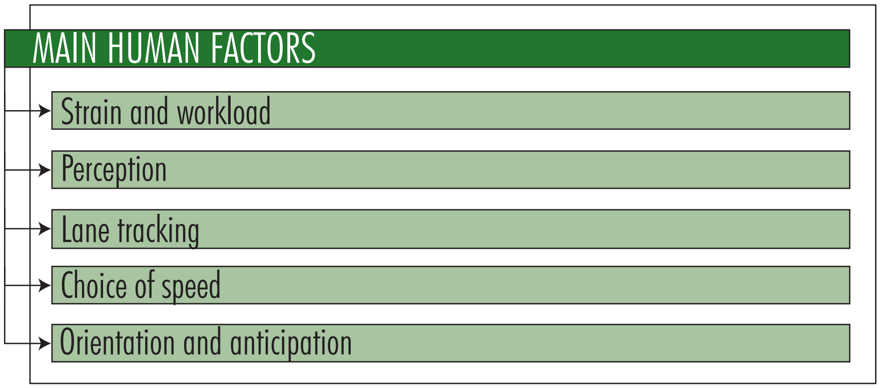
Figure HF-3 Example – Two outcomes for the same situation



Since humans make mistakes, roads should be designed in a way that "forgives" errors.

Source: Vollpracht and Birth, 2002

MAIN HUMAN FACTORS

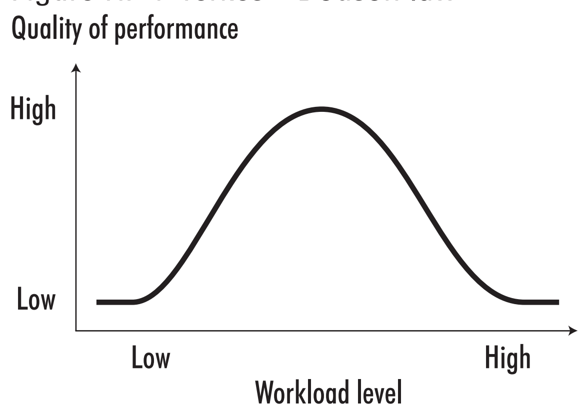


STRAIN AND WORKLOAD

Yerkes-Dodson law

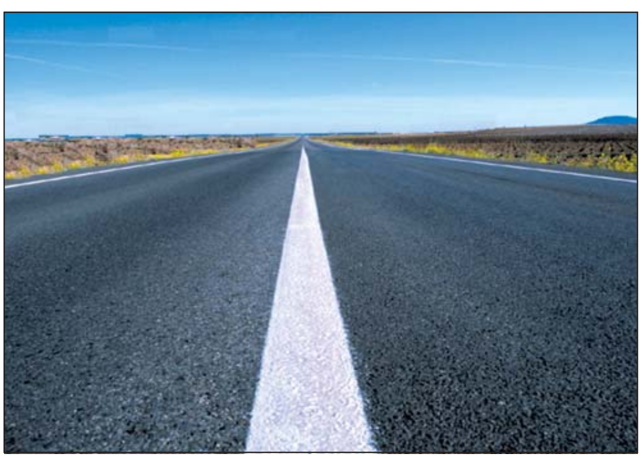
Driving performance is influenced by the workload level (Yerkes-Dodson law). Both an information underload and overload may lead to slips and lapses. Drivers' performance is best when the information workload is maintained at a moderate level (Figures HF-4, HF-5, HF-6).

Figure HF-4 Yerkes – Dodson law



Source: Birth, 2000 based on Hacker, 1984

Figure HF-5 Example – Information underload



Source: Birth

Figure HF-6 Example – Information overload

Source: Vollpracht

An information underload decreases a driver's attention and awareness. Some drivers may compensate by increasing speed. In order to reduce the monotony of a road environment, changes may be made to the road alignment, marking, planting, etc.

Human capacity in processing information is limited. The number of bits of information that can be processed simultaneously is 7 ± 2. As such, road engineers should avoid the superimposition of critical information at the same location.

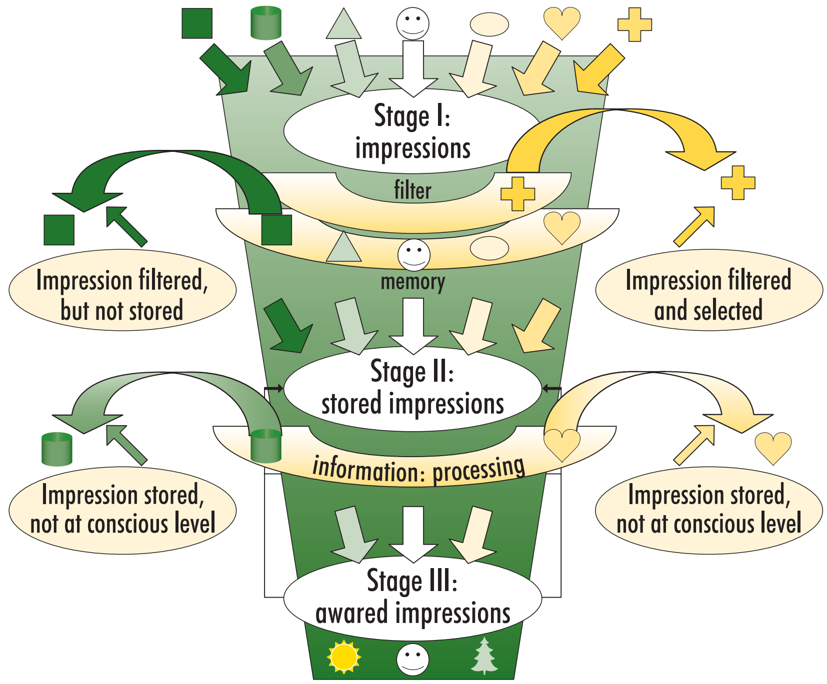
PERCEPTION

Human beings can only process a small proportion of the stimuli found in the road environment. What they perceive is filtered, selected and condensed (Figure HF-7).

Several factors have an influence on perception, including:

- ***optical illusions;***
- ***contrast and light conditions;***
- ***audible/visible cues;***
- ***age (needs of older drivers).***

Figure HF-7 The perception process



Source: Birth, 2000 based on Goldstein, 1997

Optical illusions

Various optical illusions can lead to incorrect estimations of speed, distance, direction, lane width, curve radii, etc.

- **Lane width illusion**

  The convergence of orientation lines leads to incorrect estimations of object sizes such as lane width (Figure HF-8).

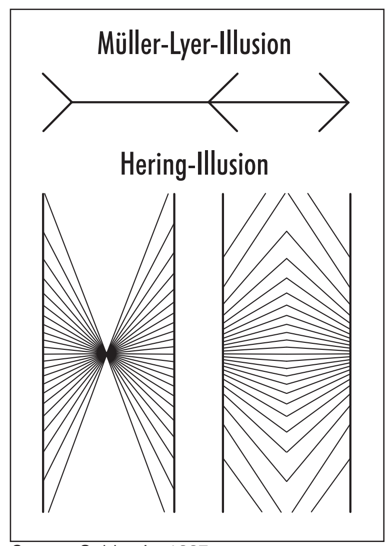
- **Distance illusion**

  The convergence of orientation lines may also lead to incorrect estimations of distances. For example, in Figure HF-9, the convergence of a tree line has the following effects:

  - the distance to the curve is perceived as being longer than the real distance (convergence is interpreted as an increased depth);
  - the lateral distance of trees is overestimated;
  - drivers arrive at the curve earlier than expected, which may lead to over-steering manoeuvres.

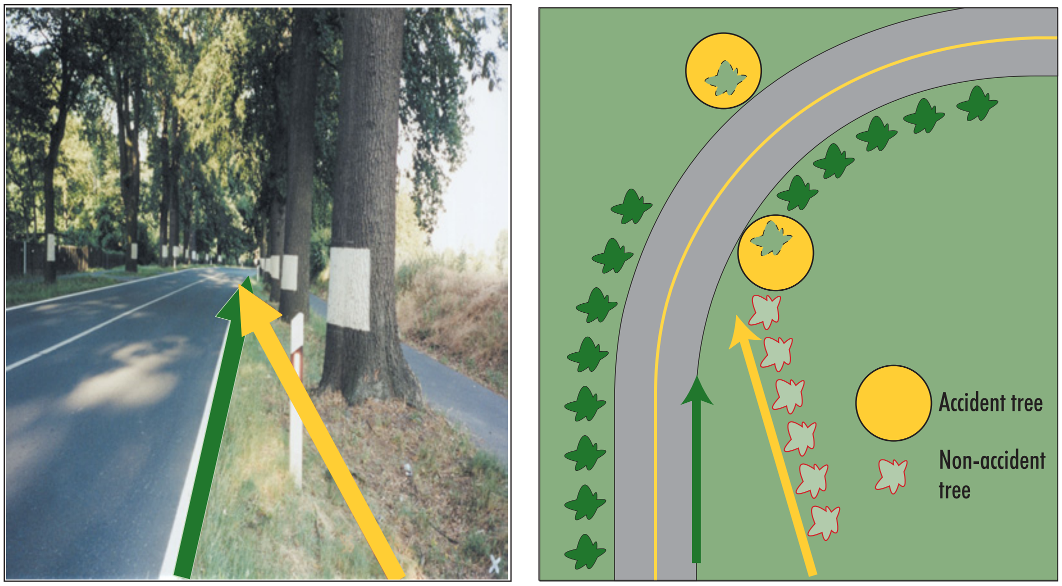
  Convergent orientation lines should be avoided (marking, road edge, line of trees or poles, crash barriers).

Figure HF-8 Optical illusion Lane width



Source: Goldstein, 1997

Figure HF-9 Optical illusion – Tree line



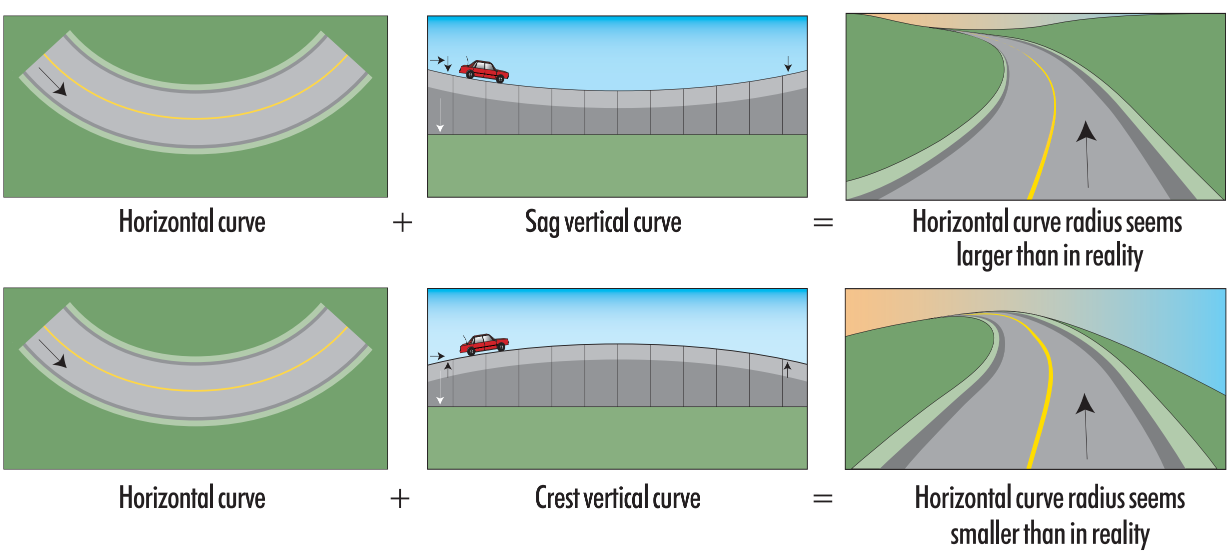
Source: Birth

- **Curve radius illusion**

The combination of an horizontal curve with a vertical sag curve suggests a wider horizontal curve radius than in reality. Drivers who prepare to steer for a wider curve suddenly have to slow down and correct their steering when approaching the curve. This is an accident-prone situation that should be avoided.

Conversely, the combination of an horizontal curve with a vertical crest curve suggests a narrower radius than in reality. This situation is much safer (Figure HF-10).

Figure HF-10 Optical illusion – Combination of horizontal and vertical curves



Contrast - Light conditions

Background problem

The possibility of distinguishing foreground and background information is critical in the detection of road signs and safety devices (Figures HF-11, HF-12).

Road engineers should ensure that adequate discriminative contrast is provided between road features and their background at all times (seasonal variations, sunrise and sunset, night-time, etc.) (Figure HF-13, HF-14).

Figure HF-11 Example – Poor contrast between foreground and background

Source: Goldstein

Figure HF-12 Improvement to road sign contrast

Before

Insufficient contrast between curve signs and background.

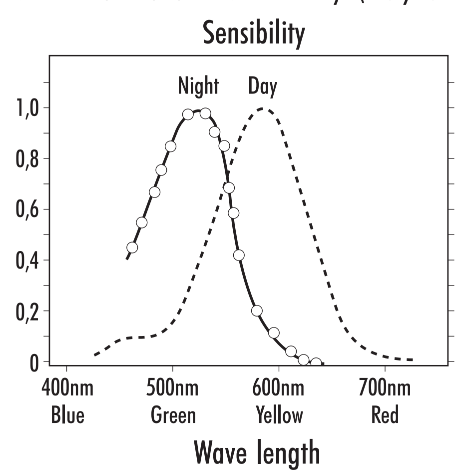
Source: Birth

After

Sign visibility has been increased by providing a yellow frame.

Source: Wartmann

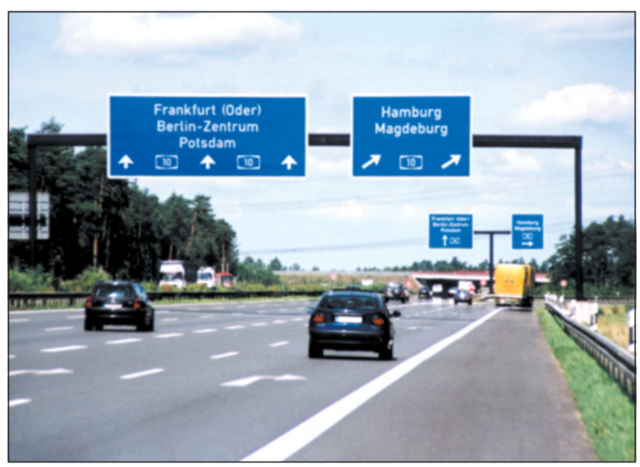
Figure HF-13 Color sensibility (day and night)



At night, blue and green colours are easier to detect than red.

Source: Goldstein, 1997

Figure HF-14 Road sign – German freeway



The combination of blue and white on road signs is easy to detect in day time and nighttime.

Source: VSVI

Light density and contrast

High light density and contrast reduce reaction time (Table HF-1). For road surfaces, moderate light density has been correlated with lower accident frequencies.

Table HF-1 Impact of light density and contrast on perception time

CONTRAST	LIGHT DENSITY	PERCEPTION
1:4	10 cd / m^2	20 ms
	60 cd / m^2	10 ms
1:6	10 cd / m^2	15 ms
	120 cd / m^2	5 ms
1:26	10 cd / m^2	10 ms
	250 cd / m^2	3 ms

Brightness

Rapid changes in brightness create stroboscopic effects that can disturb a driver's vision and perception. Road conditions that may create such effects should be avoided.

Audible and visual cues

Reaction time depends upon the nature of the message. Drivers react faster to audible signals than to visual signals (Table HF-2):

Table HF-2 Reaction times versus signal type

SIGNAL	REACTION TIME (ms)
AUDIBLE	150
VISUAL	200

They also react faster to a combination of audible and visual signs than to a single signal.

Rumble strips have been shown to be very effective in warning drivers that they are leaving the traffic lane. Studies show that they may reduce run-off-the-road accidents by up to 30% (Figure HF-15).

Figure HF-15 Rumble strips

Source: Ministère des Transports du Québec

Needs of older drivers

The needs of older drivers should be taken into account at the design stage. Older drivers have:

- longer reaction times;
- reduced psycho-motor capabilities;
- reduced visual capabilities (Table HF-3a, HF-3b):
  - visual acuity;
  - contrast sensitivity;
  - perception of moving objects.
  - lateral field of view;
  - susceptibility to blinding;

Table HF-3a Visual capabilities versus age (point of fixation)

AGE	POINT OF SHARP FIXATION OF LETTERS / SIGNS (cm)
< 40	23
< 50	40
< 60	100
< 70	400

Source: Goldstein, 1997

Table HF-3b Visual capabilities versus age (color detection)

AGE	THRESHOLD FOR VISIBILITY OF LIGHT WAVELENGTH (nm)
< 34	300
34 - 43	313
43 - 67	350
> 67	400+

Deep violet cannot be seen with increasing age

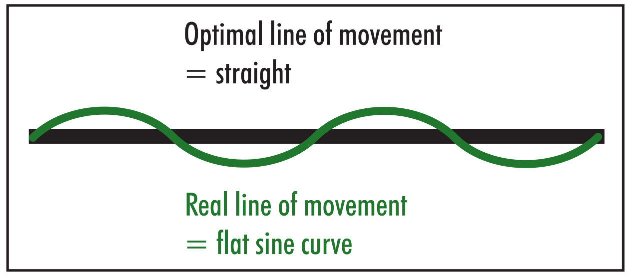
LANE TRACKING

A vehicle's optimum line of movement is in the middle of a traffic lane, not near its left or right side.

However, road users – drivers, cyclists, pedestrians – cannot move in straight lines. The real line of movement is a flat sine line (Figure HF-16).

Drivers' ability to maintain good lane tracking is influenced by several factors, including (Cohen, 1984 in Schlag 1997) :

Figure HF-16 Optimal and real line of movement



Source: Vollpracht and Birth, 2002

- the relative height of the road surface (balance-beam phenomenon):

  the higher the road surface, compared to its roadsides (e.g. bridge, bank), the more difficult it is to keep good lane tracking as drivers tend to move towards the middle of the road.

- the quality of orientation lines:

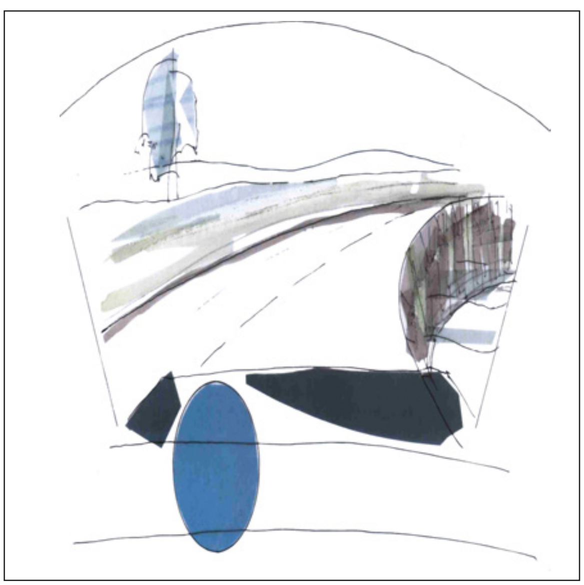
  continual and well-contrasted orientation lines (e.g. road markings, crash barriers, tree lines, walls) improve lane tracking (Figure HF-17). If lane-tracking difficulties are observed at night, check: road marking conditions, road lighting conditions and delineation devices.

- the presence of road features that require sudden speed changes:

  lateral vehicle offset increases when drivers have to reduce speed suddenly (e.g. unexpected sharp horizontal curves, steep hills, etc.).

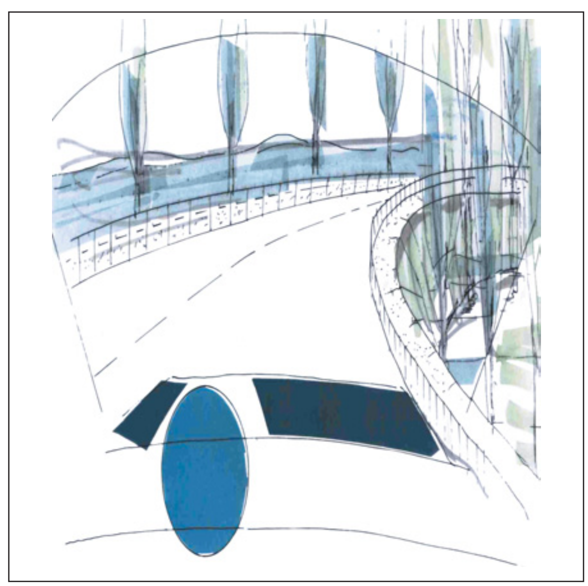
Figure HF-17 Example - Improvement to orientation lines

Before



Driver tends to stick to the middle of the road.

After



Trees and crash barriers have been added to improve lane tracking.

Source: Birth, 2000

CHOICE OF SPEED

Several characteristics of the road environment influence a driver's choice of speed:

- overall road condition:

  road environments that yield a general feeling of comfort increase speed (generous alignment, wide lanes, smooth road surface conditions, clear roadsides, low traffic conflict potential, etc.).

- contrast:

  when the contrast is decreased (e.g. rain, fog), the ability to estimate speeds and distances is reduced (drivers underestimate their speed).

- focus distance:

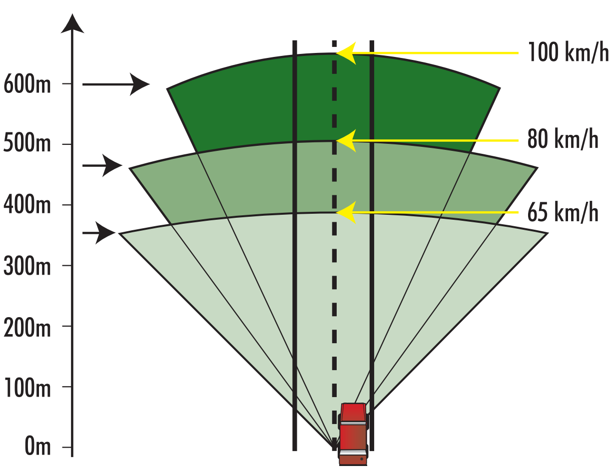
  longer focus distances increase speed.

Focus, peripheral vision

There is a relationship between the focus distance and speed (Figure HF-18). When speeds need to be kept low (e.g. residential areas), roads should be designed to avoid long focus distances *(Figure HF-20)*.

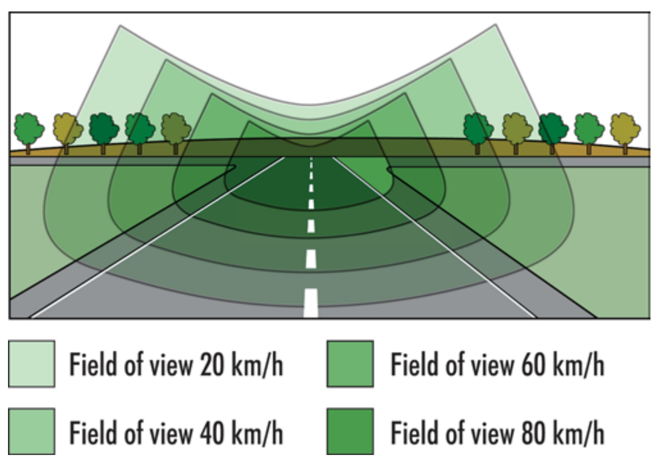
The faster the speed, the narrower is the field of view (Figure HF-19). This should be taken into consideration when choosing the lateral offset distance of road signs. However, one has to make sure that road sign poles do not become in themselves a road hazard.

Figure HF-18 Speed and focus point



Based on Cohen, 1984

Figure HF-19 Speed and peripheral vision



Based on Leutzbach and Papavasiliou, 1988

Figure HF-20 Example - Reduction of focus distances

Before

A combination of a poorly visible intersection with a straight alignment (long focus distance) contributes to increase operating speeds.

Several accidents occurred in the vicinity of the intersection.

Source: Birth

After

Delineation, marking and road surface treatment have been used to reduce focal distance and operating speeds and increase the visibility of the intersection.

The width of a driver's field of view is influenced by his driving experience and the nature of the road environment (urban or rural, Table HF-4).

Optimum angles of view are:

vertically: 20° up and 60° down

horizontally: 15-20°

Table HF-4 Visual field of view

DRIVER'S EXPERIENCE	ROAD TYPE	EXTENSION OF VISUAL FIELD VERTICAL	HORIZONTAL (100m)	HORIZONTAL (200m)
EXPERIENCED	URBAN	$\leq 5°$	9m	18m
	RURAL	9° - 10°	18.5m	37m
INEXPERIENCED	URBAN	$\leq 5°$	9m	18m
	RURAL	6° - 7°	13m	26m

Source: Cohen, 1984; Theeuwes, 1995

Speed estimation

Since drivers have trouble estimating speeds and distances, adequate cues need to be provided to assist them in these tasks (Figure HF-21, HF-22).

Figure HF-21 Estimation errors – Speed and distance

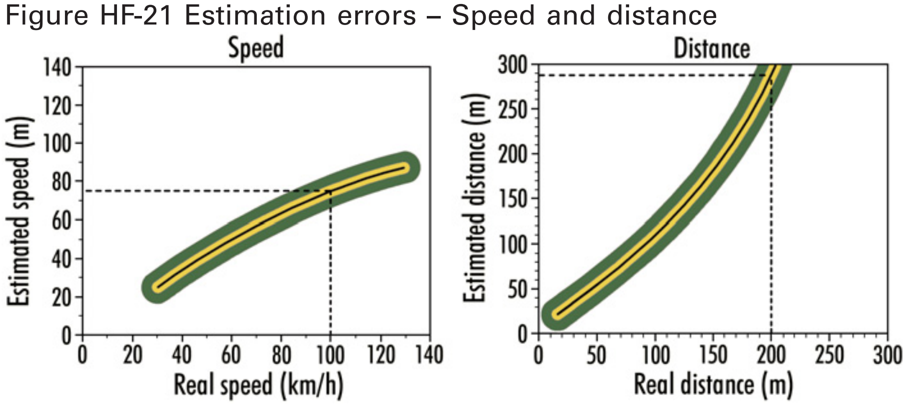
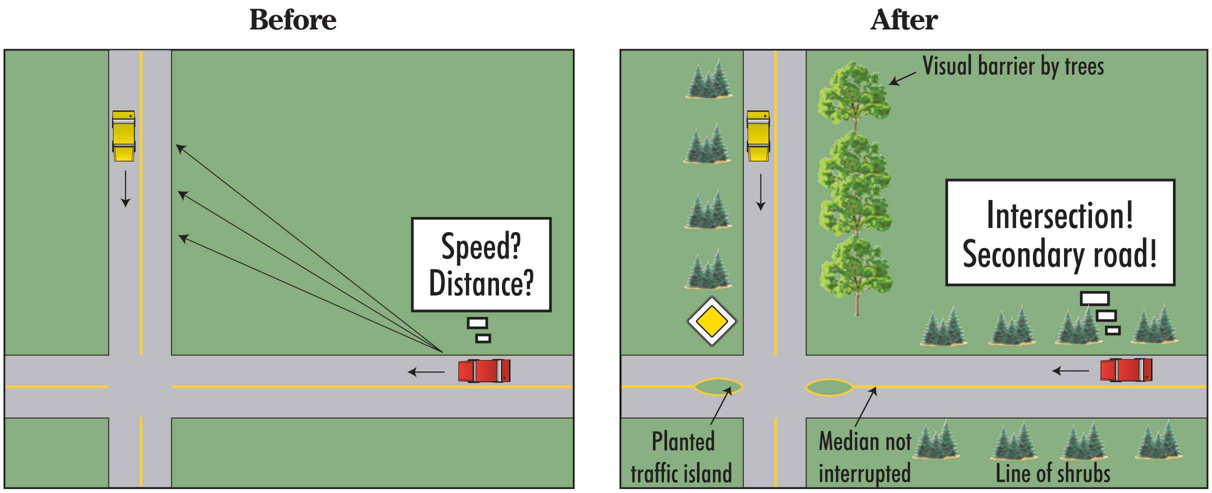


Figure HF-22 Example – Improvements at intersection



Due to the lack of orientation points, drivers have trouble estimating the other cars' speed and distance.

Priority has been clarified by installing road signs and reducing the width of the minor road (continuous median barrier).

Excessive sight lines have been reduced and the intersection has been highlighted by traffic islands, shrubs and trees.

Source: Vollpracht and Birth, 2002

ORIENTATION AND ANTICIPATION

Orientation is defined here as the awareness and perception of spatial relationships while driving: Where am I? Am I following the right path? Where am I driving to? Who is moving or stopped? Is the person moving fast or slow?

Anticipation is defined as the active search for information and the determination of a driving behaviour after detecting a new situation.

In order to improve both orientation and anticipation, two basic requirements need to be met:

1) A sound road categorization system;
2) The respect of drivers' expectancies.

Road categorization system

During a trip, drivers should be quickly able to recognize the main traffic function of the road on which they are travelling. Is it a road with a mobility function, which should allow higher speeds, or is it a road with an access function that requires lower speeds?

This calls for the establishment of a sound road hierarchical system that has a limited number of road categories – no more than 3 or 4 – each having a specific function, to which correspond specific design parameters.

Drivers sort similar signals in groups and respond by adopting similar driving behaviour. The clearer the features of a road category, the safer, faster and more homogeneous their reactions and decisions will be.

Road designers should use invariant and recurring road geometrics, surface features, signs and other road elements for each road type of the categorization system. Good examples are shown in Figure HF-23. More details are provided in ***Appendix 6-1***.

Figure HF-23 Road categorization – Good examples

Freeway with features that are coherent with a mobility function.

Wide median island to accommodate pedestrians in a shopping area.

Urban arterials allowing proper separation of incompatible road users: wide and well-marked lanes, bicycle paths with different material and color and pedestrian traffic signals.

Residential streets with a clear access function.

Source: Höppner

Driver's expectancies

See also *Appendix 6-1*.

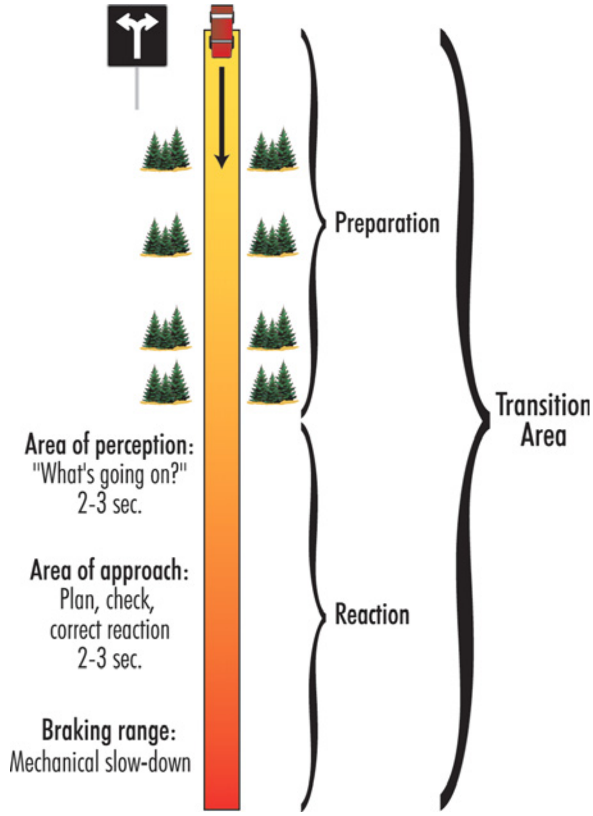
Transition

Road designers should provide adequate transitions when road conditions are changing to ensure that drivers have sufficient time to adapt to the situation (Figure HF-24 to HF-28).

Check prevailing conditions at:

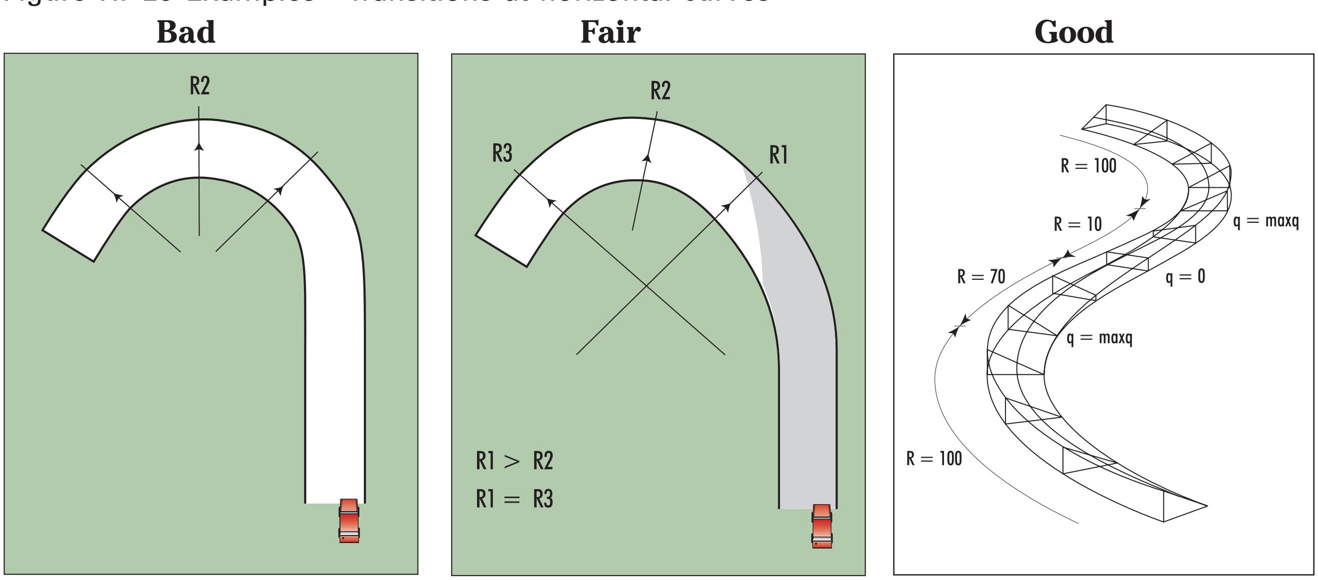
- horizontal curves;
- transitions between rural and urban areas;
- intersections;
- changes of road functions;
- changes of design speed;
- etc.

Figure HF-24 Transition area



Source: Sporbeck et al., 2002

Figure HF-25 Examples – Transitions at horizontal curves



Avoid sharp curve radius after long tangent!

Intermediate curve radius between a tangent and a sharp curve radius.

Progressive transfer between a tangent and a sharp curve radius by means of transition curves.

Source: Sporbeck et al., 2002

Figure HF-26 Example – Bad transition Intersection in horizontal curve

The main road seems to continue straight ahead but it veers to the left 300m ahead. There is a minor road in the continuity of the main road.

Recommendations:

- accentuate the outside of horizontal curve (trim trees, delineation, marking);
- improve visibility of curve warning signs;
- use road bumps, special road surface (colour, material) or marking to reduce speed.

Source: Birth

Figure HF-27 Example – Bad transition Intersection in horizontal curve

Before

Due to the presence of an intersection, the main road seems to go straight ahead. Drivers are not prepared to change direction

After

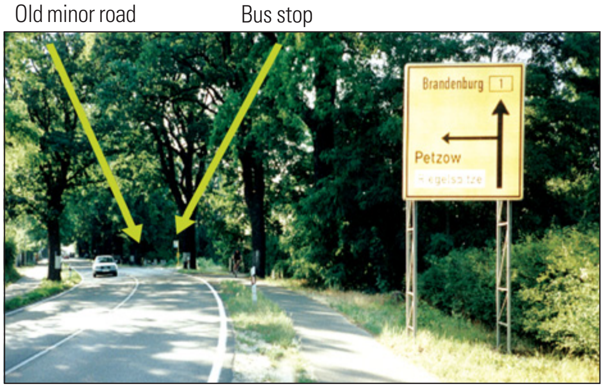
Intersection has been moved away from the curve. Embankment and trees have been added to hide the previous alignment.

Source: Sporbeck et al., 2002

Figure HF-28 Example – Bad transition at horizontal curve

Before

Old minor road Bus stop



Road sign is not coherent with road alignment. The presence of a minor road suggests a straight alignment. A bus stop is located in the curve area.

After

The road sign has been modified. The minor road has been hidden by shrubs. The bus stop has been moved out of the curve. Marking has been improved.

Source: Birth, 2000

Transition – From rural to urban areas

At the transition between a rural and an urban area, drivers should be provided with sufficient information to ensure that their speed is reduced to a level that allows safe traffic operations. Several traffic-calming measures may contribute to reducing speeds (Figure HF-29 to HF-31): horizontal shifts (chicanes), roadway narrowing (centre island, marking, distinctive road surface material), use of plantations, vertical shifts (road bumps or humps).

Figure HF-29 Example – Transition zone

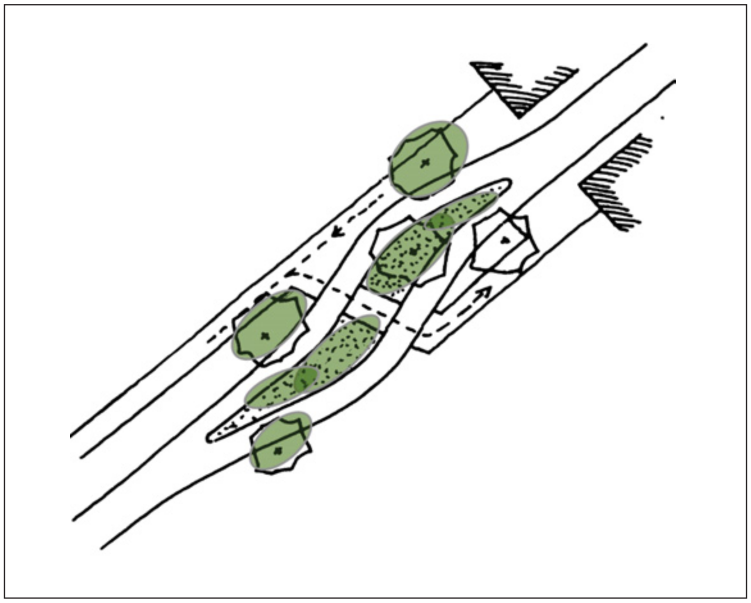


Figure HF-30 Examples – Good transitions between rural and urban environment

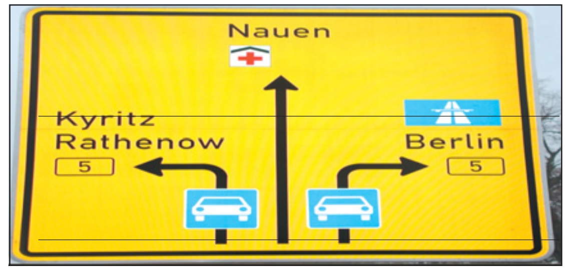
Figure HF-31 Example – Improvement at the approach to an intersection

Drivers who travel on this minor road do not expect to have to stop at an intersection because:

- the intersection itself and the intersection warning sign are hidden by trees (only visible 50m away from intersection);
- the intersection sign suggests that the driver is on the main road.

Source: Staadt

Before



After

The intersection road sign has been improved to clearly show road users that they are on a minor approach to an intersection. Distinctive road surface material, marking and plantation at intersection should be used to reinforce the presence of the intersection.

Source: Wenk

A new intersection was created on an existing road after a new road was opened. The right of way is on the new road.

In order to properly advise drivers travelling on the old road of the presence of this new intersection, the following features were included in the design (Figure HF-32):

- horizontal curves were created on both sides of the intersection to break the continuity line. These are far enough from the intersection to allow adjacent legs to cross at right angles;
- plantations were added alongside these curves to cover old tree lines (avoiding confusion with previous road alignment and warning drivers of the presence of curves).

Figure HF-32 Example – Adequate transition when approaching an intersection

Source: Sporbeck et al., 2002

CONCLUSION

The possibility of error cannot be neglected in the development of any technical system, and the road transportation system is no exception to this reality. In the past, drivers were too often blamed for committing an error, adopting inappropriate behaviour or having limited driving skills. But it is now well recognized that effective solutions to the problem require much more than simply identifying a “guilty” party.

It is important to realize that the measures taken regarding each of the basic components of the safety system (human, road environment and vehicle) and those taken regarding the interfaces between these components (human and road environment, in particular), may have a preponderant impact on the reduction of human errors and the occurrence of accidents.

Road designers, in this sense, must recognize that they can - and must - develop road environments that are well adapted to human capabilities and limitations. The recent progress achieved in traffic calming solutions clearly shows how changes in traditional urban road planning and design practices, which depend on adequate consideration of driver perceptions, can have a positive effect on road users’ safety and the well-being of the neighbouring population.

Progress is also possible in rural areas. In Germany and in some other European countries, for example, the consequences of running off the road are often aggravated by the presence of rows of trees. Some photos in this technical sheet clearly show how these trees are dangerous when they are mature. The presence of these “aisles” can cause up to five times as many victims as on roads where they are absent. If these trees are protected by law, passive safety measures (guardrails, for example) should be used to help creating roads that “forgive” errors.

Finally, it is important to recognize that human error cannot be totally eliminated and that it will continue to occur - at a lower rate - even if the road transportation system becomes better adapted to human nature. Consequently, engineers must design roads that minimize the consequences of such errors. This approach is the key element of the Swedish ***“Vision zero”***, one of the countries with the best track records in terms of road fatalities and injuries.

In the future, it must be hoped that a greater number of factors for minimizing human errors or minimizing their impacts will be integrated into the road design standards, leading to an improvement in the intrinsic safety level of road networks.

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INTERSECTIONS

Technical sheet

Sandro Rocci

INTERSECTIONS

Technical sheet

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INTRODUCTION

Intersections are an essential part of a highway network: drivers can change their path in them, thus enabling a large amount of destinations to be reached with a minimum number of highways. Speed at intersections is lower than in its approaches: sometimes vehicles even must even stop. Therefore, these are critical points of the highway network as regards capacity, level of service, and safety.

Intersection design should cater for unfamiliar, non-expert drivers and probably elderly persons. Most people drive routinely and are not fully aware of their task. When confronted with similar situations, they will look by instinct for solutions based on their experience. People who every day take the same route are so familiar with it that they will not notice substantial differences between intersections along it; but occasional users are likely to get confused by a lack of uniformity, such as catering for a left turn with a ***semi-direct turning lane***, while all other intersections carry a ***central storage lane***. Most driver errors arise from a combination of factors complicating the driving tasks: vehicle control, guidance and navigation. Many of these tasks have to be completed in a short time and while in motion ***(human factors)***.

Both design and signing must provide the correct information at an adequate time and place. Intersections needs simple signing, reflecting what the designer expects drivers to do. Signing should be considered from the earliest stages of design and not merely added at the end of it.

Some doubts can arise from the intersection layout itself:

- follow-through path is on a left-hand curve and the right turn appears straight ahead;
- non-priority movements have a smooth path that can be traveled at high speed.

Permitted movements should be self-evident and easy; non-permitted ones should be made difficult.

The choice of intersection type should be adapted to the relative importance of traffic volumes: less risk should correspond to larger volumes. Besides, risk should not be excessive even for small traffic volume.

Y intersection that may cause hasardous manoeuvres (high speed turning manoeuvres, traffic conflicts).

For instance, four-leg rural intersections are less safe than three-leg ones; the same applies to urban intersections with large ADTs (more than 20,000).

Rural intersections account for about 20% of accidents and urban ones for about 50%, a percentage far higher than their physical share of the network area:

- conflicts between vehicles and/or vulnerable users are much more likely;
- human errors are also more likely since users must choose among several paths, adjust their speed and carry out their manoeuvres under high time and space constraints.

Unconventional designs (e.g. intersections requiring drivers to divide their attention simultaneously among several conflict points) are generally unsafe: some degree of standardization is necessary. But blindly following set recipes hardly guarantees safety, especially in highly complex urban environments.

Existing intersections are often remodeled not only to improve their capacity, but also to improve safety by reducing their unfavorable features: traffic conflict reductions, signing improvements, speed-calming, etc. Remodeling often consists of a change of design: conventional intersections are transformed into roundabouts or even interchanges.

This technical sheet describes conventional intersections (typically 3 or 4 legs) and roundabouts. Interchanges are not covered.


Transformation from a Y intersection to a T intersection.

GENERALITIES

CHOICE OF INTERSECTION TYPE

The choice of an intersection design depends upon several factors. The most important ones are:

- traffic safety;
- road type and function;
- number of concurring legs;
- traffic volume and type;
- design and operating speed;
- priority setting;
- terrain;
- available room;
- adjacent land use;
- service to neighbouring population;
- network considerations (design consistency);
- environmental concerns;
- cost.

The relative importance of these factors varies between cases and should be assessed. Functionally possible solutions can later be studied, and the most adequate one chosen according to the more important factors. Consistency should be maintained through routes and areas, to reinforce driver's experience, improve their expectancies and hence safety.

This section discusses the choice of an intersection type based on:

- ***highway type***
- ***road environment***
- ***capacity***
- ***cost***

Traffic priority

By default, in right-hand-drive countries vehicles usually give way to those coming from their right side. This regulation mode should not be used in rural settings unless traffic is very low and visibility is high; it is often found in secondary urban streets (residential and industrial), especially one-way, with ADTs up to 1,000 – 1,500 vehicles.

The simplest way to actively regulate crossing traffic at an intersection is to set the priority of one flow over the other by means of STOP or YIELD signs (fixed signed priority). This can include several degrees of decreasing priority between movements. This regulation mode is usually found:

- on non-divided rural highways, provided that the capacity of non-priority legs is sufficient;
- at urban intersections with so little traffic in non-priority legs that a signal is not warranted (especially on one-way streets).

Accident frequency between priority and non-priority vehicles is heavily dependent on the volume of the non-priority vehicles, and rather less on the volume of the priority vehicles. The accident risk of non-priority vehicles is high regardless of their volume; that of priority vehicles is less, and is proportional to non-priority traffic volume.

Signals, allowing for many combinations of phases and special lanes, are a customary solution in urban environments (on arterials and main collectors). In rural environments, signals are usually a surprise, and hence, a danger.

Another way of setting priorities is the roundabout (typically in urban and suburban settings). Vehicles traveling on the ring lane have priority over those wanting to enter. More legs can be accommodated (up to 6), and accident severity is much less than in other intersection types.

Choice of intersection according to highway type

The type of intersection has to be suited to the highway type in order to maintain:

- good readability both of the highway and of the intersection;
- a satisfactory level of safety.

Types of intersections not to be used are the following:

On freeways:

- intersections or roundabouts, because of their legal definition.

On main rural highways:

- signalized intersections, except in very special cases;
- right-hand priority intersections.

Damaged guardrails at a signalized intersection on a high-speed road.

Choice of intersection according to environment

Rural highways

Eligible intersection types are:

- roundabouts

  except on divided highways with more than two lanes in each direction, since continuity is broken (unless this is precisely the aim); in this case, the roundabout must be very self-evident and the need to reduce speed should be made obvious on its approaches.

- signed priority intersections (STOP or YIELD)

Rural main highways

On rural main highways, fixed signed priority intersections have a rather poor safety level, precisely because of their operation principle: priority drivers, driving fast and conscious of their priority, interact with non-priority drivers for whom crossing the priority highway represents a delicate task. Information acquisition, treatment, decision and manoeuvering are subjected to strong time limitations. When traffic volumes are high, accident frequencies are also high and a roundabout may be a solution (Service d'études techniques des routes et autoroutes/Centre d'études des transports urbains, 1992).

Rural secondary highways

With this type of roads the following intersections are used:

- right-hand priority;
- fixed signed priority. It is not advisable to give priority systematically to a route, since this increases speed and decreases safety;
- roundabouts are adequate as soon as traffic volumes are noticeable or where there are safety problems. They may be small if the following two problems are solved:
  - central islands are conspicuous;
  - large vehicles can manoeuvre.

Intersections on bypass roads

When bypassing villages, transverse traffic can be high and the environment is often unfavorable[1]. Accidents concentrate at intersections (especially intermediate ones), where about 70% of personal injury accidents occur. The following precautions are advisable:

- main intersections should be roundabouts. If a fixed signed priority intersection is warranted at the end of a bypass, it should be a T and not a Y;
- minor intersections should be suppressed (and traffic transferred to a neighbouring intersection); if transverse traffic is important, the bypass should be crossed over or under, without connection.

[1] The intersection is often in a curve and there may be a degree of ambiguity at the beginning and end of the bypass.

Urban highways and streets:

Eligible intersection types are:

Arterials[2]:
- roundabouts;
- signalized intersections.

Collectors:
- roundabouts;
- signalized intersections;
- fixed signed priority intersections;
- right-hand priority intersections.

Local or residential streets:
- roundabouts;
- right-hand priority intersections.

Choice of intersection according to capacity

Table 1.1 indicates the approximate capacity of several types of intersections. Figure I-1 indicates the range of application of different types of intersections (England).

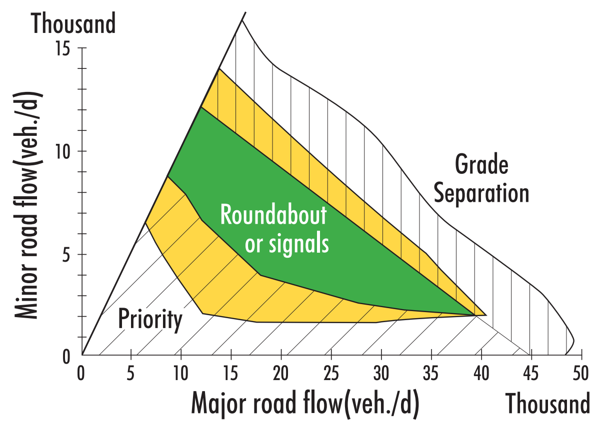
Table 1-1 Capacity based on intersection type

INTERSECTION TYPE	CAPACITY (pcph)
Right-hand priority	1,000 – 1,500
Fixed-priority	5,000 –12,000
Single-lane roundabout	20,000 – 28,000
Multi-lane roundabout	35,000 – ?[a]
Signalized intersection	20,000 – 80,000[b]

[a] Variable between countries.

[b] Depending on the lane assignment.

Figure I-1 Type of intersection based on traffic flows



Source: IHT, 1987

Choice of intersection according to cost

Land occupation and construction cost of roundabouts are relatively low, which can be an advantage over other types of intersections. Also, operation and maintenance costs are lower for roundabouts than for signalized intersections.

In existing roundabouts, it is usually possible to add a new leg if distance to the adjoining ones is sufficient for safety (not for capacity).

[2] At major intersections, roundabouts are recommended; elsewhere signals are frequent.

SAFETY AT INTERSECTIONS

Right-hand vs. fixed-signed priority intersections

Experiences in the transformation of right-hand priority intersections into fixed-signed priority ones show some increase in accidents with high traffic volumes, especially if the roadway is narrow or at the traversing of small villages (Service d'études techniques des routes et autoroutes/Centre d'études des transports urbains, 1992).

Priority vs. signalized intersections

A before-after study by the Paris Town Hall showed that, accidents were fewer at signalized intersections than on similar priority ones (most sites were four-leg intersections).

However, a German study[3] provides more cautious information (Frith and Harte, 1996) :

- transforming three-leg fixed-signed priority intersections into signalized ones does not improve safety significantly;
- transforming four-leg fixed-signed priority intersections into signalized ones reduces significantly both the number of crashes and their severity;
- transforming four-leg right-hand priority intersections into signalized ones reduces significantly the number of accidents, but not their severity.

It seems that these differences are due to the difference in shape between three and four-leg intersections, and to differences in speed between right-hand priority and signs. There were also differences in traffic volumes: the largest improvements corresponded to secondary streets with relatively high traffic.

Roundabouts vs. other types

A British study showed that, the product of the two traffic volumes being equal, there are less accidents (and less severe ones[3]) at roundabouts than at signalized intersections. Research by Brillon & Stuwe (1991) confirms this trend for medium-sized roundabouts (less than 40 m), based on a different index (ratio of accidents to total approach traffic). For old-design roundabouts (large diameter), the number of accidents seems higher than for signalized intersections, although their severity is lower.

Two-wheelers (especially bicycles) are subject to similar accident risk in roundabouts and signalized intersections; this risk is higher at roundabout entrances when speed is relatively high.

It is generally believed[4] that the installation of traffic signals reduces the number of right-angle collisions while increasing rear end collisions. This should prevent the use of this solution, unless traffic volumes on the minor approaches are high and pedestrian volumes are high (in such cases the reduction of right-angle collisions would more than compensate the increase in less severe rear-end collisions).

Therefore, for safety reasons it would seem adequate to transform high-volume intersections (especially on secondary streets) into roundabouts or at least to signalize them. For the same reasons, roundabouts should be provided at the main intersections of residential areas. For intersections of lesser importance, right-hand priority can be allowed since it tends to increase drivers' attention and decrease speeds (compared to fixed-signed priority intersections).

Since the legs are not far apart, drivers trying to enter a mini-roundabout should be well aware of vehicles inside it and prepared to react quickly when they perceive a gap. In this situation, cyclists are likely not to be seen; if their number is high, a signalized intersection would probably be safer.

3 Except if the roundabout is large.

4 Although it has not been clearly shown.

Four-leg + intersections

For safety reasons only, four-leg intersections should only be allowed on low-volume highways or where most traffic approaching from the non-priority highway turns, instead of crossing the priority highway. There is a trend to replace them by two staggered T intersections, and resulting accident reductions of up to 70% have been reported in the U.K.

Fixed-priority + intersections should be avoided in rural divided highways, since non-priority vehicles have to cross a large width. The accident risk of such crossings is:

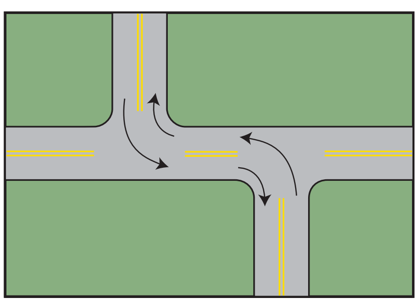
- 1.5 times that for the crossing of an undivided highway (twice if only fatal accidents are considered);
- 10 times that for traveling 1 km on a undivided highway, away from any intersection;
- 30 times that for crossing a roundabout.

4-leg rural intersection versus two staggered 3-leg intersections

There is a definite safety advantage in replacing a 4-leg rural intersection with two staggered 3-leg ones. Offset should lie between 5 m and 40 m for secondary highways, and more for a main highway. Two types of layouts are possible (right-hand-side driving):

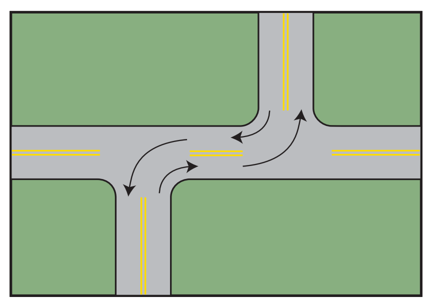
The first 3-leg intersection goes to the left:

- vehicles crossing the priority highway must watch both sides and wait for a suitable gap; they merge from the left;
- once on the priority highway, turns are only to the right, thus reducing interaction with through traffic.



The first 3-leg intersection goes to the right:

- vehicles crossing the priority highway must watch only one side and merge from the right;
- once on the priority highway, turns are to the left and usually need a ***central left-turn lane***.



Signalized intersections

Pedestrian runovers

Between 60 % and 70% of injury accidents involving pedestrian at signalized intersections, and about 90% of fatalities in the same circumstances involve a vehicle traveling on a through lane and a pedestrian trying to cross it. The vehicle is usually placed at the intersection entrance, rather than at its exit; the pedestrian is just starting to cross. In 80% of the cases pedestrians have a red signal. Less frequently, the signal is green for the vehicle and amber for the pedestrian, or vice versa.

Runovers of elderly persons are to be especially catered for: their frequency (around 8% of all runovers) is smaller than the proportion of older people in the population (around 13%), but fatality is higher (23%). The majority of these runovers take place:

- in daylight;
- when starting to cross, with vehicles turning left, leaving the intersection, or turning right on amber;
- with backing up vehicles.

Factors that increase runover risk include:

- a large number of lanes entering the intersection. Four lanes instead of one multiplies the risk by 2.5;
- a reduced sight distance when entering the intersection;
- signals belonging to a coordinated regulation system that improves the level of service (LOS) for vehicles traveling on priority streets. The increase in accidents is due to the fact that pedestrians have to wait longer and end up crossing on red;
- pedestrian-operated signals: they often lead to a longer wait. If traffic flow is small, pedestrians cross on red, which is dangerous since vehicles are traveling fast;
- a large distance between the pedestrian crossing and the adjoining intersection;
- poor signal maintenance;
- possibility of vehicles turning right on a flashing amber, especially if pedestrian volumes are high and speeds are low.

Left-turn accidents

The main safety problems related to left-turn manoeuvres are:

- difficulties for left-turners to find a correct transverse placement;
- storage difficulties;
- poor perception of opposing vehicles, especially two-wheelers;
- poor estimation of remaining time to coincide with the opposing vehicle;
- high through speed.

Lengthening the “all-red” phase increases the risk of left-turn accidents, since the number of vehicles turning on red increases, too. “All-red” phase (plus amber) should allow the intersection to be cleared before the onset of green: shortening the “all-red” phase should entail lengthening the amber one. This is dangerous because some vehicles will try to accelerate on amber when they should instead be braking.

Right-angle collisions

This type of accident is very severe. It may result from red light running or from inadequate signal timing (yellow and all-red intervals)[5]. Most of the time, the red-crashing vehicle tries to pass when the green phase is ending, rather than starting to move while the signal is still red.

Problems that contribute to the occurrence of this type of accident are:

- poor perception of the presence of signals because of speed, road environment or glare;
- excessive speed;
- belief that there is still time to pass on amber;
- fear of being tailgated;
- poor compliance to signal-controlled operation, especially by moped drivers.

Intersection design and signal phasing may contribute to these accidents:

- excessive width of intersection approaches;
- short cycles: if the cycle length is reduced from 120s to 30s, the overall accident frequency is multiplied by 2 and the right-angle-accident frequency is multiplied by 4.

But design and signal phasing may also contribute to reducing these accidents:

- layouts that encourage moderate speed, such as a slight deflection of through paths by an offset of the opposing accesses;
- central refuge island;
- reduction of the “all-red” phase to a minimum. Signal heads of the transverse street should not be visible, so that no information can be gleaned from them to squeeze the safety margin provided by the “all-red” phase.

Safety at roundabouts

Safety at roundabouts depends on many aspects of their design that are not always compatible: a compromise has to be reached to enable vehicles to change legs safely enough and with little delay. This compromise is hindered by excessive traffic volume or speed, and by lack of room: this latter often is the determining factor in urban areas.

Risk at roundabouts is relatively low. Injury accidents are less frequent than at other types of intersections as soon as traffic volume on the non-priority highway exceeds:

- 5% of traffic on the priority highway, for + intersections;
- 10%, for T intersections.

Fatalities at roundabouts are fewer than at other types of intersections for even smaller traffic thresholds since accidents are less severe.

However, despite the good safety record of roundabouts, special attention should be paid to their design:

- the most important factor is the curvature of the path of entering vehicles;
- too-large central islands (more than 30 m in diameter) are less safe;
- pedestrians and/or cyclists can pose special problems.

[5] It can also be due to flashing amber signals, or even out-of order signals.

Roundabouts – Rural and suburban areas

The main accident type is loss of control at the entrance of the roundabout and running on to the central island (nearly 40% of personal injuries and nearly all fatalities). This loss of control is often due to the surprise of frequent travelers who knew the intersection before its transformation into a roundabout up to some months after its completion. In fatal accidents, there is usually a sharp deceleration on the central island, especially with an aggressive design.

Other accident types occurring at rural and suburban roundabouts include:

- collisions between entering vehicles and those traveling on the ring lane. This type of accident can increase if entrances are flared;
- losses of control in the ring lane, especially if it is elliptical.

Roundabouts – Urban areas

The main accident type is between an entering vehicle and another traveling on the ring lane: nearly 40%[6], especially between two-wheelers and heavy vehicles. Other accident types include:

- loss of control at the entrance (around 30%), especially for motorcyclists;
- loss of control in the ring lane, especially for mopeds;
- pedestrian runovers; nearly one-third when they try to cross an entrance; some others when crossing a wide and fast exit. Another one-third involves crossing the ring lane, trying to cut across a too large-roundabout.

[6] This percentage can climb to 70 % if entrances are very flared.

DESIGN PRINCIPLES AND ROAD ENVIRONMENT

Although intersection design is site-specific, experience shows differences between rural and urban areas. For instance, in rural areas many of the design elements are safety-related, while at urban intersections more emphasis is placed in operation and capacity.

Rural intersections

The following points should be taken into account:

- on each approach and at the intersection itself, adequate sight distance should be provided;
- design should be based on operational speed on the priority highway;
- strict approach designs should be avoided: tight curves, high grades.

If right-hand priority intersections are allowed on the secondary highway network, the following measures should be adopted:

- reinforcement of the intersection presence: clearing of the roadsides, beacons, coloured pavements, destination signing, etc.;
- increase of sight distance: offsetting fences and greenery, parking prohibitions (combined with a narrower highway);
- many of the principles pertaining to fixed-priority intersections should be applied: readability, simplicity, compactness, speed-calming, etc.

Urban intersections

At urban intersections the following points should be taken into account:

- approach capacity should be maximized by a judicious choice of cross-section;
- pedestrian activity should be foreseen;
- needs of all types of road users have to be properly addressed (cyclists, transit, etc.);
- driveway problems next to the intersection should be solved;
- additional lanes should be able to operate independently from through lanes.

Residential intersections

In residential streets, accessibility is more important than mobility and capacity. Advantages of a lower mobility (and speed) are a greater safety for pedestrians and children, less pollution (vehicle emissions, noise) and more convenience for residents.

Residential streets operate at a fair safety level if the following principles are followed:

- the number of direct connections to arterial or main streets is limited and achieved mainly through collector streets;
- the street network in the residential area is either discontinuous or circuitous, preventing rat-running.

Traffic calming measures at intersection (residential area).

Improvements to residential street networks – aimed at reducing both traffic volumes and speeds should be carefully planned, to ensure that existing problems do not simply migrate to the next residential area.

Roundabouts

In rural areas, the loss of priority imposed to through traffic by a roundabout result in a lower LOS: this can be inadequate on a main route.

In urban or suburban areas, traffic conditions may not always be compatible with roundabout operations (high traffic volumes with heavy hourly variations, vehicle platoons, and spatial limitations).

CONFLICT POINTS AT INTERSECTIONS

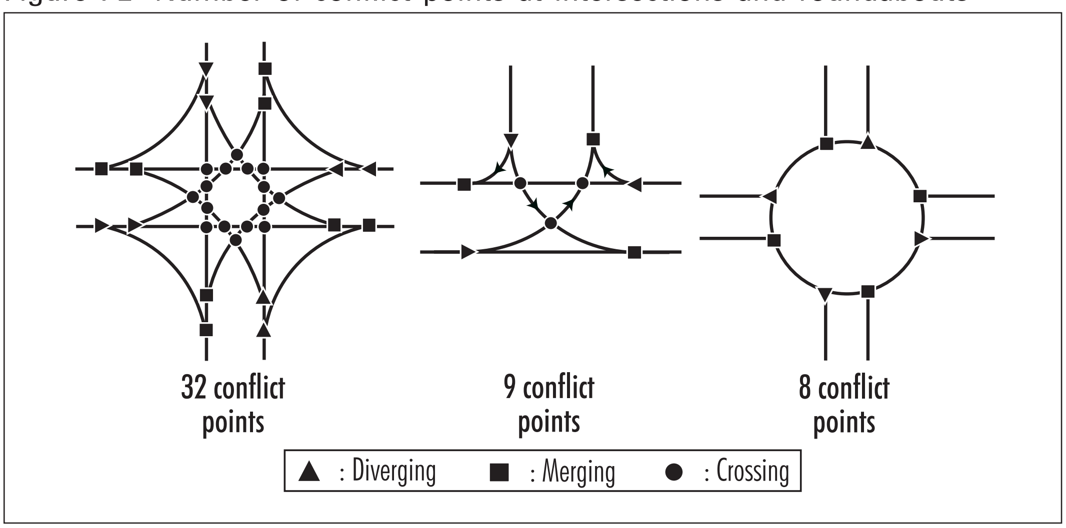
An intersection has a set of conflict points between vehicle paths, and a good design should aim at minimizing the severity of potential accidents at these points. Interactions related to these specific conflict points can be classified as:

Divergences	with a suitable deceleration lane, they can evolve to a parallel traffic
Convergences	with a suitable acceleration lane, they can also evolve to a parallel traffic
Crossings	with a suitable median refuge, these manoeuvres can be completed in two steps.

The number of conflict points increases rapidly with the number of intersection legs (Figure I-2) Traffic operation improves:

- with fewer conflict points, especially if there are few gaps in the interacting traffic, i.e. traffic volume is high. Therefore, 3-leg intersections are safer than 4-leg ones; and more than 4 legs call for other solutions, such as roundabouts. Suppressing non-priority movements, or grouping two movements reduces the number of conflict points;
- with an adequate phase setting (signalized intersections);
- with greater distances between conflict points, by means of traffic islands and/or auxiliary lanes. Vehicle speed and the need for an eventual storage must be taken into account. At signalized intersections there is a time separation, which reduces the need for space separation.

Figure I-2 Number of conflict points at intersections and roundabouts



Angles at which conflicts occur should be properly managed:

- for convergence and divergence manoeuvres, angle between paths must be very small (less than 5°), hence the need for ***speed changing lanes***;
- for crossing manoeuvres, the angle between paths should be as perpendicular as possible (between 75° and 105°). It improves visibility and speed evaluation, and reduces crossing distances;
- for insertion manoeuvres, the angle between the paths controls the insertion speed. It should lie between 20° and 60°.

DISTANCE BETWEEN INTERSECTIONS

A compromise should be sought between the specific requirements of each single intersection and the operation of the highway network as a coherent system. Intersection location is largely a result of land use, either spontaneous or planned. Increased land use entails not only more traffic, it also creates pressure for more intersections.

The distance between adjoining intersections has a great effect on both level of service (LOS) and safety of a highway:

- distance should be greater in highways, mainly assuring mobility;
- too short a distance (less than 450 m of "normal" section) between poorly designed intersections can lead to an increase in the accident rate.

In urban and suburban areas it is often impossible to keep an ideal distance between intersections, especially if land use is high. In arterial streets, a "green wave" in both directions can be achieved by synchronizing signals. Operation improves if:

- distance is uniform and above 200 m[7];
- arterial is one-way;
- some left turns are prohibited.

Minimum distance between adjoining intersections should be:

- 60 m on a collector street and for 4-leg intersection on local streets;
- 40 m for 3-leg intersections on local streets.

[7] Distance to a right-turn-only intersection can be lowered to 100 m (right-hand drive countries).

ROAD ALIGNMENT

Horizontal alignment

Ideal location for an intersection is on a tangent. Location in curves causes problems:

- visibility is reduced;
- a fraction of the available skid resistance is already consumed to keep the vehicle on a curved path: there is less friction available for braking;
- there is a larger conflict potential for vehicles trying to cross a priority highway;
- superelevation and lane widening make the situation more complicated.

Roundabouts should not be placed on a curve as it may create visibility and orienteering problems. Indeed, it is sometimes possible to replace a curve with a roundabout: both tangents are maintained and the change in direction takes place inside the roundabout.

Vertical alignment

Ideally, approaches to an intersection should not have grades over 3%, and never more than 6%[8] in order to:

- improve visibility;
- improve the comfort of vehicle passengers having to stop at the intersection;
- enable drivers to correctly evaluate needed speed changes.

Hazardous combination: hill, intersection, accesses, horizontal curve.

Intersections should preferably not be located at or near crest vertical curves.

Both in the approaches to an intersection and inside it, there should not be large variations in grade. Possible guidelines are:

- for speeds higher than 70 km/h, grade difference between ends of a vertical curve should not exceed 2%;
- for a 50 km/h speed, the difference can reach 4% if visibility is sufficient. Some comfort is lost, but safety is not impaired;
- For a 30 km/h speed, the difference can be as high as 6%.

Vertical curves should not reach to less than 20 m from the common pavement zone; this distance can be reduced (to 10 and even to 5 m) if the intersection carries little traffic.

[8] Intersections with little traffic and low speeds, such as those in residential areas, may have approach grades up to 4 - 6%.

SPECIAL ROAD USERS

Heavy vehicles

Small intersection radii increase heavy-vehicle encroachment and short deceleration lanes can increase heavy-vehicle accidents - especially jackknifing of trailers and semi-trailers when mobilized friction is larger than .25. In roundabouts, such crashes are seldom fatal, but load spillage can cause long delays. Experience shows that in this case one or more of the following circumstances are present:

- too-small path deflection at the entrance, resulting in high speeds;
- long straight sections in the roundabout lane, terminating in short-radius curves;
- sharp turns at roundabout exits;
- sharp changes in superelevation.

Heavy-vehicle encroaching on opposing lane when turning at intersection.

Pedestrians

In urban and suburban areas, pedestrian paths should be studied: they tend to be as short as possible.

Provision of pedestrian crossings, suitably delineated by zebra stripes, tends to reduce runover accidents. Their presence:

- warn drivers of the possibility of a conflict with pedestrians (in a limited way);
- show pedestrians the safest path to cross;
- confine pedestrian crossings to certain protected predetermined spots. This can be enhanced with channelizing barriers preventing them from crossing elsewhere (provided they do not hinder driver visibility and do not impose too long a detour).

Central refuge island at pedestrian crossing.

The efficiency of pedestrian crossings is lower[9] only where the width to be crossed is considerable (more than 10 m): a misleading protection feeling can even be present. In these cases it would be best that pedestrians use a split-level crossing, even if this solution is normally not appealing to them. Besides, the following elements can take a part in the solution:

- a limited narrowing of the roadway at the pedestrian crossing by enlarging sidewalks, often combined with a line of parking;
- a central refuge island so that pedestrians can cross in two phases;
- a contrasting pavement, such as cobbled or of a different colour.

[9] By more than 60 %.

Some other factors contributing to accident reductions at pedestrian crossings are:

- the proximity to the intersection (reductions can be significant if the distance between the crossing and the curb line of the transverse street is less than 2 m);
- a large volume of crossing pedestrians (which makes them more noticeable);
- parking control near the crossing (to enhance their visibility).

There are conflicting opinions about the improvements achievable by signalizing formerly STOP or YIELD sign-controlled intersections:

- risk at signalized pedestrian crossings seems higher than at unsignalized ones (although the risk is lower than where there are neither signals nor a crossing or where pedestrians cross far from an intersection);
- if vehicle volume is low, there will probably be a high frequency of pedestrians crossing on red, especially if they have to actuate the system and wait for their phase;
- signals have less influence if average speed of through vehicles is less than 30 km/h or turning volumes are high.

Disabled pedestrians require special measures:

- a gap in the curb for wheelchairs, with no steps above 10 mm nor slopes higher than 1 in 12;
- a textured pavement recognizable by blind people. Frontier to the roadway should be marked by a 10 mm step.

In roundabouts:

- crossing of the central island should be avoided at all costs;
- segregated pedestrian paths are desirable, crossing the entrance flares at enough distance (> 10 m) from the yield line so that the distance to be crossed is narrower. Refuges on the dividing islands help;
- in some cases underpasses or overpasses should be considered.

Transit

Bus stops tend to be located near intersections so that their customers have an easier access to a larger number of their destinations. Stops located after the intersection facilitate bus re-entry into normal traffic.

In roundabouts they can be located off-road, both before the entrance or after the exit (here speed is higher).

Two-wheelers (at roundabouts)

Two-wheelers, especially cyclists, may account for nearly 50% of injury accidents at roundabouts, a much higher rate than cars. Their drivers try to increase their radius paths and their vision field may be hampered by their helmet.

Where a large number of cyclists is expected, the following measures should be considered:

- alternative routes off the roundabout;
- split-level routes both for pedestrians and cyclists;
- a different type of intersection (e.g. signalized).

ACCESS CONTROL

For a safe and fluid traffic operation, intersections and roundabouts should be kept free from the perturbations caused by driveways and minor connections: parking lots, service stations, farm roads, etc.

If a commerce cannot be removed, its access should be located as far as possible from the intersection on the secondary road. Its width should be properly controlled (curb).

Wide opened garage access at intersection.

ROADSIDES

Leaving the platform is a risk. If its consequences are to be limited, a safe zone should be provided at the roadside, without rigid obstacles and/or ditches.

Driveways and median crossings, both placed in the safety zone, usually have slopes normal to the vehicle paths, and often combined with drainage tubes and their headwalls.

Neither the grade of these slopes nor the design of the headwalls should represent an obstacle for a runoff vehicle.

Hazardous location of a poll in intersection corner.

SIGHT DISTANCE

Road users approaching an intersection should have sufficient visibility to safely stop their vehicle. The available sight distance must also be sufficient to allow drivers who are stopped at the intersection to complete all non-priority manoeuvres safely.

Depending upon the intersection characteristics, different visibility criteria may need to be met. These are described in the ***sight distance*** *technical sheet*. The ***sight distance*** *technical study* describes how to measure sight distance at intersections.

Sight obstruction in intersection corner.

COMPARISON OF VIABLE SOLUTIONS

At the design stage, both the intersection and the connection of each of it legs should be the subject of a functional analysis in which, besides assessing their capacity, LOS, and design aspects, the ease of operation and route continuity are evaluated from the viewpoint of a driver unfamiliar with to the intersection.

This application of the driver workload concept to assess the consistency of intersection design should include the following points:

- situation, proximity and sequence of connections (exits and entrances) and other convergences and/or divergences;
- weaving sections;
- destination clearness and visibility of signs;
- clearness of paths.

Each route should be tested in relation to other design elements that could affect a driver trying to follow it. For this, it is useful to have a plan showing:

- number of lanes;
- peak-hour traffic volumes;
- expected speeds;
- available sight distances;
- orientation signing.

This functional analysis will show whether it is possible to be misled by the proximity of connections, or whether conflicts due to weaving are to be expected. Path clearness and possibility of signing should also be shown: a path may be direct and easy to follow, or complex and riddled with conflicts with other elements.

The functional analysis should also include a check of design parameters such as deceleration lane lengths and turning radii. This is especially useful for intersections following non-conventional patterns.

CONVENTIONAL INTERSECTIONS

FIXED-SIGNED PRIORITY – 3-LEG INTERSECTIONS - GENERALITIES

Y intersections should be avoided, especially in rural areas; they can be replaced by a T intersection or a roundabout.

Possible movements

At **T** intersections the following movements are possible:

- two through movements in the priority highway;
- two right turns;
- two left turns, the treatment of which defines the intersection.

Through movements

Through movements should be carried out with the utmost continuity and ease: sometimes the legs should be remodeled to fit the relative importance of the traffic and achieve a suitable crossing angle.

Right turns[10]

Right turns are solved directly and, according to their volume, desired speed, and available space, some of the following elements can be used:

- unchannelized turning lane;
- channelized turning lane;
- ***transition wedges;***
- ***speed-changing lane.***

Left turns[10]

Left-turn treatment defines the intersection by the way it solves conflicts with through traffic. A large volume of left-turning vehicles can hinder through movements; they should wait outside through lanes.

For safety reasons, the following principles should be observed at priority T intersections:

- simplicity and compactness (few islands, as few reserved right-turn lanes as possible);
- absence of ambiguities (both in intersection operating principles and leg layout);
- drivers should take their decisions one at a time;
- coherence between layout and priority. The correct path should be readily apparent, easy to follow and unfalteringly continuous;
- deflections in non-priority paths (except, perhaps, in very dense urban environments).

Left-turn treatment may be dealt with in the following ways:

- ***unchannelized;***
- ***channelized - tear drop;***
- ***central left turn lane;***
- ***semi-direct turning lane.***

[10] Right-hand-side driving.

FIXED PRIORITY – 4-LEG INTERSECTIONS – GENERALITIES

X intersections should be avoided and transformed into a + or a roundabout.

Possible movements

At 4-leg intersections, the following movements are possible:

- 4 through movements, for vehicles continuing on the same highway;
- 4 right turns, normally without problems (right-hand drive countries);
- 4 left turns, the treatment of which defines the intersection.

Through and right turn movements

Most principles that apply for the treatment of through movements and right-turn movements at 3 leg intersections also apply at 4-leg intersections.

Left turns

Left-turn treatment may be dealt in the following ways:

- ***unchannelized;***
- ***channelized with two teardrops;***
- ***central left turn lanes;***
- ***split roundabout.***

SIGNALIZED INTERSECTIONS – GENERALITIES

Most principles that apply for fixed-signed priority intersections can also be applied to signalized ones. However, signalized intersections allow a time separation for conflicting crossings and left-turning manoeuvres (right-hand-driving countries). Special left-turning phases are often combined with reserved lanes. Signal operation is one of the design elements.

As in other intersection priority rules, multi-leg intersections should be avoided (more than four legs), since they would require many phases (capacity loss) and moreover a complex design.

The following elements should also be considered at signalized intersections:

- transit (location and operation);
- pedestrians (volumes, manoeuvres);
- parking (prohibition nearby the intersection);
- other traffic-management needs (one-way streets, turning prohibitions, etc.).

Left-turn manoeuvres at signalized intersections can start from a reserved lane or from the left-most lane of the entry leg (shared with the through movement). Besides, how these turns are made should be taken into account:

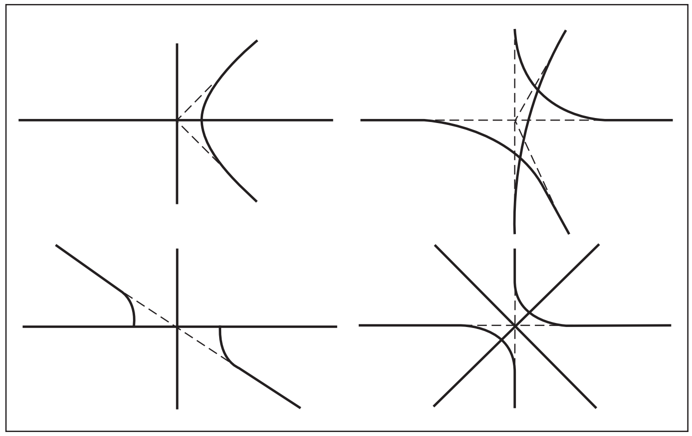
- **protected** turns are from a reserved turning lane, with a special phase that stops conflicting opposing traffic;
- **permitted** turns are done through the gaps in opposing traffic, to which the turning vehicles must yield. If coming from a shared lane, this may cause some congestion;
- **no-opposition** turns do not need a special phase; as they do not have to yield to opposing traffic. This happens at 3-leg intersections, at one-way intersections, or when movements are controlled by independent phases on each leg.

INTERSECTIONS WITH MORE THAN FOUR LEGS - GENERALITIES

At fixed-priority intersections having more than four legs, conflict points increase largely, even if some of them are signalized. They should be avoided.

A solution may be to alter the layout of some of the legs, so that the intersection is transformed into a set of two or three adjoining intersections, each of them with 3 or 4 legs (Figure I-3)

Figure I-3 Transformations of multi-leg intersections



INTERSECTIONS – LEG LAYOUT - GENERALITIES

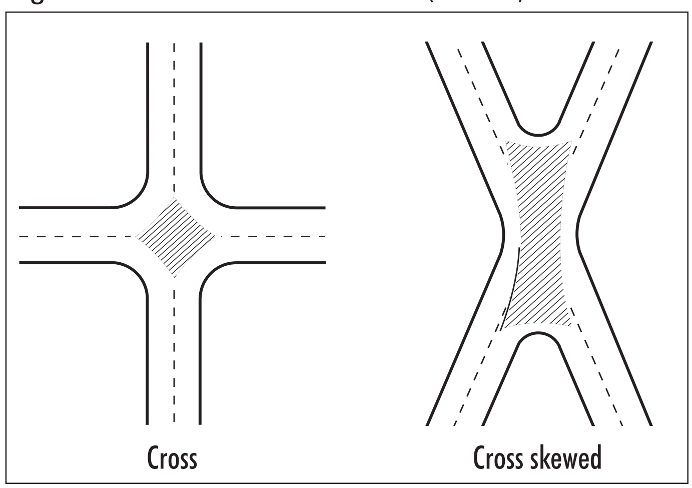
If the leg layout is at right angles (or nearly):

- the intersection surface is minimized;
- drivers are better able to judge distances and speeds of other vehicles;
- crossing times are minimized;

Although sometimes a skew layout might favour a high-volume turn, angle between legs should be kept to the interval 75° – 105°, especially in the following situations:

- traffic on each leg is higher than 200 pcph;
- non-priority traffic is higher than 200 pcph;
- two important highways are crossing;
- at least one of the highways has more than one lane in a direction;
- at least one of the highways has a design speed above 80 km/h.

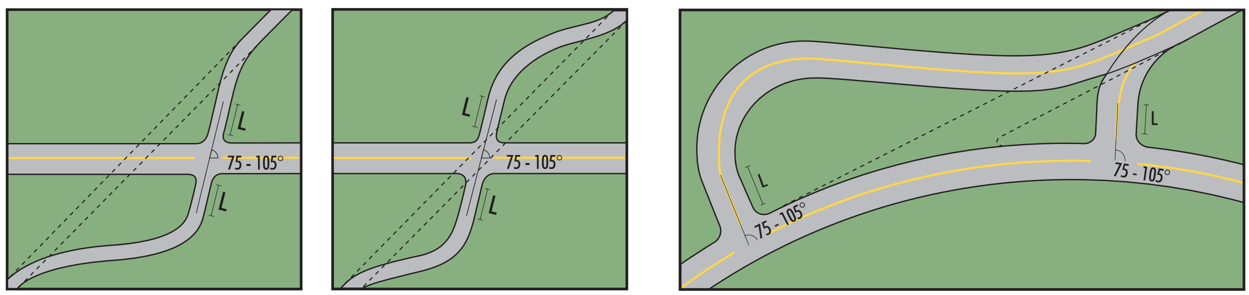
Figure I-4 Intersection surface (+ vs x)



To achieve such an angle it may be necessary to re-align locally at least one of the highways (usually the non-priority one, figure I-15), so the intersection is displaced to a tangent with a higher visibility.

A small tangent (20 m minimum length) should be included in the re-aligned layout near the intersection to improve sight distance and to achieve a better grade transition. The abandoned part of the re-aligned highway should be demolished and screened from view.

Figure I-5 Examples – Intersection re-alignments



L = 20 m minimum

Source: Transportation Association of Canada, 1999

In urban areas it is often impossible to achieve such realignment due to lack of space. If the accident rate is high, the riskier turns can be suppressed or the intersection signalized.

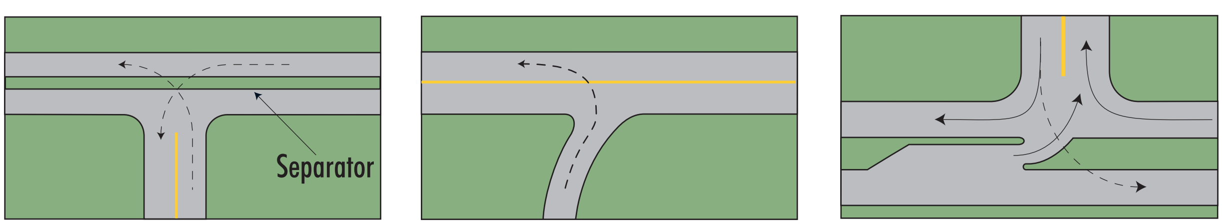
SUPPRESSION OF MOVEMENTS - GENERALITIES

Prohibiting some movements, usually left turns, can result in a simpler and safer intersection (right - hand side driving). This can be done in many instances:

- if the distance between adjoining intersections is small, such as in urban areas;
- if left-turn manoeuvres at a driveway are too close to an intersection;
- if an intersection has more than 4 legs;
- if traffic rat-running through a residential area is to be prevented.

Prohibition can be materialized through careful channelization and shorter radii, combined with pavement marking.

Figure I-6 Examples – Movement prohibitions at intersections



Source: Transportation Association of Canada, 1999

CONVENTIONAL INTERSECTIONS – THROUGH MOVEMENTS

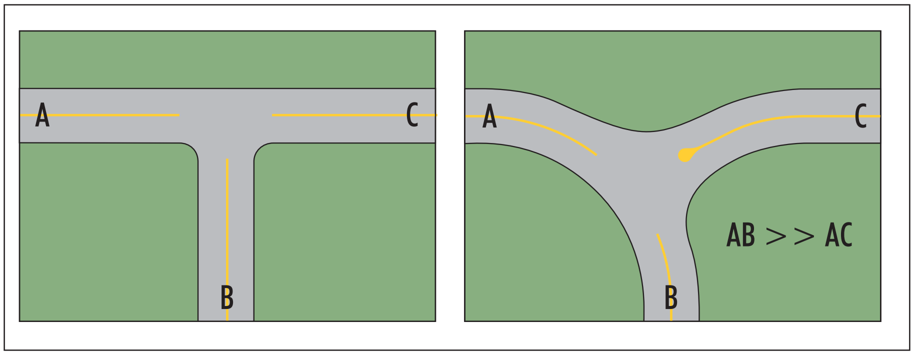
Layout

The layout of an intersection must enhance drivers' perception of through movements and facilitate their task, although some braking might be necessary.

3-leg intersections

Through movements should be carried out with the utmost continuity and ease: sometimes the legs should be realigned to fit the relative importance of the traffic and to achieve a suitable crossing angle (Figure I-7). The third leg should be implanted in the priority highway at an angle between 75° and 105°.

Figure I-7 Re-alignment of a 3-leg intersection



Speed

Urban streets

In urban streets it is generally desirable for a priority itinerary to maintain a uniform speed across the intersection.

A good approach speed to a "YIELD" sign is 25 km/h, thus calling for a design speed around 35 km/h. On non-priority streets, "STOP" signs can accommodate even lower design speeds. Also, pedestrian runovers at non-signalized intersections where overall speed does not exceed 30 km/h are about half of those with a higher speed. Therefore, it is advisable:

- to avoid designs favoring high speeds on priority legs: wide cross-sections, right-turn slip lanes (which do not increase capacity very much and make crossing difficult for cyclists and pedestrians;
- to use speed-calming design features, such as a dynamic tension (a somewhat twisted path).

Rural highways

On rural highways, design should be based on the 85th percentile of the actual speed distribution, especially on priority highways.

Drivers tend to get used to long periods of high-speed driving. If they have to slow down when approaching an intersection, they must become aware of its presence sufficiently early in terms of time and distance.

It is advisable to avoid designs favouring high speeds on priority legs (e.g. more than one lane in each direction). However, deflections in the alignment of priority lanes, when too large, can lead to loss of control; they should be clearly noticeable.

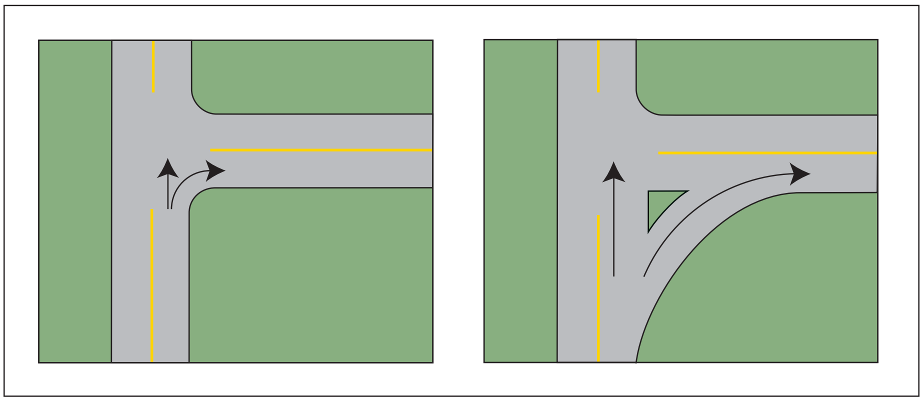
CONVENTIONAL INTERSECTIONS – RIGHT TURNS

The normal way to solve a right turn is by a direct turning manoeuvre, leaving and entering on the right side, without crossing any other path. Occupation is restricted to only one quadrant.

When the insertion is regulated by a STOP sign, turning volumes are low and speeds are low (less than 25 km/h), the turning manoeuvre can be completed within the intersection area.

However, if traffic volume on any of the legs entering the intersection is more than 300 pcph, right turns should be made at a slightly higher speed (at least 25 km/h, depending on the available space). Therefore, the radius needs to be increased and the turning lane is segregated from the crossing area by a channelizing island. A "YIELD" sign should be used instead of the "STOP" sign.

Figure I-8 Right-turn manoeuvres



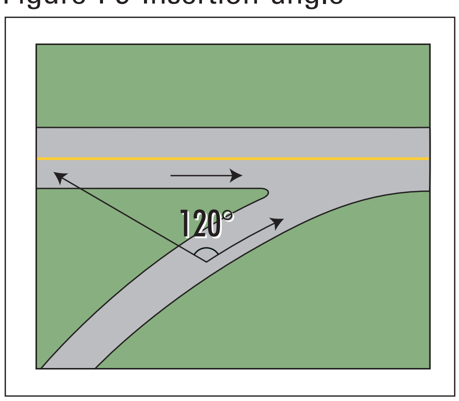
Insertion of this turning lane on a priority path should be made with a deflection angle higher than 60° so that drivers do not have to turn their heads more than 120° to check the priority traffic.

Insertion without stopping (acceleration lane) requires smaller angles (5° – 10°) so that drivers can check oncoming vehicles in their rear-view mirrors.

Channelization of a right turn does not favor either pedestrian safety (unless the island is designed as a refuge) or through cyclist safety (conflicts with right-turning vehicles).

The turning lane can be preceded by a ***transition wedge*** or a ***deceleration slip lane*** if speed above 40 km/h is desired.

Figure I-9 Insertion angle



CONVENTIONAL INTERSECTIONS – LEFT TURNS

Unchannelized

The simplest way of dealing with left turners at conventional intersections is through a direct manoeuvre, i.e. leaving and entering on the left side. This type of left-turn treatment is only compatible with low traffic volumes, both turning and through. It is used where there are severe limitations to available room or in environmentally sensitive areas.

Vehicle turning left from the priority highway and waiting in the through lane for a gap in the opposing traffic should not interfere appreciably with through traffic.

Channelized - Tear drop

An easy improvement of the unchannelized left-turn treatment consists of the separation of turning movements by tear drop island(s). At T intersection, a teardrop island is built on the non-prioritary highway to separate both left turns. At + intersections, a tear drop island is built on each non-priority highway.

This setting offers several advantages:

- favours perception of both the intersection and the priority loss;
- reduces speed by introducing a visual tension and an important path deflection;
- allows for a better placement of the stopping line;
- serves as a refuge for pedestrians in dense urban areas;
- right-angle collisions are reduced between 30 % and 50%.

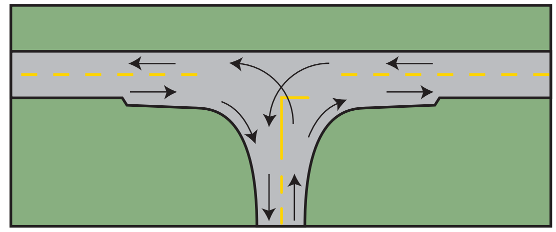
Semi-direct left-turn lane

With semi-direct left-turn lanes, left-turn manoeuvres from the priority highway are replaced by a combination of a right-turn manoeuvre followed by a crossing of the two priority through lanes. Waiting zones lie off the priority highway, but the intersection takes more space.

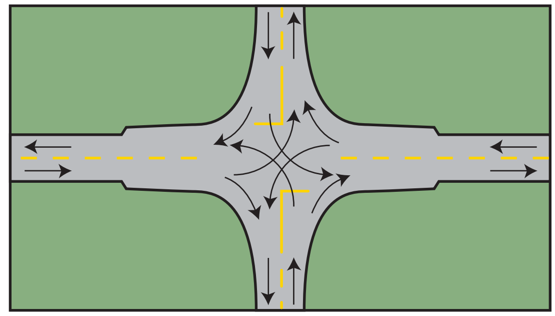
Since waiting vehicles must yield to both through movements, this solutions loses its efficiency when traffic volumes are high (suitable gaps in both traffic streams are not likely to be coincident). A signal may help, but it can be dangerous in rural areas.

In Spain this type of left turn treatment is banned when the priority highway ADT is above 3,000 vehicles. The split roundabout is another layout that allows semi-direct left-turn manoeuvres, while minimizing delays to through road users.

Figure I-10 Unchannelized left turn(s)

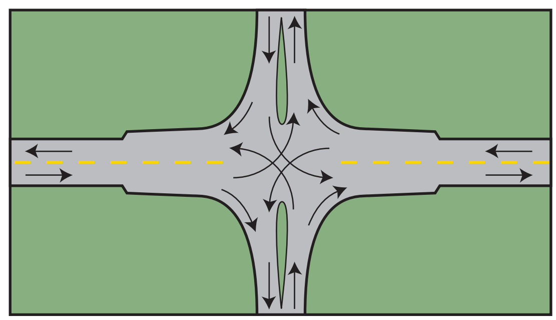


at T intersection



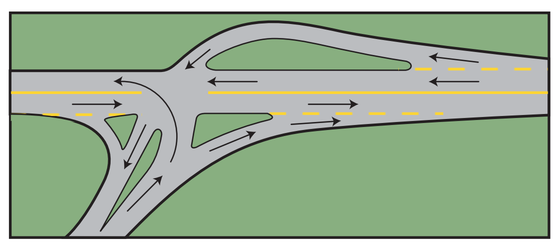
at + intersection

Figure I-11 Tear drop islands

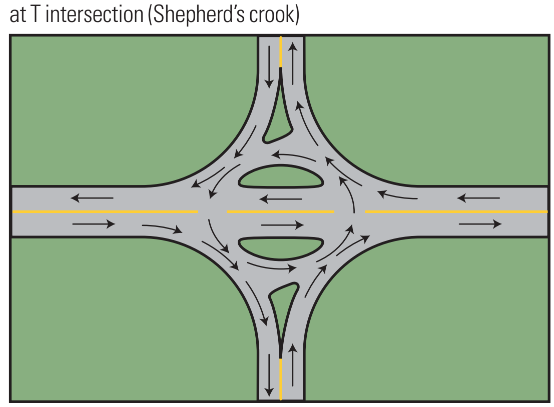


at + intersection

Figure I-12 Semi-direct left-turn lanes



at T intersection (Shepherd's crook)



at + intersection (Split roundabout)

Central left-turn lane

Vehicles waiting to turn left from the priority highway can be stored in a central additional lane, preceded by a deceleration lane. Thus, they only have to cross one through traffic stream, instead of two as in the semi-direct left turn lane.

A central left-turn lane effectively reduces conflicts between left-turning and through vehicles, thereby improving both capacity and safety.

On divided highways, the central left-turn lane can be placed in the median (if it is wide enough).

On undivided higways, one or both the opposing lanes must be offset:

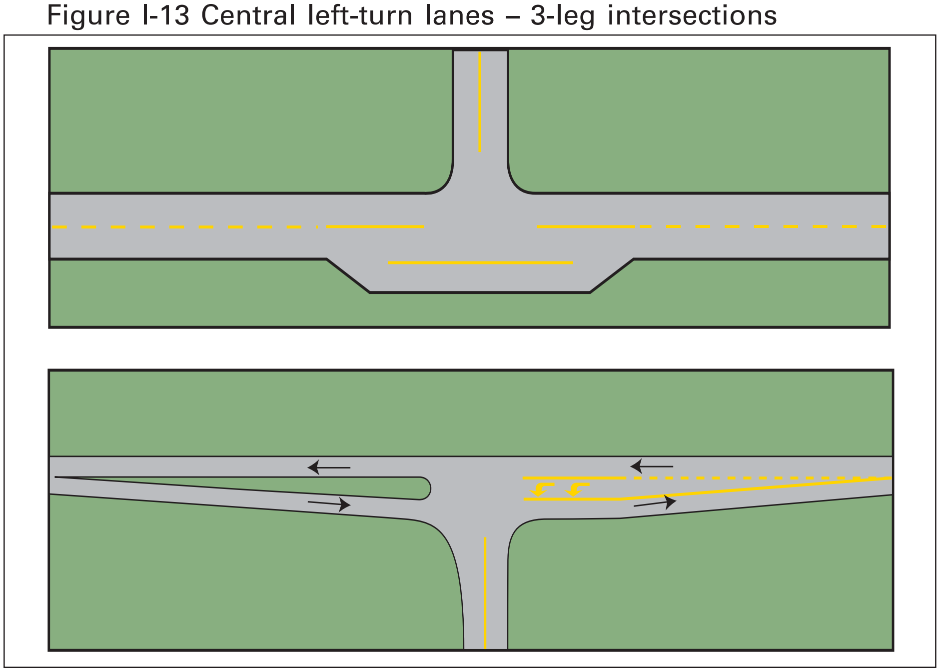
1. with road marking only
   - if the central left-turn lane is not long enough to cater for all left-turning vehicles during peak periods, the zebra-ed area can act as reserve storage, with less encroachment to the through lanes.
2. with a curbed island (dummy median) protecting left-turners. At rural intersections, this choice is safer than road markings only:
   - the intersection is more easily detected;
   - vehicles in the turning lane are better protected;
   - left-turning paths are more clearly defined, especially on wet pavement;
   - conflicts with nearby driveways are reduced.

3-leg intersections

At 3 leg intersections where a central additional waiting lane is not warranted, the shoulder can be enabled for through vehicles to bypass those waiting. Also, when the construction of a full fledged central left-turn lane is not warranted, a reduced one can be built instead. Its full width should lie on the original through lane (which is offset to the right), between 30 m before and 15 m after the centerline of the non-priority highway.

For left-turn lanes with a curbed island the best solution is to have the dummy median aligned to the left of the original centerline. Thus, approaching through vehicles do not have to deflect their path.

Figure I-13 Central left-turn lanes – 3-leg intersections



Source: Transportation Association of Canada, 1999

4-leg intersections

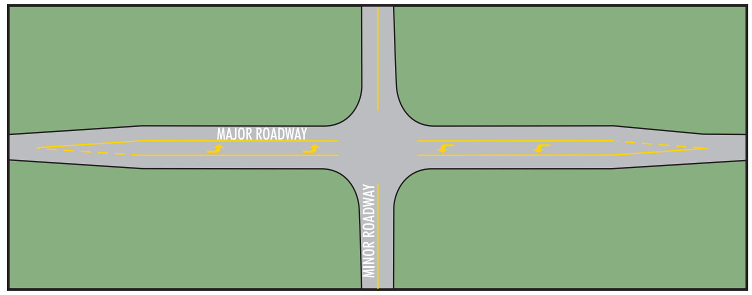
At 4-leg intersections, there may be two opposing central additional storage lanes in the priority highway.

They can be aligned, which is the most adequate layout for a fixed-priority intersection; however, where large vehicles are present, they can hinder the visibility. A roundabout should then be considered.

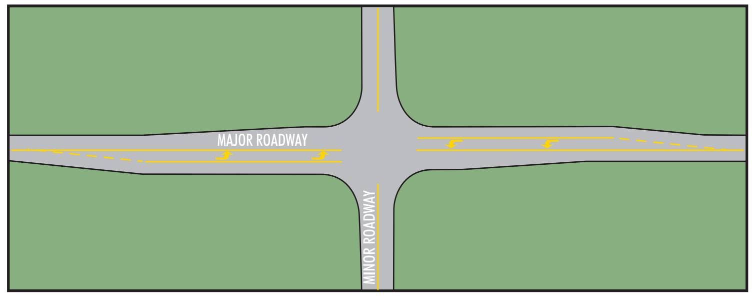
They can be staggered to the right. This layout causes visibility problems to left-turning drivers who may have trouble seeing opposing traffic. However, this layout can be more adequate if the intersection is at the end of a descending grade, since through vehicles have an easy escape path not interfered by opposing left turns.

Two adjoining intersections on a tangent can have their storage lanes back-to-back.

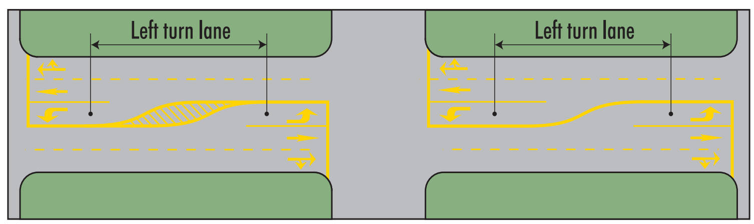
Figure I-14 Central left turn lanes – 4-leg intersections



Aligned design



Staggered design



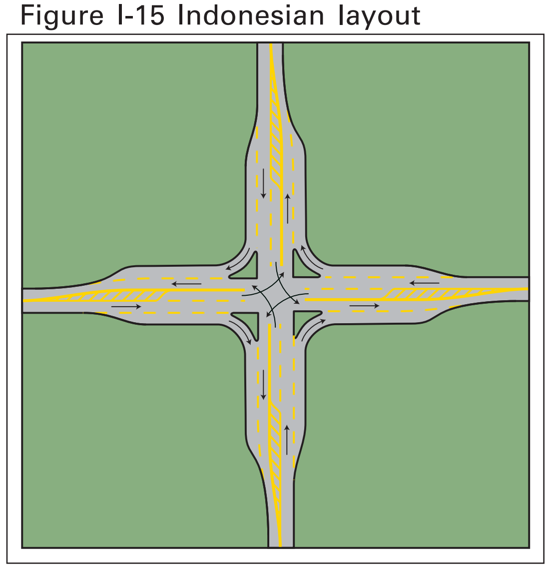
Source: Transportation Association of Canada, 1999

Indonesian layout

Especially with signals, the two left turns from the priority highway should not hinder each other. The so-called Indonesian layout, in which they do not cross each other, can help in this respect.

If there is enough traffic volume, waiting lanes may be placed on all legs (Figure I-15); This layout usually requires signals, to determine which of the two pairs of left turns has the priority over the other pair. Thus, it is a more urban layout.

Figure I-15 Indonesian layout



At signalized intersections with heavy left-turn volumes, two and sometimes three central additional storage lanes may be warranted. These alternatives have both advantages and disadvantages.

Advantages:

- congestion and delays are reduced;
- waiting lane length and conflicts before the intersection are reduced;
- green phase can be shorter and spared time can be assigned to other movements.

Disadvantages:

- pedestrian conflict potential is increased;
- in the transverse highway, downstream of the intersection there is an uneven distribution of vehicles among lanes;
- path delineation in the turning area is unclear;
- there usually is no room to cater to heavy-vehicle manoeuvres;
- there might be a cheaper solution.

Length of central turning lanes

At unsignalized intersections, storage length must cater to at least the average number of vehicles accumulated during a 2-min period of time and it should not be less than 15 m.

At signalized intersections, storage length depends on phase and cycle length and on turning volumes. If the approach design speed does not exceed 60 km/h, storage must cater to at least 1.5 times the average number of vehicles waiting for the turn in a non-congested cycle and twice as much if speed is higher.

CONVENTIONAL INTERSECTIONS – TRAFFIC ISLANDS

Traffic islands delineate the space not to be invaded by vehicles; their inner part should contrast with the remainder of the platform. They are used for some of the following functions:

- divide traffic streams in through movements, right turns and left turns;
- reduce useless pavement areas where turning radii are large and/or layouts skew;
- spread and reduce conflict areas so that drivers are not confronted with more than one choice at a time;
- reduce conflicts with right-turning vehicles. However, in congested urban areas:
  - this type of island is not very useful since right-turning vehicles have little difficulty merging with the transverse street;
  - there might be conflicts with pedestrians, who have to cross a wider distance.
- set proper crossing and/or merging angles;
- reduce speeds;
- impede or hinder unwanted, unsafe or wrong-way movements;
- create protected areas for the storage of turning vehicles, allowing their drivers to decelerate and to wait off the through paths;
- restrict access to nearby properties.

The number of traffic islands should be reduced to the bare minimum necessary to carry out the assigned functions. Simple designs are:

- better understood by drivers;
- better adapted to changes in traffic conditions, and;
- easier to build.

Shapes and sizes of traffic islands should:

- favor prevailing paths;
- favor speeds adequate to a safe operation, especially if there are conflicts with pedestrians;
- reduce conflicts between vehicles.

Very large islands, similar to those between interchange ramps, should be provided with shoulders and treated as a landscaped roadside. Plantings should not-interfere with visibility. Noses of this type of island should be offset .5 to 1.0 m from the shoulder edge, especially if they are preceded by an auxiliary lane.

Traffic islands should not be used where the approach visibility is restricted. Decision sight distance should be provided for. Noses of traffic islands placed in the vicinity of crest vertical curves or horizontal curves should be brought forward so they can be seen and recognized by approaching drivers.

Traffic islands – Delimitation

Traffic islands can be delimitated either by road marking or by curbs.

By road markings

Traffic islands delimitated by road marking can be more easily modified and adapted to real vehicle paths. Even when curbs are to be built later, markings can be placed provisionally to test those paths and improve the final design.

The drawback is that road markings cannot be seen easily on wet nights or when there is snow on the pavement, unless highly reflective equipment is used (e.g. cats' eyes). Road marking islands are more often used in urban and suburban areas, where there is public lighting and speeds are lower.

By curbs

In many instances, curbs are used to delineate traffic islands of a fair size (> 6 m^2) so that drivers can see them easily, even at night. Curbed traffic islands are also used for the following functions:

- locate and protect driving aids such as signs, signals and/or lighting. Both design and size of the traffic islands should enable these aids to be clearly perceived;
- provide pedestrians with a refuge between traffic streams, especially where the width to be crossed in a single operation exceeds 25 m, or where these is a large percentage of elderly or disabled persons. In order to function as a pedestrian refuge:
    - islands should be at least 1.2 m wide (2.5 m better);
    - islands should not be less than 9 m^2 (larger if wheelchairs are to be provided for).

No refuge islands should be placed where they are less than two lanes apart from another island or the curb.

Curbs are to be offset .5 to 1.0 m from the pavement edge. Corners should be rounded with a minimum .5 m radius. Moreover, noses should be further offset: 1.0 to 2.0 m from a through lane, and .5 to 1.0 m from a turning lane. A 15:1 parabolic flare should be used.

Curbed islands are used both in urban and rural areas; in urban areas where curbs are not frequently present, they should be mountable and used only in small or medium-sized islands. Lighting is recommended.

Where the number of semi-trailers is important and pedestrian volumes are low - such as in industrial parks - curbed islands are not advisable since they hinder turning movements.

The following paragraphs describe two distinct types of traffic islands:

dividing islands

channelizing islands

Dividing islands

On non-divided highways, dividing islands are used at intersections to separate opposing traffic: Dividing islands also:

- efficiently control left turns, especially at skewed intersections;
- allow the implementation of a central left turn lane;
- provide a refuge allowing pedestrians to cross wide roads in two phases, hence improving both safety and capacity (vehicles do not have to wait for pedestrians to cross the whole road).

In urban areas, trees and bushes can be planted on dividing islands, providing that they do not hamper visibility. Plant maintenance, may however, be a problem on narrow islands.

The minimum length of a dividing island is 30 m in rural areas and 4 m in urban areas. Short dividing islands should be preceded by road markings, zebra stripes, projections or cats' eyes, and cylindrical beacons.

Channelizing islands

Channelizing islands are used to simplify the driving task. They lie between vehicle paths in the same direction, pointing clearly to drivers the correct one, and reducing large paved areas in which they could get lost. There should not be many of them, for this would be misleading.

Their shapes are varied, the most frequent ones being triangular with straight or slightly curved sides. Their sudden appearance close to the vehicle path should be avoided.

CONVENTIONAL INTERSECTIONS – SPEED-CHANGING LANES

The need for a speed-changing lane stems from the difference between the design speed of a main highway and the lower design speed of a turning lane. Speed-changing lanes allow easier entrances (acceleration lanes) and exits (deceleration lanes) from a main rural highway by allowing the associated convergences and divergences to take place off the main traffic lanes. Speed-changing lanes should be provided on the following types of rural highways:

- divided highways;
- highways with full access control;
- undivided highways with a design speed ≥ 80 km/h;
- undivided highways with a design speed ≥ 60 km/h and ADT > 1 500 vehicles.

In urban environments, speed-changing lanes can be less advisable since they may cause safety problems to crossing pedestrians by increasing the distance to be crossed. Cyclists may also experience problems with right-turning vehicles, especially heavy vehicles.

Deceleration lane

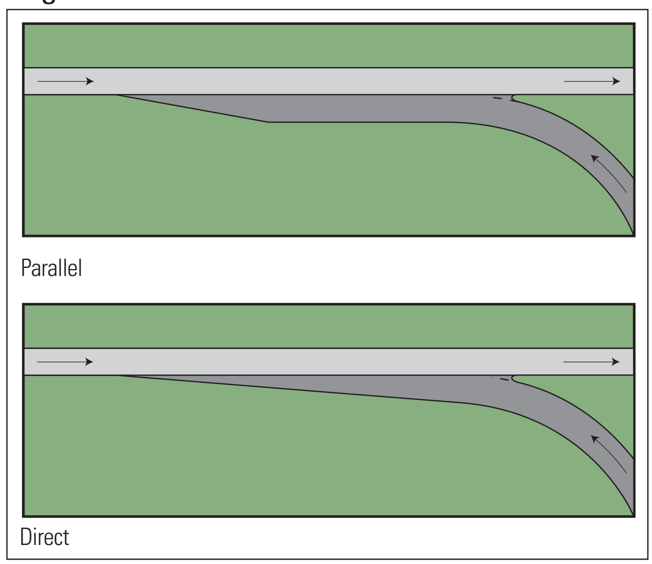
Two layouts may be used for deceleration lanes.

Parallel, which consists of the addition of one lane preceded by a transition wedge, the length of which is equal to the distance traveled at the $\mathbf{V_{85}}$ speed during 3 sec.

Direct, departing the main highway at a small angle. A direct deceleration lane in a left-hand curve is likely to mislead drivers.

Shoulders should be paved, to allow drivers mistakenly entering a deceleration lane to correct their path.

Figure I-16 Deceleration lanes



Acceleration lane

Acceleration lanes should always be of the parallel type and the length of the transition wedge following them should be equal to the distance traveled at the $\mathbf{V_{85}}$ during 6 sec.

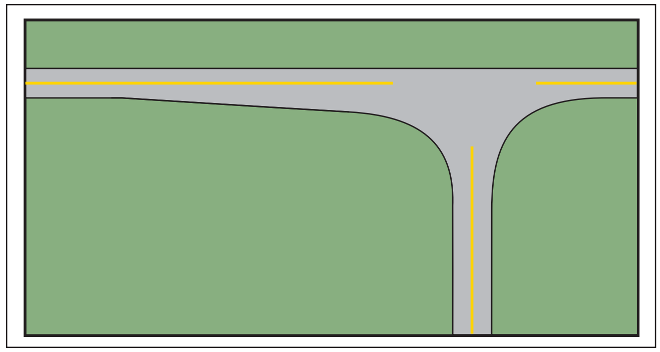
Figure I-17 Acceleration lane

TRANSITION WEDGES

A transition wedge should be provided to improve the safety of exit movements (sometimes entering movements, too) on rural highway intersections having a maximum design speed of 60 km/h, when speed-changing lanes are not warranted.

In urban areas, transition wedges are less advisable since they increase the width pedestrians have to cross; also cyclists can be in conflict with right-turning vehicles.

Figure I-18 Transition wedge



An exit wedge can be warranted if right turns exceed 10 – 20% of total approach volume.

At channelized T or + intersections with fixed-signed priority, an entrance wedge to the non-priority highway can be placed, regulated by a “Yield” sign. On the other hand, at signalized intersections where through traffic is fast, the entrances should have an acceleration lane wherever possible.

Distance between an entry wedge and the next exit wedge should not be less than 250 m; otherwise, they should be unified in an auxiliary lane.

ROUNDABOUTS

GENERALITIES

Where all legs have a similar importance, as it is often the case in urban or suburban areas, and speed reductions (or even stops) are of no concern, a frequently used solution is the roundabout.

In roundabouts, vehicles travel counter clockwise[11] on a ring lane around a central island.

Vehicles trying to enter the ring lane should yield to those already in it, and insert themselves in the available gaps. When they reach the exit they intend to take, they leave the ring lane. Traffic operation at roundabouts is based on this yield.

The simplicity and ease of operation of normal roundabouts make them well understood by drivers. Also, drivers can make U-turns to correct wrong destination choices. Some studies show that beyond a roundabout, drivers do not feel compelled to make up lost time and therefore accelerations and speeds are not significantly higher.

Roundabouts are especially adequate when the sum of all concurring ADTs is larger than 8,000 vehicles. Capacity at roundabouts is higher than at fixed-signed priority intersections and delays are shorter (except at peak hours). Roundabouts are especially adequate if all approaching legs have roughly the same traffic volume or if turning movements are larger than through movements.

Roundabouts are also to be preferred to signalized intersections:

- in rural environments, with high approach speeds, smaller fluctuations in traffic volumes, and less spatial limitations;
- on divided highways with a balanced traffic volume.

In divided rural highways, roundabouts contribute to speed moderation and are favorable for vulnerable users (pedestrians, cyclists).

Roundabouts can also be used as multi-leg intersections (up to 6 legs), especially if left turns are important.

Besides the above-mentioned reasons, other safety-related factors may also warrant a roundabout:

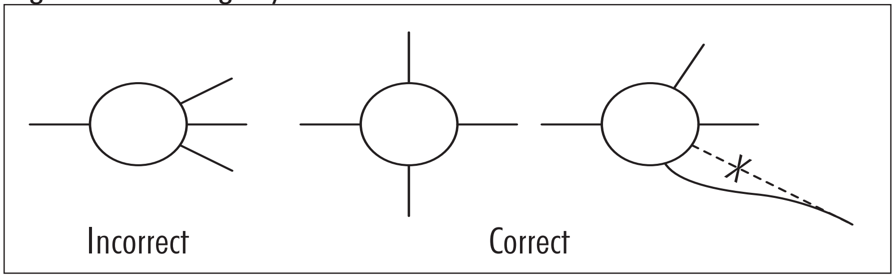
- the need for a design creating a break in driver behaviour: the limit between two types of highway, between rural and urban areas, etc.;
- the treatment of safety problems with other types of intersections;
- the suppression of left turns into driveways located close and before an intersection (replaced by a U-turn at the roundabout and a right turn into the driveway).

[11] In right-hand-driving countries.

Leg layout

Uniform leg spacing along the roundabout is desirable; this may require some realignment.

Figure I-19 Leg layout of a roundabout



Speed

Measures aimed at reducing speed - or at least not increasing it - are favourable. However, some treatments should be avoided:

- approaches on **S**-curves that leave the roundabout outside the field of easy vision and make it difficult to be perceived;
- excessive number of warning devices – road signs, beacons, and especially humps (well-designed roundabouts are very safe road entities; unjustified use of warnings leads to a loss of their credibility and efficiency).

Roundabouts should not be used as a mere speed-limiting device (e.g. two-leg roundabouts).

Roundabout types

The main types of roundabouts are ***normal roundabouts*** and ***mini-roundabouts***. These are described in more detail in the following pages. Other types include signalized roundabouts and double roundabouts. Double roundabouts can be especially useful:

- to connect two parallel highways divided by a linear obstacle, such as a river, a railway or a freeway;
- in very asymmetrical or skewed intersections, where another type would entail a major realignment of the approaches and a normal roundabout would take up too much space;
- in replacing a congested normal roundabout, since capacity is increased by reducing volume beyond critical approaches.

For intersections having more than four legs, a double roundabout achieves a higher capacity and an acceptable safety level, together with an efficient use of available room.

NORMAL ROUNDABOUTS

Central island

A normal roundabout has a central island, usually curbed, 4 m or more in diameter.

Central islands in standard roundabouts should be circular in shape or, at most, elliptical (with a ratio of minor to major axis not less than 3/4). Where shape causes strong variations in path curvature, vehicle speed in the less curved sections is higher and accidents increase.

Smaller sized roundabouts are safer, even those with a diameter of 10 m[12] of the central island. Capacity does not increase very much above 20 m. Semi-trailers can turn perfectly well in roundabouts having an outside diameter of 28 m. Diameters of 60 m or more in the central island, to enable later evolution of the roundabout to an interchange, are to be avoided. A smaller roundabout is to be preferred even if it is going to be wasted. Diameter of the central island should be 1.0 m less than that of the ring lane.

Inside the central island

In **rural areas**, the following elements should be avoided, at least for new roundabouts:

- aggressive, rigid, compact obstacles: rocks, stone or concrete sculptures, lampposts, storm drainage fixtures, trees (not bushes), etc.;
- elements liable to abruptly block an out-of-control vehicle: ditches, barriers, slopes above 15%, walls, non-mountable curbs that may act as a launching pad and increase accident severity, especially for two-wheelers.

The above does not prevent some conditioning of the central island for other purposes (perceptibility, decoration): a gentle fill (less than 15%, low shrubbery, light or fragile sculptures, waterspouts, etc.).

In **urban areas**, similar principles should be applied with some variations:

- slope can be increased up to 25%;
- somewhat more aggressive obstacles may be tolerated (under specific circumstances)

[12] Except, perhaps, for very small roundabouts with flared approaches that are too wide.

Entrance

Accidents at roundabout depend very much on the speed at the entrance and on the ring lane. The minimum path radius passing at 1.0 m from the islands determines this speed.

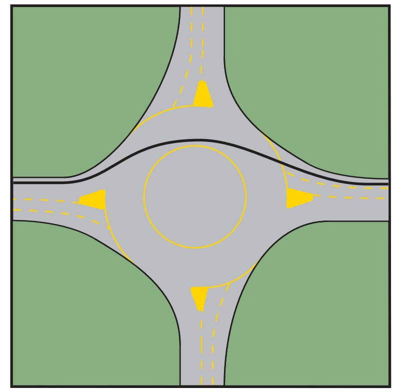
The size of the dividing islands at a roundabout entrances, the width of its ring lane and its entrance and exit radii should all be related to the central island diameter in order to avoid overly direct paths.

Minimum path radius should lie between 6 m and 100 m; 20 m is optimum to assure a reasonable entrance speed.

Deflection is achieved by the presence of the central island (and usually also by that of the dividing island on the approach) and should lie between 20° and 60°, with an optimum of 25°:

Too small a deflection forces entering drivers to look over their shoulder for a gap in the roundabout lane and favours high entrance speeds.

Figure I-20 Path radius at roundabout

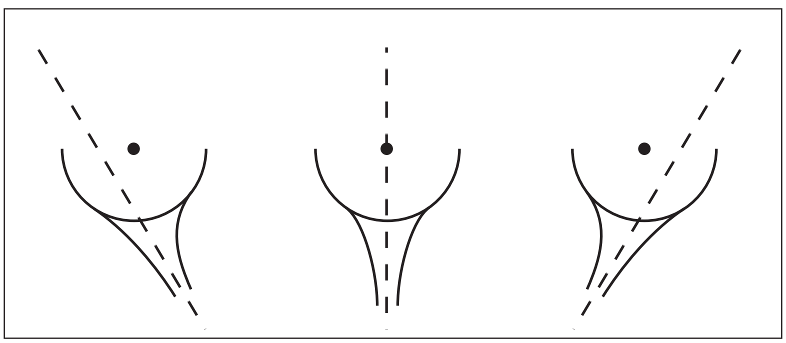


Path radius

Too large a deflection makes drivers tackle their conflicts more as a crossing than an insertion.

A good deflection can usually be achieved by offsetting the approach centerline to the left of the central island.

Figure I-21 Deflection at a roundabout entrance



Number of legs

The recommended number of legs is 3 or 4.

Normal roundabouts operate particularly well with 3 legs (better than signalized intersections), provided that traffic volume is balanced between the legs.

With more than 4 legs, drivers' understanding may be affected and a larger roundabout is needed, resulting in higher speeds: in these circumstances, a double roundabout may be more adequate.

Number of lanes

In the case of rural highways having more than one lane towards the roundabout, its presence can be enhanced by closing the leftmost lane.

If the roundabout is very noticeable and the entry speed can be reduced by an adequate deflection of the vehicles' paths, additional lanes at the entrance:

- enable more than one vehicle to enter the roundabout simultaneously;
- provide more flexibility in the event of any increase of traffic volume;
- allow a stopped vehicle to be passed;
- facilitate manoeuvrings of long vehicles.

It is not recommended to add these lanes on the left side nor to add:

- more than two lanes in two-way, two-lane entrances;
- more than four lanes in multilane entrances.

Minimum length of additional lanes is 5 m in urban areas and 25 m in rural areas. Length of flares should not be more than 100 m.

Lane width

Lane width determines the capacity of the entrance to a roundabout; larger widths are usually required in urban areas.

Minimum width of an entrance lane is 2.5 m at the entrance stop line; additional lanes should be differentiated after their width reaches 2.0 m. However, if heavy vehicles are present, wider lanes are recommended: three 3.33 m lanes are preferable to four 2.50 m ones.

A very wide entrance to a roundabout favours loss of control. Moderate widths are safer:

- speeds on the ring lane are limited;
- distances to be crossed by pedestrians are narrower.

Accordingly, at rural roundabouts with no capacity problems, it might be advisable to reduce a dual-lane entrance to a single lane, at least in new developments (and also in existing ones with poor safety records). The same can be applied in urban areas: later widening is always possible.

Shoulders

Entrances to roundabouts usually have curbs and shoulders should be terminated before the flare. A simple way is to start the curbs outside the shoulders and flare them in gradually.

Superelevation

At roundabout entrances, superelevation should be based on path curvature and vehicle speed, without exceeding 5%. At yield lines, superelevation may be reduced to the minimum necessary for drainage purposes, since speed is reduced by the path deflection.

Ring lane

Width

The ring lane width should be constant and somewhat greater (up to 20%) than the maximum width of any entrance.

Table I-2 Recommended ring lane width and roundabout outer diameter (Spain)

CENTRAL ISLAND DIAMETER (m)	WIDTH OF RING LANE (m)	ROUNDABOUT OUTER DIAMETER (m)
4	12.0	28.0
6	11.4	28.8
8	10.9	29.8
10	10.4	30.8
12	10.0	32.0
14	9.6	33.2
16	9.3	34.6
18	9.0	36.0

No lane markings should be painted in ring lanes.

Superelevation

In the ring lane, no superelevation is needed to offset the centrifugal force. All that is required is a transverse slope for drainage, around 2%, which can be reduced to 1.5% or even 1.0% in roundabouts set on a grade, avoiding excessive superelevation breaks which can be a nuisance to heavy vehicles.

Neither a slope towards the central island (unless it implies a dangerous ditch) nor two-slope superelevation seems to have a negative influence on safety. The most suitable setup could be a slope away from the central island.

On a normal roundabout, counter-superelevations in the main paths should be avoided, if possible.

Exit lanes

Roundabout exits should have at least the same number of lanes as the highway to which they lead. If possible, an additional lane should be placed on the right, closed with a linear transition, of a length 15 – 20 times its width; if on an upgrade, it should be lengthened to reduce the disturbance caused by heavy vehicles.

For exits to be easy to negotiate the radius of the inner curb should be no less than 20 m, and better still, no less than 40 m. However, in presence of pedestrians crossing at the exit of a roundabout, the radius should be kept sufficiently low to prevent high speeds. Single-lane exits should be at least 6.0 m wide close to the dividing island to enable a stopped vehicle to be passed.

At exits, superelevation helps acceleration. The same as at the entrances, the transverse slope near the ring lane should be kept to the minimum necessary for drainage. If the exit is followed by a left-hand curve, its superelevation should not be reached too soon, and it should be limited to avoid vehicles encroaching on the opposing lane.

Source: Ministère des Transports du Québec (M. Séguin)

Segregated right-turning lanes

Segregated right-turning lanes allow drivers to take the exit next to their entrance without having to yield to others on the roundabout. They should only be provided when:

- this manoeuvre is completed at peak hour by more than half the entrance volume, or more than 300 pcph;
- there are no driveways along the segregated lane;
- the roundabout entrance is congested. Other measures should be tried first, such as widening.

The complexity and lack of readability introduced by a segregated right-turning lane is likely to make it less safe, especially for pedestrians who have to cross it.

Segregated right-turn lanes should not induce high speeds: their width should lie between 3.0 and 3.5 m. Especially when they are separated from the roundabout ring lane by a curb, accommodation of long vehicles should be checked.

MINI-ROUNDABOUTS

Mini-roundabouts have a central island of less than 4 m diameter, which should be circular and easy to run over (e.g. by fire trucks). No signs, beacons, light standards or other highway fixtures should be placed on the central island.

Central islands are generally made of asphalt concrete, Portland cement concrete, or paving blocks. They are usually surrounded by a ring of paving blocks, 5 mm above the level of the ring lane, or by a steel ring with a maximum step of 15 mm. Pre-fabricated central islands can be fixed to the pavement with epoxy resins. Central islands should be painted reflecting white. Materials not contrasting with adjoining pavement are not readily noticed when visibility is poor.

The crown at the center should be as large as possible, not exceeding 15 cm in height. This crown, together with some counter-superelevation in the ring lane, makes mini-roundabouts more noticeable by drivers.

The outer diameter of the mini-roundabout should not be greater than 28 m (this can accommodate large heavy vehicles).

Mini-roundabouts should be used only if speed is limited to 50 km/h or less at all approaches.

Entrances to mini-roundabouts may (or may not) be flared. Although path deflections are typically small, loss of priority makes mini-roundabouts safe. Deflection can be somewhat improved by road markings and small dividing islands, clear of any fixture except the necessary direction signs.

Most mini-roundabouts involve tight turns producing severe braking and tire marks: they should be systematically inspected to ensure that central islands are intact and clearly visible.

Since they are inexpensive, mini-roundabouts can be very effective in improving urban intersections with both capacity and safety problems.

Source : M. St-Jacques

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PART 4

Technical studies

SPOT SPEED

Technical study

Carl Bélanger

SPOT SPEED

Technical study

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TABLE

INTRODUCTION

In a spot speed study, a sample of speeds are collected at a specific road location in order to determine the speed distribution of vehicles and to calculate some statistics that are used to make engineering decisions.

WHEN TO CONDUCT A SPOT SPEED STUDY

The results of a spot speed study are used to:

- establish the speed limit to be posted. The 85th percentile speed (the speed at or below which 85% of the vehicles travel) is often used to this end;
- check compliance with posted speed limits;
- assess whether speeding may contribute to accidents (on horizontal curves, at intersections, around school zones, etc.);
- check speed dispersion and speed differentials between road users (e.g. between passenger cars and trucks);
- validate external requests (citizens, elected officials, etc.);
- verify the effectiveness of measures taken to reduce speed.

[SPEED BEFORE /AFTER TEST]

Observation period

In most cases, speeding problems do not occur under congested conditions and accordingly, spot speed studies generally need be conducted outside rush hours.

Also, the study should not be undertaken under unusual conditions that may modify normal speed patterns: adverse weather conditions, construction area, police surveillance, etc.

HOW TO CONDUCT A SPOT SPEED STUDY

Speed data can be collected by either manual or automatic methods:

Manual methods:

radar or laser gun, stopwatch

Automatic methods:

loops or tubes

Manual methods require the presence of an observer during the entire data collection period. With automatic methods, surveyors are required only to install and uninstall the equipment. Automatic methods should therefore be used when speed data need to be collected over long periods.

Sample size requirement

A sample size of 100 to 200 vehicles is generally sufficient to obtain reliable speed estimates and at least 30 speed observations must be collected in order to maintain some statistical accuracy.

MANUAL METHOD – RADAR GUN OR LASER GUN

Personnel and equipment

1 person

1 radar gun or laser gun

Hand-held radar gun

Description

A radar gun works on the Doppler principle. A wave beam is aimed at a moving vehicle; the beam is then reflected back to the radar unit. The change in frequency between the transmitted and reflected signal is proportional to the vehicle speed.

In the case of a laser gun, several laser beam pulses per second are aimed at a moving vehicle, which are then reflected back to the device. The vehicle speed is calculated according to the distance travelled by the vehicle between two pulses.

The main difference between both devices is the width of the transmitted beam. A radar gun's beam is much larger, making it harder to measure the speed of a selected vehicle when traffic is dense or spread over several lanes. However, the observer has to aim more accurately with a laser gun.

Guns are either hand-held, vehicle-mounted or tripod-mounted.

Data collection

Observers should try to remain inconspicuous to avoid influencing drivers' behaviour.

Bias resulting from selecting certain types of road users in a proportion that is not representative of the traffic flow distribution at the site should be avoided. Emphasizing the fastest or slowest drivers (e.g. trucks) are frequent sources of error. Random sampling techniques, such as measuring every single vehicle when the traffic is low or every second, fifth or nth vehicle at higher volumes, help reduce this bias.


Position of observer

The angle between the gun's beam and the vehicle's travel direction has to be kept to a minimum to obtain accurate results (Figure SS-1). The measured speed is accurate when the angle is zero but becomes progressively less than the actual speed of the vehicle as the angle increases. The magnitude of the error, based on the angle of observation, is shown in the table below. For example, at an angle of 30° and a measured speed of 100 km/h, the actual speed is 115 km/h.

Figure SS-1 Angle of observation

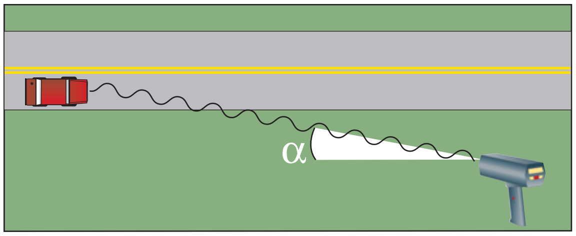


Table SS-1 Correction factors for angle of observation

ANGLE (°)	CORRECTION FACTORS
0	0
1	0.999
10	0.985
20	0.940
30	0.866
40	0.766

MANUAL METHOD – STOPWATCH

Personnel and equipment

1 person
1 stopwatch
1 odometer
2 posts or paint to mark the road surface

Description

The vehicle speed is estimated by measuring the time it takes to a vehicle to travel over a known distance, using the following equation:

$$V = 3.6 \times \frac{d}{t} \qquad \text{[Eq. SS-1]}$$

where:

V = speed (km/h)
d = distance (m)
t = time (s)

Data collection

The observer must first determine the beginning and end of the road segment on which measurements will be taken. The length of this segment is based on the average vehicles' speed and should be such that the average travel time is around 2.0 to 2.5 seconds (30 m at 50 km/h; 50 m at 90 km/h).

The beginning and the end of the measuring area must be clearly indicated by paint marks on the road or posts on the roadside.

The observer should be located at a point that is inconspicuous to drivers and around the middle of the measuring area to avoid parallax errors. The observer starts the stopwatch as the front wheel of the vehicle crosses the first reference point and stops it when the vehicle crosses the second reference point. The travel time is recorded. If a laptop is available, data can be transferred directly to a worksheet and the speed can be automatically calculated.

As for gun methods, care should be taken not to introduce bias in the analysis by selecting certain types of road users in a proportion that is not representative of their distribution at the site.

The main advantage of the method is its low cost. Its main disadvantage is that it can be inaccurate.

AUTOMATIC METHOD – LOOPS OR TUBES

Personnel and equipment

1 person
tubes or loops and recording device (and equipment to secure them)
measuring tape

Description and data collection

This method also estimates speed according to the time it takes for a vehicle to travel over a known distance. Pneumatic tubes, induction loops, or other types of detectors are laid on the pavement surface to record the passing of vehicles. Detectors are used in pairs, each of them recording the travel time of the same vehicle, which is transmitted to a recording device located on the side of the road and translated into speed (the distance between the pair of detectors being known).

Speed measurements using tubes

Most collecting devices can simultaneously record the vehicle speed, the vehicle classification, and the traffic volumes but the installation procedures may vary according to the type of equipment used. Measurement accuracy must be validated at the beginning and end of the observation period.

Automatic methods record the speeds of all vehicles, hence avoiding collection bias. However, data may not be representative of free flow speeds. An advantage of automatic methods is that they are not easily detected by drivers.

PRESENTATION OF RESULTS

The average and standard deviation of the collected speed sample are first calculated and the frequency distribution and cumulative frequency distribution are then prepared. These two curves contain the information that is required to make engineering decision[1]:

- the 85th percentile, which is the speed at or below which 85% of vehicles travel (V_{85});
- the pace, which is the range of speeds at which the largest number of vehicles travel (the pace is usually computed for a speed interval of 10 km/h or 20 km/h);
- the median, which is the speed at which half of the vehicles are slower and half are faster. When the data is normally distributed (not skewed), the median and mean speeds are identical (V_{50}).

Typical presentations of results obtained from a spot speed study are shown below. Such outputs can be prepared using the ***"Spot speed study"*** calculator.

Figure SS-2 Example – Frequency distribution table

Frequency distribution table

Speed class (km/h)	Class mid value (km/h)	Frequency	Percentage	Cumulative percentage
34 - 36	35	2	2,3	2,3
36 - 38	37	3	3,5	5,8
38 - 40	39	2	2,3	8,1
40 - 42	41	5	5,8	14,0
42 - 44	43	4	4,7	18,6
44 - 46	45	10	11,6	30,2
46 - 48	47	5	5,8	36,0
48 - 50	49	17	19,8	55,8
50 - 52	51	8	9,3	65,1
52 - 54	53	9	10,5	75,6
54 - 56	55	10	11,6	87,2
56 - 58	57	5	5,8	93,0
58 - 60	59	1	1,2	94,2
60 - 62	61	2	2,3	96,5
62 - 64	63	2	2,3	98,8
64 - 66	65	1	1,2	100,0
	Totals :	86	100,0	

Minimum speed 34,8 km/h

Maximum speed 65 km/h

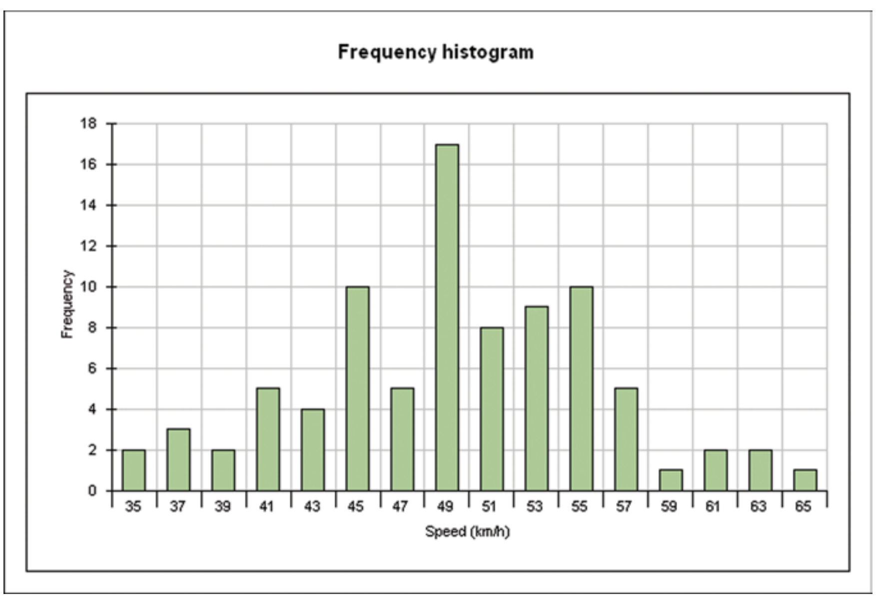
Average speed 49,4 km/h

Standard deviation 6,5 km/h

Number of classes 16

Class interval 2 km/h

Figure SS-3 Example – Frequency histogram



1 It is generally assumed that operating speeds follow a normal distribution and the properties of this statistical distribution are used to calculate the frequency distribution and cumulative frequency distribution. This hypothesis should be verified with a chi-square test.

Figure SS-4 Example – Frequency distribution

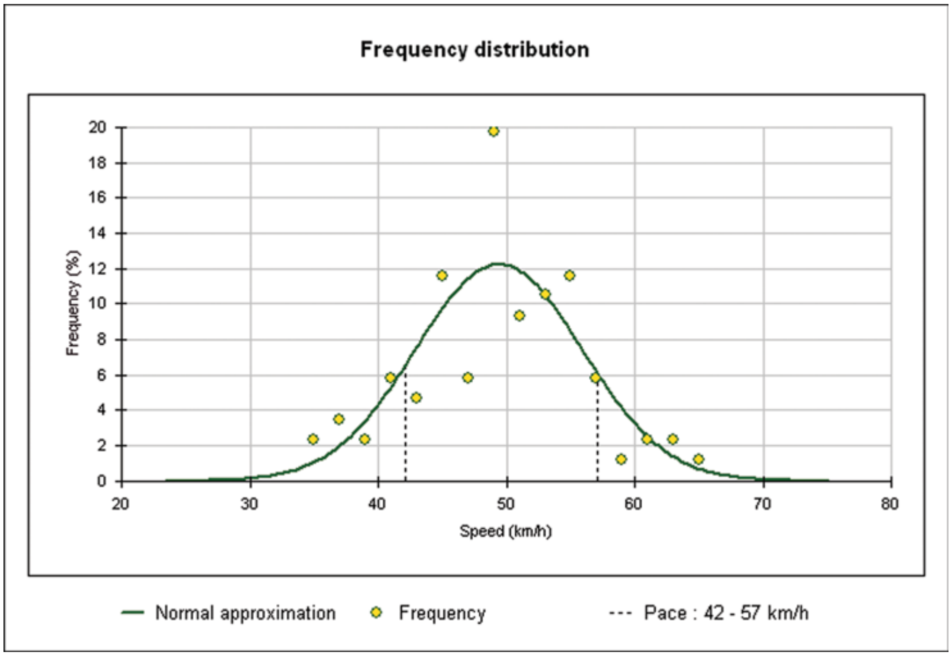
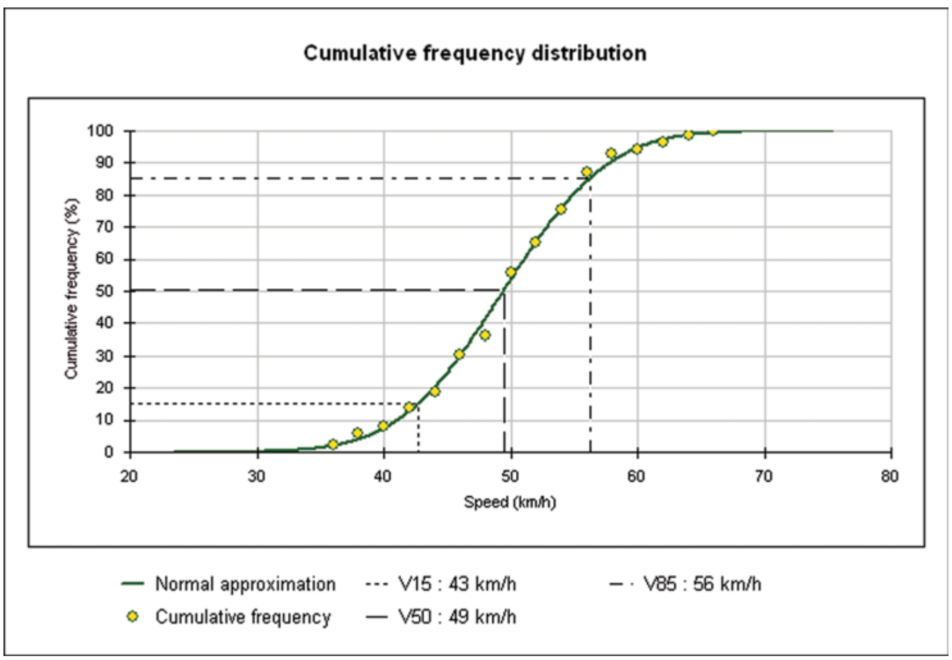


Figure SS-5 Example – Cumulative frequency distribution



[SPOT SPEED STUDY]

TRAFFIC COUNT

Technical study

Carl Bélanger

TRAFFIC COUNT

Technical study

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INTRODUCTION

Counts of the number of vehicles passing at a site are often required in safety analyses, in order to determine if road safety problems may be related to traffic flow deficiencies.

These counts generally consist of short traffic samples that are later expanded to be representative of average traffic conditions, based on data collected at permanent traffic stations. On road sections, the number of vehicles travelling in each direction (and sometimes in each traffic lane) is counted, while at intersections, it is the number of vehicles completing each possible manoeuvre (left, through, right), on each leg, that is of interest.

Given that different types of vehicles have different characteristics, it is often useful to count them in separate categories, which may include passenger cars, light trucks, heavy trucks, buses, motorcycles and bicycles. Pedestrians are also counted separately.

This engineering study outlines some of the main aspects related to traffic counts that needs to be considered in safety studies. For a more in-depth discussion of the topic, please refer to traffic engineering manuals (e.g. Garber et al., 2001 and Ross et al., 1998).

WHEN TO CONDUCT A TRAFFIC COUNT

Traffic flow estimates may be required at different stages of a safety diagnosis:

- when the accident analysis reveals a pattern that may be related to traffic conditions; it may be a concentration of accidents:
    - of a specific type: right angle, rear end, opposing vehicles when one of the two vehicles is turning, etc.;
    - at a specific time (peak hour, end of sports events, etc.);
    - involving a specific road user category (trucks, pedestrians, etc.).
- when observations made at the site reveal traffic operation deficiencies: excessive delays, vehicle queues, hazardous crossings or passing manoeuvres, etc.;
- when the installation criteria for specific highway equipment considered as a potential solution are based on traffic flow conditions (traffic signal, pedestrian crossing, turning lane, etc.).

Observation period

Traffic counts should always be planned when the conditions of interest are the most likely to be observed: on a regular weekday in a business area, in summer on a recreational route, over a winter week-end for a route serving a ski resort, etc. Prior to initiating a traffic count, observers should always make sure that normal traffic conditions are not disturbed by any special events, such as a road work area ahead of the site, a major labour conflict, an important cultural event.

A 12-to-24 hour traffic count is often conducted to estimate standard traffic parameters that are used to take engineering decisions, such as ***peak hour volume*** and ***average annual daily traffic (AADT)***. When accidents cluster at a specific hour of the day, such as during the morning or evening peak hour, or after a shopping centre closes, a traffic count for a few hours during that period may very well be sufficient. In other instances, when a costly investment is being considered, the installation of ***automatic counters*** to collect traffic information over a long period may be worthwhile.

Definitions

The ***peak hour volume*** is the maximum number of vehicles passing a point on a highway during a period of 60 consecutive minutes of an average day. The hourly ***rate of flow*** is based on the vehicle arrival rate over a shorter peak period within the peak hour (generally 15 minutes) and is used for capacity calculations (traffic breakdowns are often due to short arrival peaks). To calculate the hourly ***rate of flow,*** the ***peak hour factor*** first needs to be estimated. Assuming a 15 minutes interval:

$$\text{Peak hour factor (PHF)} = \frac{\text{peak hour volume}}{4 \times (\text{volume during the maximum 15 minutes of the peak hour})} \quad \text{[Eq.TC-1]}$$

$$\text{Rate of flow} = \frac{\text{peak hour volume}}{\text{PHF}} \quad \text{[Eq.TC-2]}$$

A calculation example is shown in Figure TC-8.

The ***average annual daily traffic (AADT)*** is the total number of vehicles passing a point during a year divided by the number of days in that year. On a road section, AADT is derived from the sum of vehicles passing through the site in both directions while at an intersection, AADT is derived from the measure of the total number of vehicles entering the intersection ***(estimation of AADT)***.

HOW TO CONDUCT A TRAFFIC COUNT

Traffic counts are generally conducted using either ***manual*** or ***automatic methods***. With recent technological developments, a number of new collecting methods are rapidly emerging (***videos and new technologies***).

The choice of method depends on the type of information required, on the duration of the traffic count and on the available budget (Table TC-1).

Table TC-1 Choice of counting methods

INFORMATION	MANUAL	AUTOMATIC (TUBES AND LOOPS)	VIDEO AND NEW TECHNOLOGIES
Short term traffic count			Although video recording and new technologies can be used for a wide range of counting studies, installation procedures are often too complex for short term counts.
-road section	yes	yes	
-intersection (with turning manoeuvres)	yes	differentiating each manoeuvre may be difficult	
-vehicle occupancy	yes	no	
-vehicle classification	yes	yes	
-pedestrian count	yes	no	
Long term traffic count	yes but not cost effective	yes	yes

MANUAL METHODS

Since the installation procedures are much simpler, manual methods are often preferred over automatic methods when short-term traffic counts are conducted, which is generally the case in safety studies.

Manual methods are also often preferred over automatic methods at intersections, since it is difficult to obtain accurate counts of each possible manoeuvre with these latter methods.

Personnel

The required number of observers depends upon several factors: duration of the counting period, traffic volume, level of detail of the required information (turning manoeuvres, vehicle classification, vehicle occupancy) and site layout. For instance, one person can generally conduct a traffic count on a section of a rural two-lane highway but several observers will be required to count the number of vehicles passing at a busy intersection when details of turning manoeuvres and vehicle classifications need to be known.

Observers should look for a location where they can easily see all road users who need to be counted without interfering their progression.

To avoid counting errors that may be linked to excessive fatigue, observers need to take regular breaks. The number of vehicles not counted during those breaks needs to be estimated based on the number of vehicles counted right before and after the break (McShane and Roess, 1990).

Equipment

Manual counts can be conducted with three different types of equipment:

traffic count forms, watch and stopwatch
mechanical counter, summary form, watch and stopwatch
electronic counter

Manual method – Traffic count forms, watch and stopwatch

The passage of each vehicle (or pedestrian) is noted by a tick mark in the appropriate area of a traffic count form. Separate forms are used to count vehicles (e.g. Figure TC-1) and pedestrians (e.g. Figure TC-2). More than one vehicle category can be counted on a same form. For instance, Figure TC-1 separates passenger vehicles and heavy vehicles.

Observers use a watch and a stopwatch to determine the beginning and end of each pre-established counting period (e.g. 15 minute). A separate form is used for each counting period. The heading of each form must be thoroughly completed to avoid confusion when data are summarized later, especially when several counts are successively conducted.

Figure TC-1 Intersection – Vehicle count form

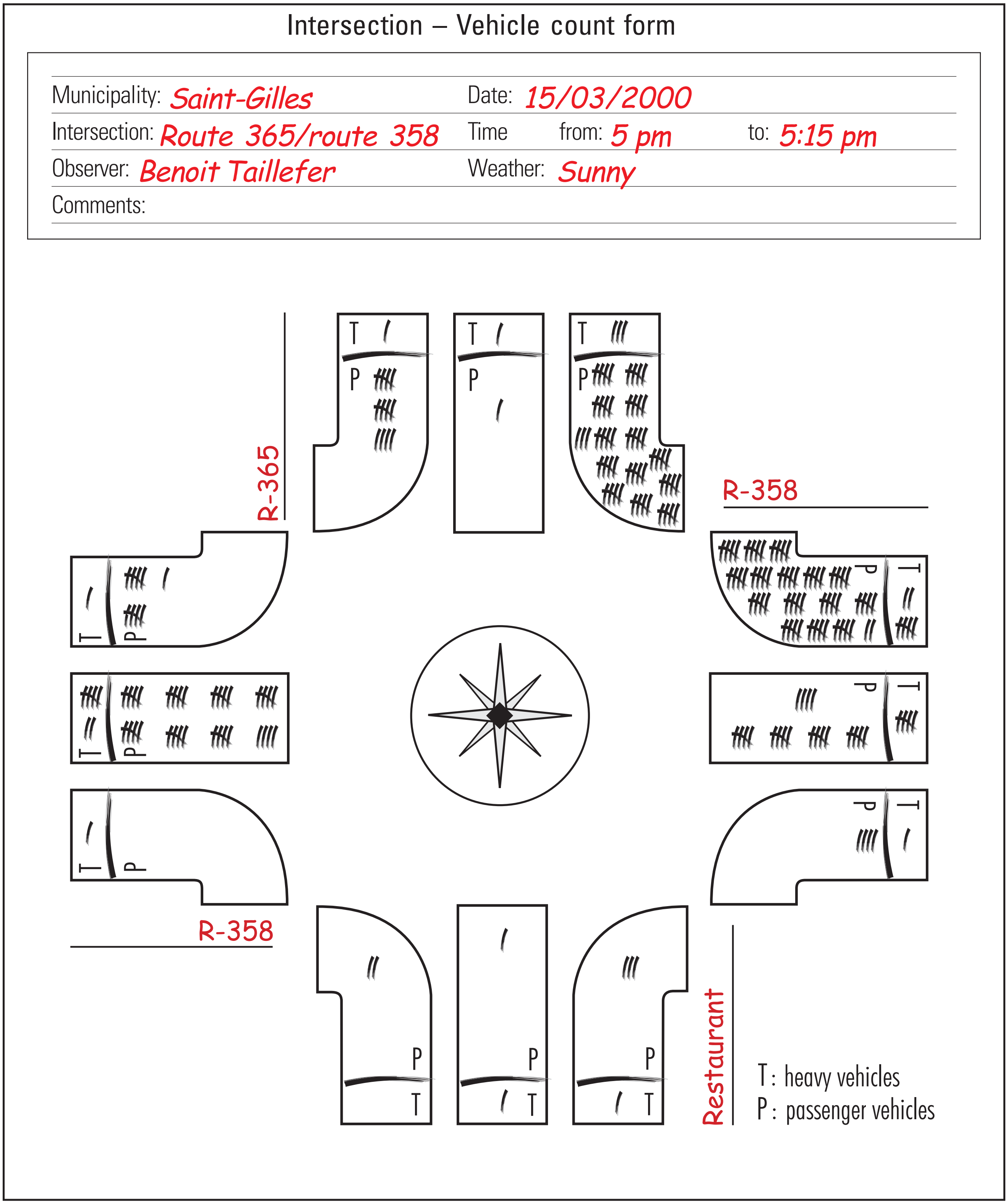


Figure TC-2 Intersection – Pedestrian count form

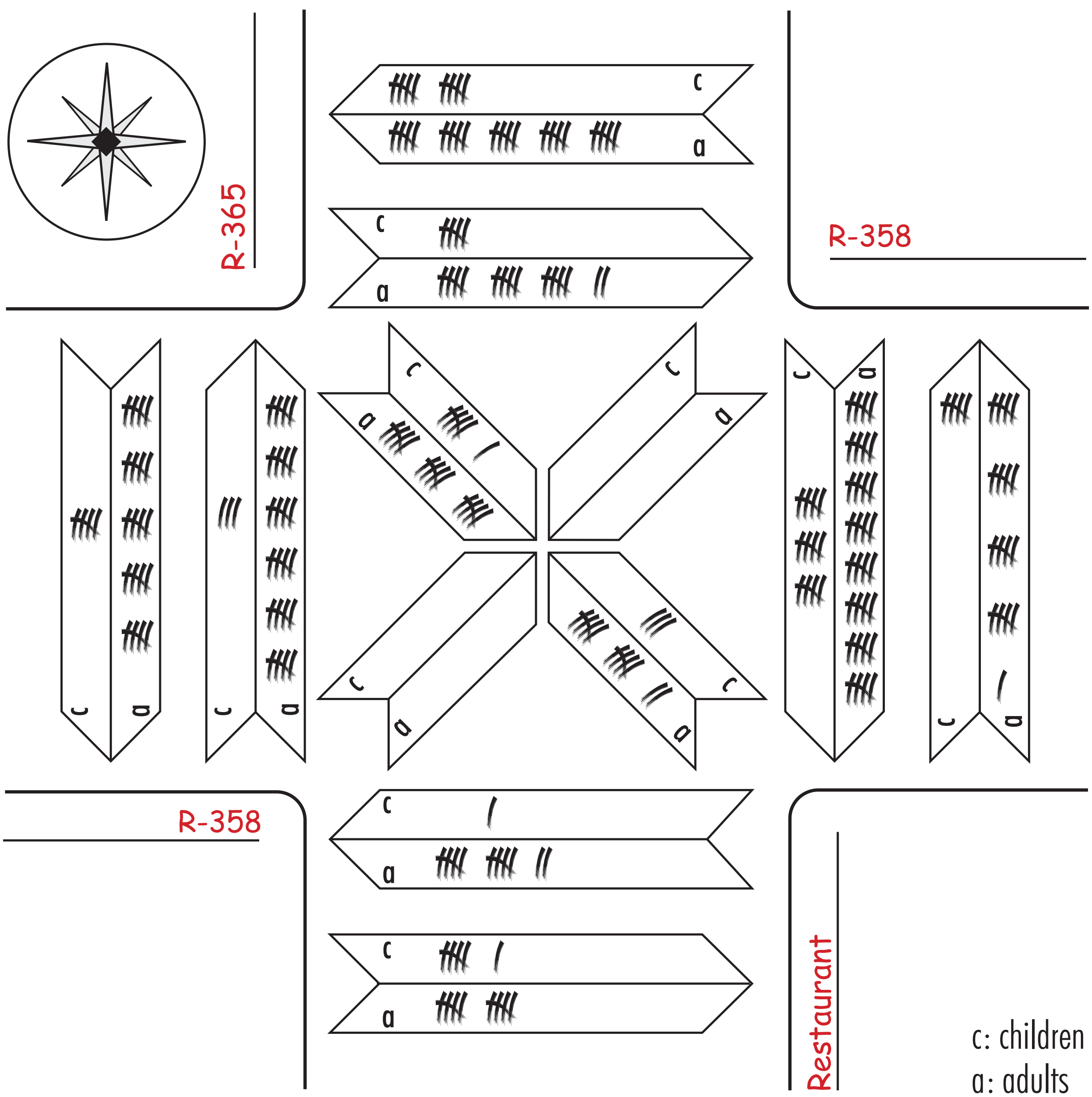
Intersection – Pedestrian count form

Municipality: *Saint-Gilles* Date: *15/03/2000*

Intersection: *Route 365/route 358* Time from: *5 pm* to: *6 pm*

Observer: *Benoit Taillefer* Weather: *Sunny*

Comments:



Blank forms are included in Appendix TC-1.

Manual method – Mechanical counter, summary form watch and stop watch

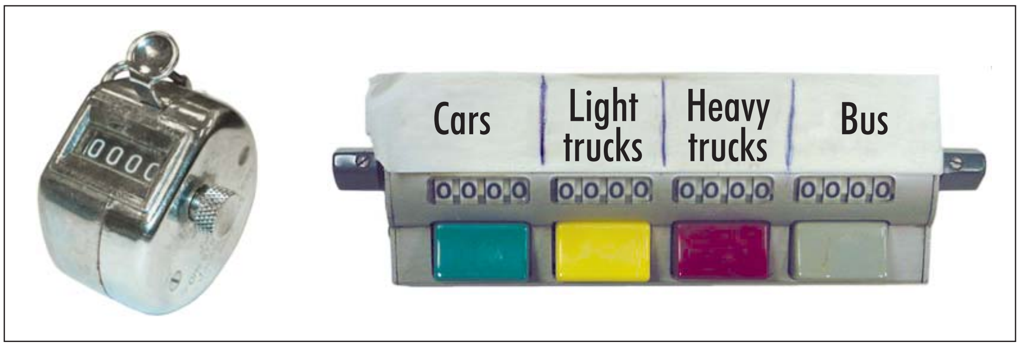
The passage of a vehicle is recorded by pressing one of the mechanical counter's push-button. Different types of mechanical counters may be used; for example, the counter shown on the left of Figure TC-3 can only count one traffic feature at a time while the one on the right side of this figure can count up to 4 separate features. It may consist of:

- the number of vehicles completing a manoeuvre (left, through, right);
- the number of road users in a given category (passenger car, light truck, heavy truck, bus);
- the number of vehicles in each traffic lane.

For instance, a traffic count at a 4-leg intersection that separates each possible manoeuvre would require 4 counters each having 3 push buttons.

A watch and a stopwatch are used to determine the beginning and end of each pre-established counting period. At the end of each of these periods, the number of vehicles is noted on a summary form and each dial of the counter is reset to zero. An example of a summary traffic count form is included in Appendix TC-1. Procedures have been established to minimize errors associated to this data transfer (e.g. Roess et al., 1998).

Figure TC-3 Mechanical counters

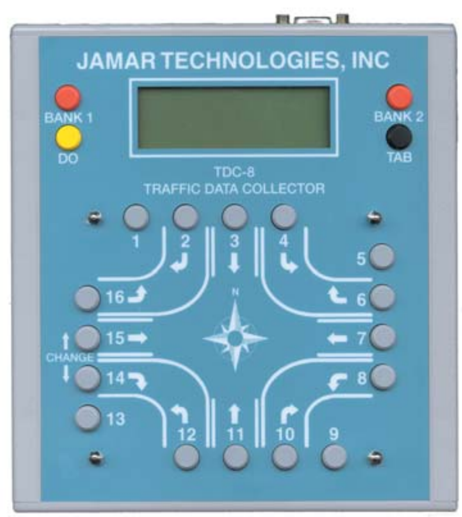


Manual method – Electronic counter

The passage of each vehicle is recorded on the electronic counter by pressing the appropriate button.

These counters have built-in clocks and storage capabilities that eliminate the need for stopwatches and summary forms. The total number of vehicles is automatically recorded for each time interval selected by the observer.

At the end of the study, data are downloaded onto a computer and reports can be automatically prepared, using the manufacturer's software. This greatly reduces the risk of handling errors and may result in significant cost savings when the number of traffic counts is large.



Electronic counter
Courtesy of Jamar Technologies, inc.

AUTOMATIC METHODS (tubes, loops, others)

The passage of vehicles is detected by sensors, using either an electro-mechanical or electro-magnetic device. The sensors are connected to data recorders that are placed on the side of the road. Some data recorders have digital displays showing the data being recorded, which is convenient for validating the device at the beginning and end of the study. Automatic methods can be used either for short-term or long-term counts, the main difference being related to the nature of the installation.

Short-term counts

On road sections, installation procedures are fairly simple, which facilitates the use of these methods. Sensors are laid on the road surface and data recorders are locked on any fixed equipment found on the roadside.

At intersections, the lane configuration sometimes makes it possible to count part of the vehicle manoeuvres using automatic counters, hence reducing the necessary manpower (Figure TC-4).

Automatic methods should also be used whenever prevailing conditions jeopardize observers' safety. A patrol car should be available during the installation.

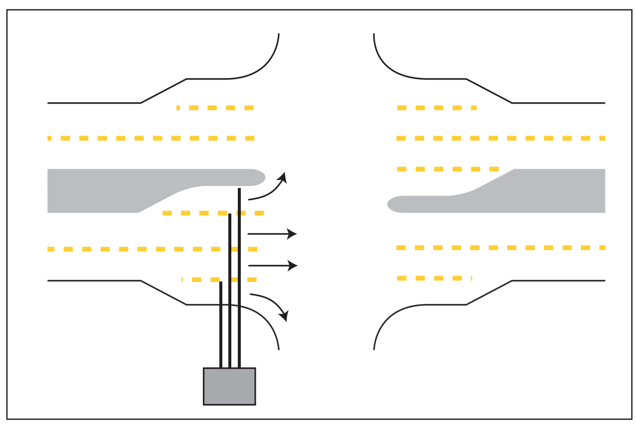
Automatic counters (short term installation)
Source: Ministère des Transports du Québec (B. Bussière)

Long-term counts

Most road authorities install a number of permanent counting stations at strategic locations in a road network as part of a nation-wide counting program. Continuous recording at these stations allows the accurate monitoring of traffic flow variations and trends. Among other applications, this data is used to make short-term counts representative of average annual daily traffic conditions ***(estimation of AADT)***.

For long-term counts, sensors are imbedded in the road surface and data recorders are kept in permanent storage cabinets to better protect them against adverse weather conditions, theft and vandalism.

Figure TC-4 Example – Setting for an intersection automatic count



VIDEOS AND NEW TECHNOLOGIES

An alternative counting method consists of recording a video at the site and then processing these images to derive traffic counts using either a specialized software or manually counting the number of vehicles.

One advantage of videos is that the same recording can be used not only to count vehicles, but also to observe several other traffic features: delays and queues, traffic conflicts, hazardous manoeuvres, compliance with existing regulations, etc.

The main drawback of videos is the complexity of installation procedures. It is often difficult to find a location with an unobstructed view of all possible manoeuvres, where the equipment can be quickly and inexpensively installed, and without risk of vandalism.

However, it should be noted that recent technological improvements have considerably changed how video recording could be used to monitor highway conditions. Various combinations of videos and vehicle sensors are now routinely used to automatically detect traffic operation and safety problems, including speeding and red-light running.

Video cameras coupled with advance variable message signs are also commonly used in metropolitan areas to permanently monitor traffic and reduce both congestion and accident risk.

Recent advances in video image processing as well as in other types of vehicle detection technologies (microwave radar, infrared, laser, ultrasonic) have substantially increased the choice of methods that can be used to monitor and count traffic (Klein, 1997).

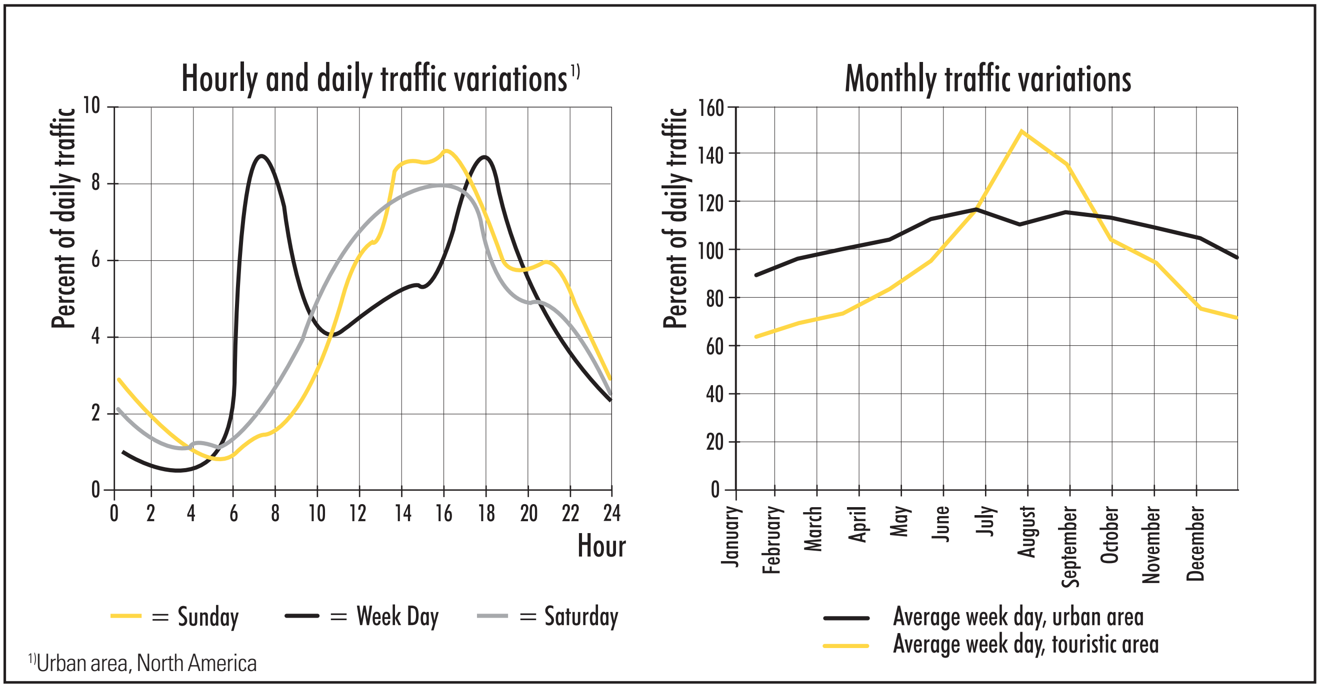
Traffic management camera

ESTIMATION OF AADT

Traffic flow changes over the hours of the day, the days of the week, the months of the year and it also fluctuates from year to year. These variations are influenced by several factors, including the nature of the environment (rural versus urban) and the trip purpose (business, recreational). For example, monthly variations are greater on roads serving recreational traffic; hourly peaks are greater on urban roads and on business days.

Examples of traffic volume variations observed at permanent counters are shown in Figure TC-5. It illustrates how significantly the volume of traffic counted at a given location can change, depending on the time when observations are made.

Figure TC-5 Example – Traffic volume variations



To avoid erroneous conclusions, traffic engineering decisions are often based on the average annual daily traffic (AADT). This parameter is estimated by adjusting short term traffic counts based on data collected at permanent counting stations having similar characteristics to those of the analyzed site.

The adjustment procedure is illustrated in the following example.

Example

A 12-hour traffic count was made between 07:00 and 19:00 at an intersection on a Wednesday in the month of March 2000. A total of 9,375 vehicles were counted during that period. Hourly, daily, and monthly traffic variations recorded at a permanent traffic station having similar characteristics are shown on Figure TC-6. Given that these data are recent (at the time of the safety analysis), a yearly adjustment does not need to be made. However, the 12-hour count needs to be expanded to 24 hours and corrected to take into account seasonal variations:

Extension to 24 hours

Traffic was counted between 7 am and 7 pm. Data collected at the permanent counting station show that on an average weekday, 81.87% of all vehicles travelling on this type of road during a 24-hour period do so during this twelve hour period. Consequently, the 24-hour traffic flow can be estimated as follows:

$$9{,}375/0.8187 = 11{,}451 \text{ vehicles}$$

Seasonal correction

Traffic has been counted on a Wednesday in March. Data collected at the permanent counting station show that on average, traffic volume is only 82.77% of the AADT at that time. Consequently, the AADT of the site becomes:

$$11{,}451/0.8277 = 13{,}835 \text{ vehicles}$$

It is this value of 13,835 vpd - which in this example represents a traffic increase of 48% as compared with the 12-hour count - that should be used to make engineering decisions that are based on average annual daily traffic volumes (e.g. calculation of accident rate and critical accident rate).

Figure TC-6 Example – AADT calculation based on a 12 hour traffic count

TRAFFIC COUNT
Day of the week: Wednesday
Month: March
Time: 07:00 to 19:00
Total count: 9,375 vehicles

DAILY AND MONTHLY TRAFFIC VARIATIONS

	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
January	80.15	71.36	72.83	75.21	78.43	83.26	66.49
February	94.30	74.77	75.56	76.41	82.15	89.91	74.62
March	100.17	77.66	80.17	82.77	87.03	94.49	80.28
April	109.73	84.76	86.84	89.55	93.87	105.07	89.36
May	129.87	94.84	97.04	99.44	104.81	121.35	102.88
June	142.39	103.93	105.95	107.85	113.11	129.52	112.30
July	150.16	114.67	116.29	117.00	124.27	135.99	120.65
August	150.98	111.50	112.86	114.26	119.90	135.83	120.80
September	133.76	95.65	98.69	100.33	106.05	119.89	101.57
October	121.92	92.60	94.99	96.37	101.54	114.88	96.27
November	102.65	84.98	86.60	88.20	92.30	98.29	79.83
December	86.65	79.38	80.22	77.57	85.46	91.84	72.21

Seasonal correction $\frac{11,405}{0.8277}$ = 13,835 vpd

HOURLY TRAFFIC VARIATION

	Sunday	Saturday	Weekday
0	2.80	2.00	0.92
1	1.92	1.24	0.45
2	1.30	0.91	0.31
3	0.88	0.73	0.28
4	0.45	0.41	0.29
5	0.45	0.68	1.73
6	0.88	1.46	6.55
7	1.18	2.16	8.68
8	1.79	3.25	5.49
9	2.95	4.67	3.66
10	4.33	6.12	4.01
11	5.86	6.84	4.41
12	6.72	7.31	4.91
13	8.54	7.84	5.14
14	8.61	8.01	5.42
15	8.85	8.12	6.46
16	8.28	7.93	8.43
17	6.93	6.49	8.75
18	5.76	5.11	6.51
19	5.76	4.70	5.11
20	5.67	4.09	4.19
21	4.62	3.28	3.49
22	3.29	3.28	2.57
23	2.12	3.17	1.79

81.87%

Extension to 24 hour $\frac{9,375}{0.8187}$ = 11,451 vpd

PRESENTATION OF RESULTS

Raw traffic data must be summarized and organized in a suitable form to facilitate analysis. For manual counts made on paper forms, each tick mark must first be added up in order to prepare data summaries. If electronic manual counters or automatic methods are used, the manufacturer's software can greatly ease the presentation of results.

Typical summary tables and graphs are shown in Figures TC-7 to TC-9.

Figure TC-7 Example – Traffic count summary

Intersection – Traffic count

Municipality: *Saint-Gilles* Date: *15/03/2000*

Intersection: *Route 365/route 358* Time from: *7 am* to: *7 pm*

Observer: *Benoit Taillefer* Weather: *Sunny*

Comments: *Count of passenger vehicles only*

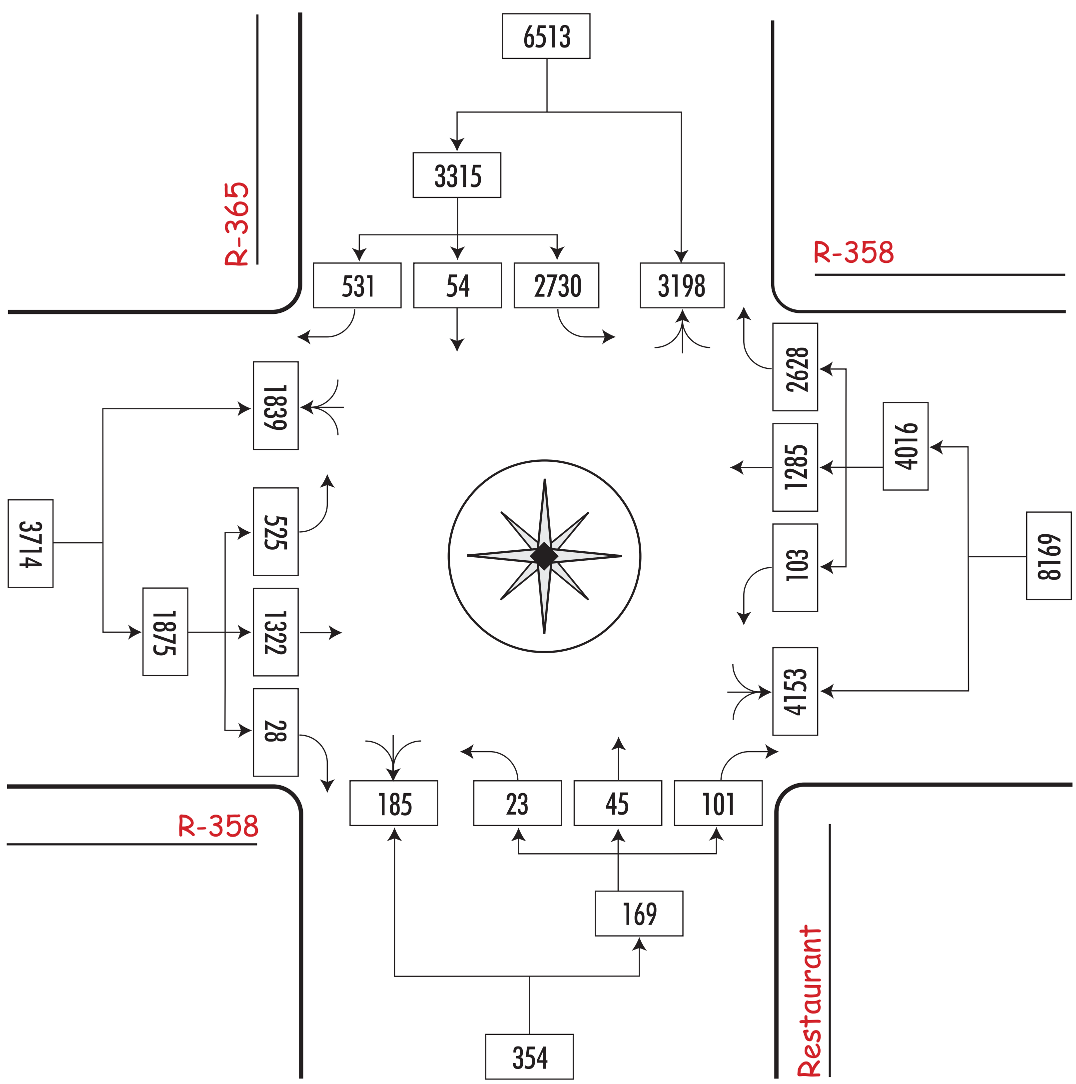


Figure TC-8 Example – Summary table

Municipality: *Saint-Gilles* Date: *15/03/2000*

Intersection: *Route 365/route 358* Time from: *07:00* to: *19:00*

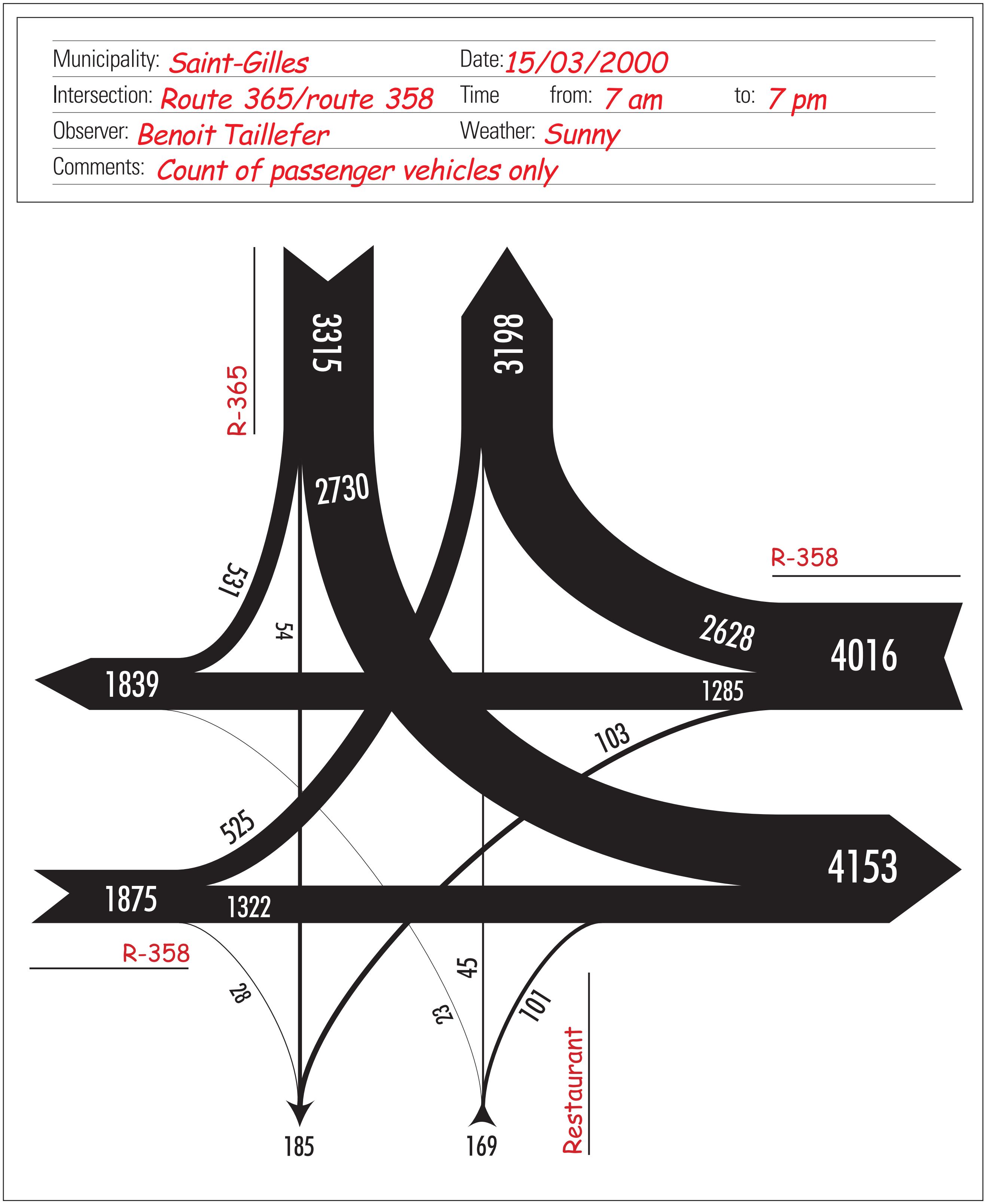
Observer: *Benoit Taillefer* Weather: *Sunny*

Comments: *Count of passenger vehicles only*

	From North				From South				From East				From West				
	R-365				Restaurant				R-358				R-358				
	Left	Through	Right	Total	Left	Through	Right	Total	Left	Through	Right	Total	Left	Through	Right	Total	Total
07:00	52	0	10	**62**	0	0	2	**2**	0	17	25	**42**	6	13	0	**19**	125
07:15	56	0	15	**71**	1	1	0	**2**	1	31	33	**65**	9	18	1	**28**	166
07:30	53	0	11	**64**	0	1	1	**2**	1	21	62	**84**	6	17	0	**23**	173
07:45	63	0	15	**78**	0	1	1	**2**	1	40	48	**89**	7	20	0	**27**	196
08:00	38	0	7	**45**	0	0	0	**0**	0	26	64	**90**	7	18	0	**25**	160
08:15	48	0	10	**58**	0	1	1	**2**	2	14	41	**57**	3	21	0	**24**	141
08:30	33	0	11	**44**	0	0	1	**1**	1	25	50	**76**	8	23	0	**31**	152
08:45	46	0	14	**60**	0	2	0	**2**	1	22	48	**71**	12	24	2	**38**	171
09:00	43	0	8	**51**	0	0	2	**2**	1	20	46	**67**	10	24	1	**35**	155
09:15	44	1	8	**53**	0	1	1	**2**	1	20	46	**67**	11	24	0	**35**	157
09:30	43	1	8	**52**	0	2	0	**2**	1	20	46	**67**	11	24	0	**35**	156
09:45	44	1	8	**53**	0	1	1	**2**	0	20	47	**67**	11	24	0	**35**	157
10:00	59	0	13	**72**	0	1	2	**3**	0	25	44	**69**	9	21	1	**31**	175
10:15	59	0	13	**72**	0	0	1	**1**	0	25	45	**70**	9	22	0	**31**	174
10:30	59	0	14	**73**	0	0	2	**2**	0	25	45	**70**	9	21	0	**30**	175
10:45	59	1	14	**74**	0	1	0	**1**	0	24	45	**69**	10	22	0	**32**	176
11:00	51	2	14	**67**	0	0	2	**2**	3	30	59	**92**	12	30	0	**42**	203
11:15	51	1	14	**66**	0	0	4	**4**	4	31	59	**94**	12	30	1	**43**	207
11:30	57	3	15	**75**	0	1	4	**5**	8	31	47	**86**	6	26	1	**33**	199
11:45	54	1	11	**66**	2	0	3	**5**	5	13	53	**71**	11	46	1	**58**	200
12:00	55	4	11	**70**	1	3	6	**10**	6	28	64	**98**	21	39	5	**65**	243
12:15	55	3	6	**64**	2	5	3	**10**	10	28	55	**93**	10	24	0	**34**	201
12:30	83	1	9	**93**	0	1	2	**3**	5	18	51	**74**	22	16	1	**39**	209
12:45	71	1	14	**86**	2	4	4	**10**	8	54	75	**137**	8	40	2	**50**	283
13:00	59	2	10	**71**	1	2	1	**4**	3	47	40	**90**	9	49	2	**60**	225
13:15	45	1	14	**60**	1	1	5	**7**	2	26	51	**79**	11	23	1	**35**	181
13:30	59	2	8	**69**	1	2	3	**6**	2	27	63	**92**	14	20	0	**34**	201
13:45	58	0	7	**65**	1	1	2	**4**	0	28	64	**92**	15	21	0	**36**	197
14:00	62	4	11	**77**	1	0	4	**5**	1	36	55	**92**	10	27	1	**38**	212
14:15	61	3	11	**75**	0	0	4	**4**	1	26	55	**82**	10	28	1	**39**	200
14:30	61	2	10	**73**	0	0	3	**3**	1	26	55	**82**	11	27	0	**38**	196
14:45	61	1	10	**72**	0	1	1	**2**	1	27	55	**83**	11	28	0	**39**	196
15:00	56	2	15	**73**	1	1	4	**6**	2	29	56	**87**	12	33	1	**46**	212
15:15	55	1	15	**71**	1	1	4	**6**	2	29	57	**88**	13	33	1	**47**	212
15:30	55	1	15	**71**	1	0	2	**3**	2	29	57	**88**	13	33	0	**46**	208
15:45	55	1	16	**72**	0	0	2	**2**	2	30	57	**89**	13	34	0	**47**	210
16:00	78	1	13	**92**	0	2	2	**4**	1	23	58	**82**	20	46	1	**67**	245
16:15	67	0	10	**77**	0	0	1	**1**	0	28	78	**106**	12	38	0	**50**	234
16:30	64	2	16	**82**	0	0	0	**0**	0	41	83	**124**	18	40	0	**58**	264
16:45	83	3	9	**95**	1	0	2	**3**	3	37	76	**116**	13	44	0	**57**	271
17:00	68	1	14	**83**	2	1	3	**6**	4	24	77	**105**	11	39	0	**50**	244
17:15	78	0	10	**88**	1	1	3	**5**	3	22	65	**90**	18	35	1	**54**	237
17:30	42	2	6	**50**	0	2	3	**5**	4	24	69	**97**	8	24	1	**33**	185
17:45	53	2	4	**59**	2	0	2	**4**	4	24	57	**85**	5	25	1	**31**	179
18:00	59	1	9	**69**	1	2	2	**5**	3	23	50	**76**	9	22	1	**32**	182
18:15	58	1	9	**68**	0	1	1	**2**	2	24	50	**76**	9	22	0	**31**	177
18:30	59	1	8	**68**	0	1	2	**3**	1	23	51	**75**	10	22	0	**32**	178
18:45	58	0	8	**66**	0	0	2	**2**	0	24	51	**75**	10	22	0	**32**	175
Total	2730	54	531	3315	23	45	101	169	103	1285	2628	4016	525	1322	28	1875	9375

Peak hour: 16:30 to 17:30 Peak hour factor (PHF) $= \dfrac{1016}{4 \times 271} = 0.937$ Rate of flow $= \dfrac{1016}{0.937} = 1084$

Figure TC-9 Example – Intersection flow diagram



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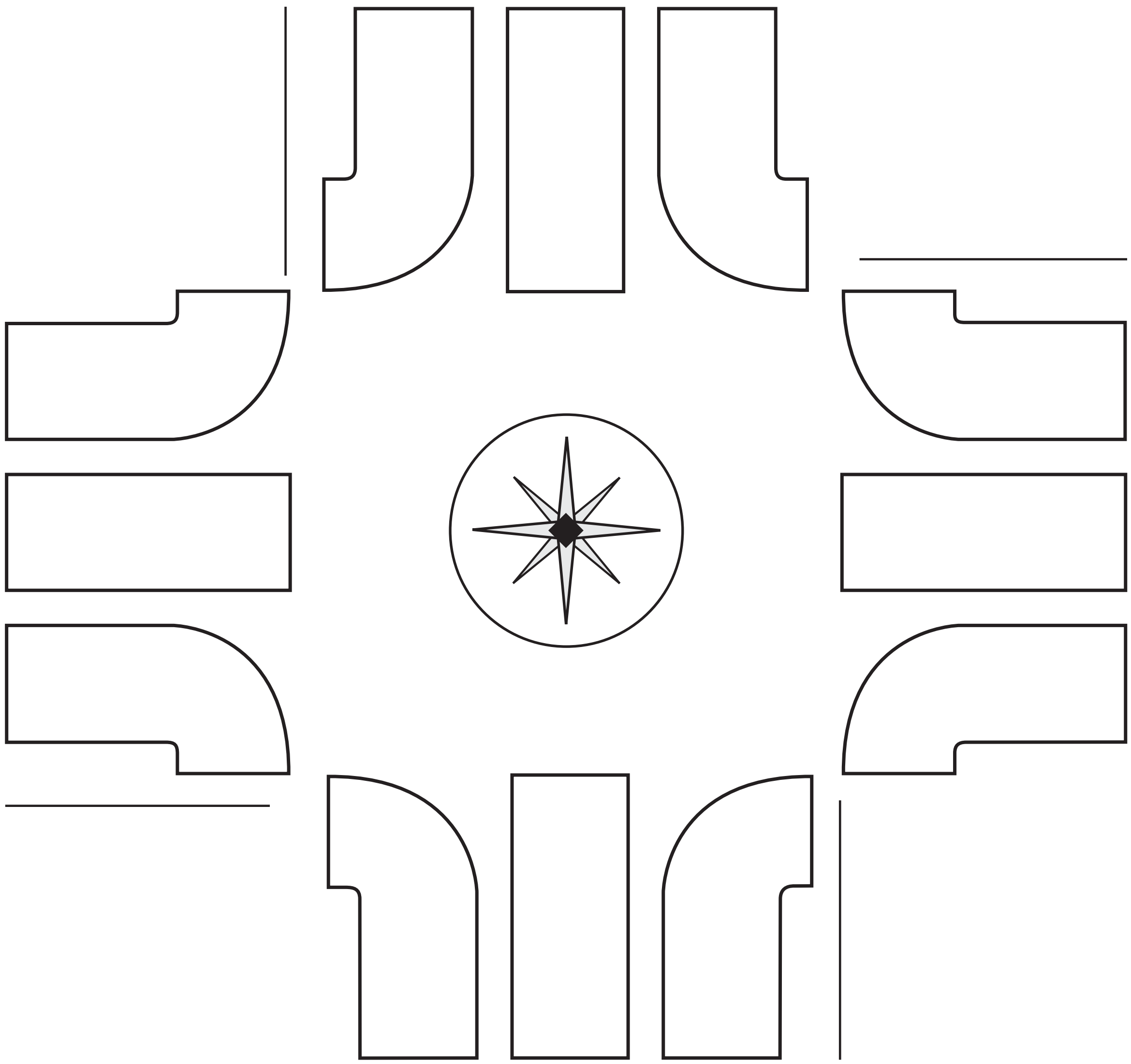
Roess, R.P., McShane, W.R. and Prassas, E.S. (1998) *Traffic engineering, 2nd Edition,* Prentice Hall, Upper Saddle River, N.J.

Appendix TC-1

Blank Forms

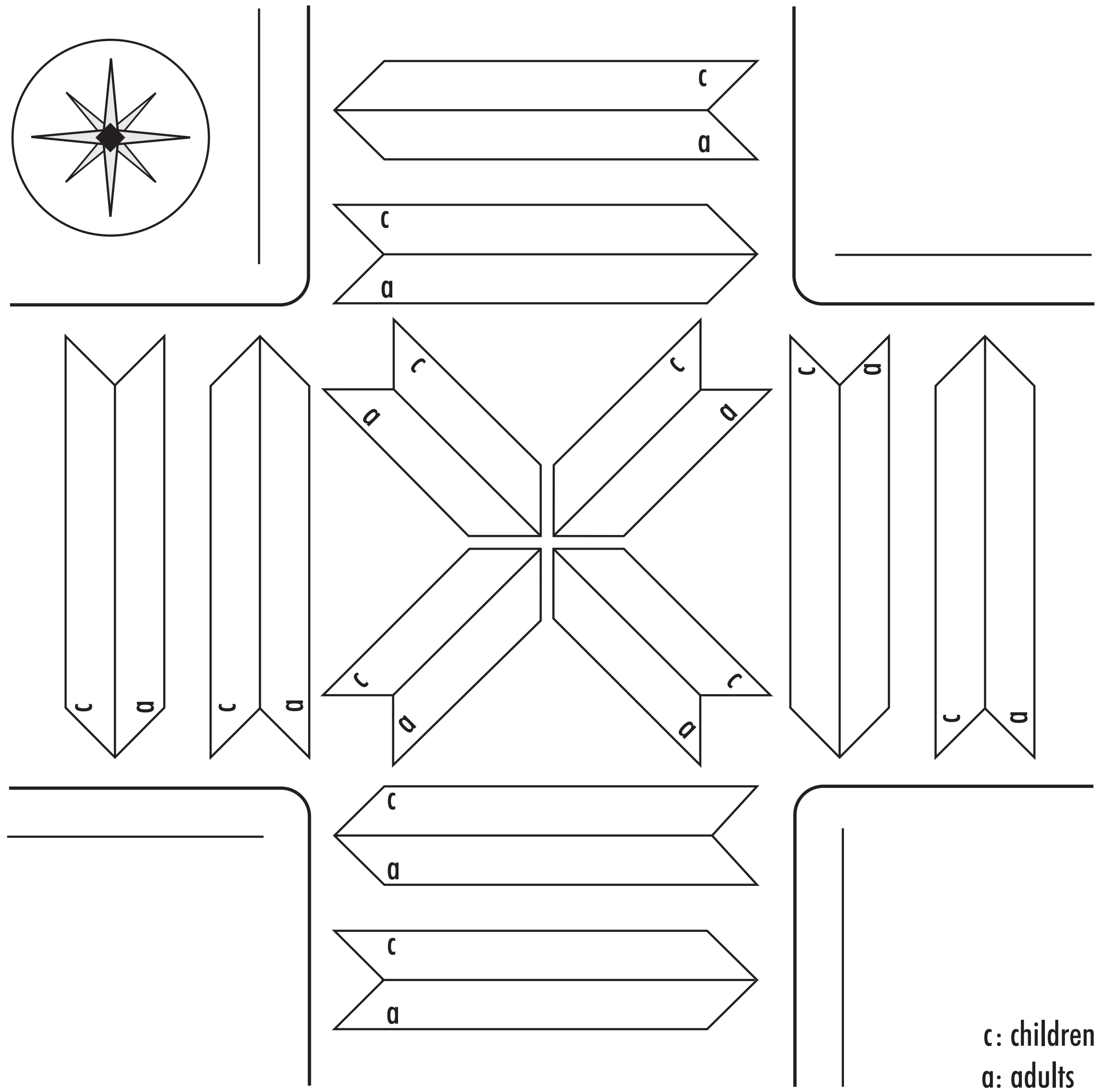
Intersection – Vehicle count

Municipality:	Date:		
Intersection:	Time	from:	to:
Observer:	Weather:		
Comments:			



Intersection – Pedestrian Count

Municipality:		Date:	
Intersection:		Time from:	to:
Observer:		Weather:	
Comments:			



c: children
a: adults

Summary of Vehicle Counts

Municipality: Date:

Intersection: Time from: to:

Observer: Weather:

Comments:

HR:MN	From North				From South				From East				From West				
	Left	Through	Right	Total	Left	Through	Right	Total	Left	Through	Right	Total	Left	Through	Right	Total	Total

FRICTION

Technical study

Carl Bélanger

FRICTION

Technical study

LIST OF FIGURES

TABLE

INTRODUCTION

The accident risk increases as skid resistance decreases. The risk is higher under wet surface conditions and at sites where the friction requirement is high (e.g. intersections, horizontal curves, downhill slopes).

This technical study outlines the main observations that need to be made at a site to verify if road surface friction is adequate and determine the need for instrumented tests. However, it does not describe in their details the numerous testing methods and equipments that have been developed over the years to identify and quantify road surface deficiencies. It is a topic that is already well covered in a number of specialized publications (e.g. AIPCR, 1995b; Ministère des transports du Québec, 2002; Miller and Bellinger, 2003).

WHEN TO CONDUCT FRICTION TESTS

Instrumented friction tests may be required during a safety diagnosis when:

- a high proportion of wet surface accidents has occurred at the site;
- the site visit reveals potential road safety problems (see ***visual observations*** below);
- the road surface has recently been treated to correct a skid resistance problem.

Several road administrations routinely conduct friction tests throughout their network to detect hazardous locations and plan maintenance works.

HOW TO DETECT FRICTION PROBLEMS

There are two main approaches to the identification of friction deficiencies:

1) Visual observations of road surface conditions

2) Friction tests

In road safety diagnoses, friction tests are generally conducted after visual observations or accident analyses reveal a problem.

VISUAL OBSERVATIONS

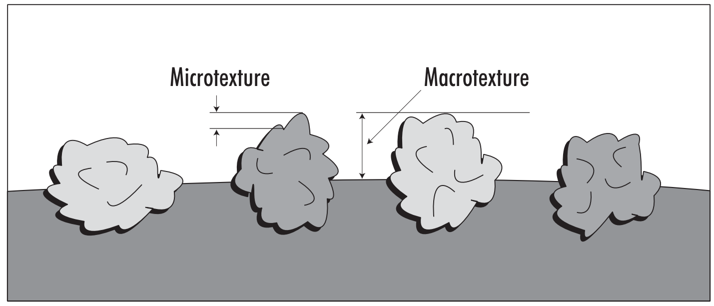
Visual observations at the site may uncover various road surface deficiencies. While roughness problems are easy to detect, friction deficiencies may be more difficult to recognise by non specialists.

Since friction is closely related to the quality of a surface microtexture and macrotexture, these two properties are first described. Then, some frequent causes of friction deficiencies are discussed.

- ***aging of aggregates;***
- ***bleeding;***
- ***water accumulation;***
- ***surface contamination.***

Microtexture and macrotexture

Figure FT-1 Microtexture and macrotexture



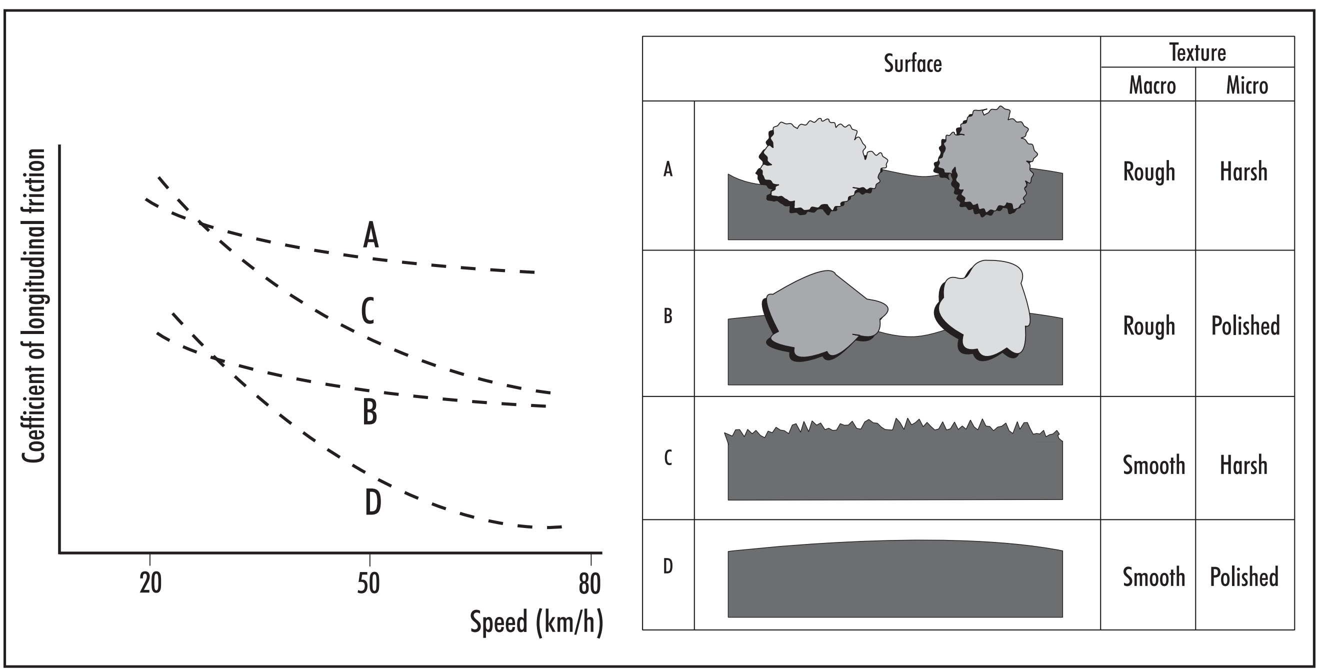
The road surface **microtexture** is defined as the amplitude of deviations from the plane with wavelengths of less than or equal to 0.5 mm. Microtexture results from irregularities at the surface of the pavement aggregates. It controls the maximum skid resistance attainable at low speed and as such, is often described as the low-speed friction parameter. However, it affects the level of skid resistance at all speeds.

Macrotexture is defined as the amplitude of deviations from the plane with wavelengths of 0.5 to 50 mm. It results from the presence of coarse aggregate particles at the road surface. Macrotextures larger than 0.8 mm are quite good. The macrotexture provides escape channels for the water located at the tire-pavement interface and determines the rate at which skid resistance is lost as speed increases. It is often described as the friction-speed gradient parameter.

Microtexture can be measured in the laboratory using microscope-based techniques. However, results of friction tests conducted at low speeds are generally considered to be a fair indicator of its quality.

The relationship between microtexture, macrotexture, speed and friction is illustrated in Figure FT-2. It shows that while a good microtexture may be sufficient to provide adequate friction at lower speeds, good micro and macro textures are necessary at higher speeds.

Figure FT-2 Relationship between microtexture, macrotexture, friction and speed



Source: OCDE, Caractéristiques de surface de revêtements routiers : leur interaction et leur optimisation, figure II.8.1 and figure II.8.2. Copyright OCDE, 1984.

Aging of aggregates

- The polishing of aggregates reduce the anti-skidding properties of a road surface by gradually eliminating its original microtexture and macrotexture.
- Aggregates' resistance to polishing depends on their composition. Some types of rocks offer a very poor resistance to polish and wear and should not be used in pavement materials (e.g. limestones, dolomite) while others are very resistant (e.g. granite, sandstone, bauxite).

Several other factors also have an effect on the aging rate of a road surface. They include:

- traffic volumes (particularly heavy vehicle volumes);
- operating speeds;
- acceleration and deceleration manœuvres;
- presence of road **surface contaminants** (they act as abrasives);
- use of studded tires.

The aging of aggregates is identified by the smooth aspect of the road surface.

Aging of aggregates
(Source: P. Langlois, Ministère des Transports du Québec)

Bleeding

Bleeding is a defect in bituminous pavements in which the asphalt component works up to the surface and covers the aggregate, thereby reducing or eliminating the surface texture. Under wet conditions, the surface becomes very slippery.

Bleeding may be due to a surplus of asphalt, an inappropriate surface mix formulation or a combination of high temperatures and heavy vehicles.

The problem is identified by the presence of a black and oily surface texture.

Surface bleeding

Water accumulation

The presence of water on the road surface reduces the contact area between the tire and the road. Under certain combinations of pavement texture, tire tread, vehicle speed and water thickness, contact can be completely lost. This phenomenon is called hydroplaning, and the driver then loses the control of his vehicle.

Water accumulation

- a thin film of water has been shown to be sufficient to produce hydroplaning. For example, an American study reports that as little as 0.025 mm of water on the pavement can reduce the tire-pavement friction by as much as 75% on surfaces having poor skid resistance characteristics (Harwood et al., 1989). The risk of hydroplaning is greatly influenced by the vehicle speed. At low speeds, the impact of the water is limited as there is enough time to squeeze the water out of the tire-surface interface. However, as speed increases, water may remain trapped under the tire, particularly when the macrotexture is inadequate.
- road surface deformations that prevent drainage (rutting, local depressions, etc.) may contribute to water accumulation on the road surface and should be looked for during the site visit.

In northern countries, ice or snow on road surfaces may also greatly reduce the available friction. In some of these countries, friction measurements are taken in winter to assess winter maintenance conditions. Given the cold temperatures, tests have to be conducted without water and it is thus the presence of ice, snow or slush on the road surface that governs the friction value (Wallman and Astrom, 2001).

Surface contamination

Road surface contamination can take different forms, such as:

- sand, gravel, clay;
- oil (spills, vehicle residues);
- farm waste, fallen leaves;
- etc.

Contaminants can cover the pavement texture and accelerate its aging. The situation may be particularly hazardous at the beginning of a first rain after a dry spell, as the contaminants on a road surface may form a slick coating over the pavement.

Contaminant sources should be identified during the site investigation and proper measures taken to eliminate them.

Surface contamination

FRICTION TESTS

Several testing devices have been developed over the years to measure road surface characteristics. The results of a survey published in 1995 by PIARC lists more than a hundred measurement devices, 29 of which are used to measure friction.

Some devices directly measure the coefficient of friction (longitudinal or transversal) while others measure the surface texture characteristics (microtexture, macrotexture).

Tests can be divided into two main categories:

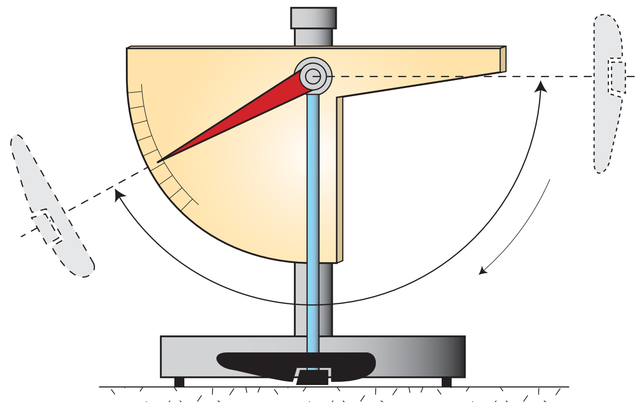
- **static tests** conducted at a specific site (e.g. British pendulum);
- **dynamic tests** conducted with a testing tire moving at a constant speed over the road surface, often at speeds that do not impede regular traffic (e.g. SCRIM.).

Test results are influenced by several factors:

- road surface characteristics (micro and macro texture, contamination, roughness);
- depth of water at the road surface/tire interface;
- tire characteristics (tread pattern, rubber composition, size);
- vehicle speed;
- slip ratio;
- wheel load;
- temperature.

Figure FT-3 Examples – Measuring devices

British Pendulum (ASTM E 303)



Road surface friction is measured by the energy lost when a rubber slider edge is propelled over a test surface. Test results are expressed in terms of BPN (British Pendulum Number).

SCRIM[1] testing truck

The SCRIM is used to measure skid resistance on a wet surface. A truck equipped with a freely rotating testing wheel travels at a constant speed (usually 50 km/h). The testing wheel is inclined at an angle of approximately 20° to the vehicle's direction of motion. A water film of constant depth is sprayed ahead of the testing wheel that is applied to the road surface under a known wheel load. The skidding force is measured (coefficient of side friction).

Routine inspection tests must therefore follow standardized procedures in order to allow unbiased comparisons of results. Several of these testing procedures are described in ASTM standards.

At the international level, efforts are being made to develop tools that facilitate comparisons between friction test results being reported in different countries. An International Friction Index (IFI) has been proposed (which is a common device-independent friction scale). The IFI is now an ASTM standard (ASTM E-1960).

[1] SCRIM : Sideway-Force Coefficient Routine Investigation Machine.

FRICTION ADJUSTMENT FACTORS

Test results need to be adjusted when the objective is to estimate the friction level for conditions that differ significantly from those that have been tested, which is often the case in accident reconstruction studies. In road safety diagnoses, results of friction tests may need to be adjusted to take into consideration differences in speeds, temperatures, and percent slips between testing conditions and "representative" driving conditions.

Vehicle Speed

Skid resistance generally decreases as speed increases. The decreasing rate is a function of the road surface characteristics. The friction loss is higher on surfaces having a poor macrotexture; it is also higher on bituminous surfaces than on concrete surfaces. Two adjustment procedures are described (direct and indirect).

- **Direct method**

This method requires the conduct of friction tests at different speeds at the site of interest. A regression equation is then developed between speed and coefficient of friction, based on the test results. As always, the choice of the functional form used for the regression equation needs to be suited to the set of collected data but in most cases, either a linear or exponential equation will be adequate (see ***example*** below).

Functional Form	Equation	
Linear	$cf_v = cf_0 - \beta V$	[Eq. FT-1]
Exponential	$cf_v = cf_0 * \exp(-\beta V)$	[Eq. FT-2]

- **Indirect method**

When friction tests cannot be conducted at various speeds, the friction-speed relationship can be approximated, based on the properties of the microtexture and macrotexture (Leu and Henry, 1978).

The ***skid number*** at a given speed can be estimated using the skid number at the zero speed intercept (SN_0) and the normalized friction speed gradient (PNFSG). SN_0 is estimated from a British pendulum test and PNFSG is estimated from a sand patch test.

$$SN_v = SN_0 \exp[-(PNFSG/100)\,V] \qquad \text{[Eq. FT-3]}$$

where:

$SN_0 = -31 + 1.38BPN$
(BPN is the result of a British pendulum test)
$PNFSG = 0.45(MD)^{-0.47}$
(MD is the mean texture depth measured during a sand patch test).

The friction speed relationship can therefore be determined using the results of two simple static tests (BPN and sand patch).

Calculators in this manual using the coefficient of friction as an independent variable, allow computations with either a fixed or variable friction-speed coefficient. For the variable case, one of three functional forms for the friction-speed relationship must be selected (linear, exponential or Leu and Henry) and the parameters of the selected functional form must be provided.

Example – Friction speed adjustment (safety diagnosis)

Suppose that a concentration of wet surface accidents has been identified on a rural road. The posted speed is 90 km/h.

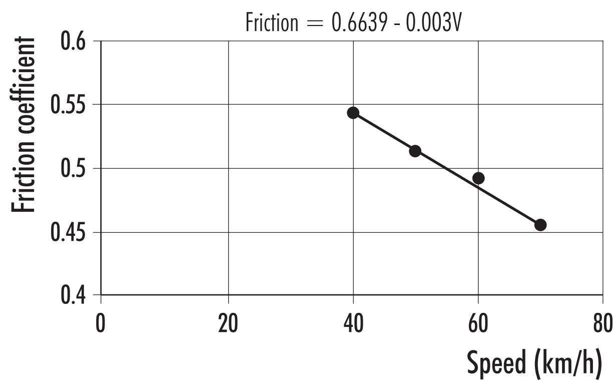
Observations made at the site revealed that the surface texture at the site is smooth and polished. Friction tests were conducted between 40 km/h and 70 km/h and the following linear equation was found to fit the data (Table FT-1 and Figure FT-4)

$$f_{lv} = 0.6639 - 0.003V$$

Table FT-1 Friction-speed relationship

SPEED(km/h)	FRICTION
40	0.5460
50	0.5130
60	0.4920
70	0.4545

Figure FT-4 Friction-speed relationship



A spot speed study showed that the site's 85th speed is 112 km/h, with a corresponding f_{l_112} value of 0.33 (Westbound direction). This value is very close to the design value of 0.30, which is considered a strict minimum. Improving the surface friction is obviously required.

Temperature

A road surface's coefficient of friction decreases as temperature increases. Variations of up to 2 points of transverse friction per degree C° have been measured on some road surfaces (Amiri, 1997). Variations are greater on bituminous pavements and at sites with a poor macrotexture.

When the coefficient of friction needs to be estimated for a temperature that significantly differs from that prevailing during the friction test, results need to be adjusted. Also, when the objective is to determine the worst friction level that can be reasonably expected at a site, a high enough temperature should be selected to reflect these conditions.

Several methods have been suggested to establish the friction-temperature relationship, which once again includes deriving a regression equation from the results of friction tests conducted at different temperatures.

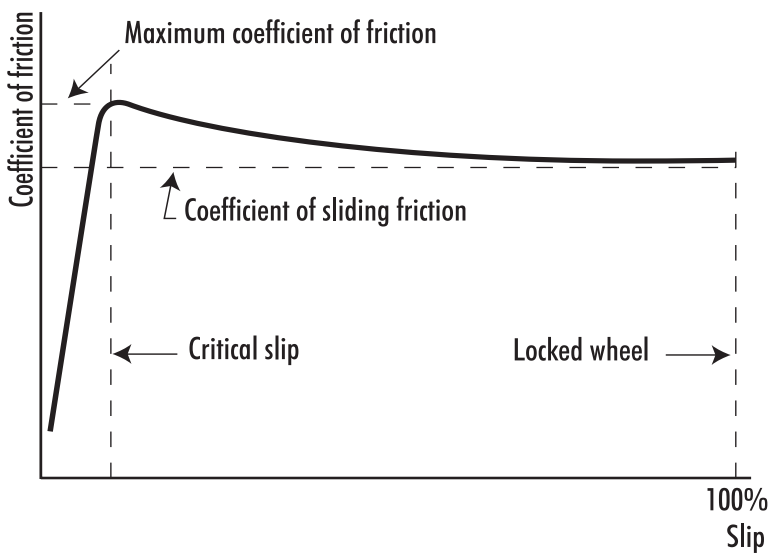
Slip ratio

Percent slip is defined from the difference between the angular speed of a wheel and the vehicle speed during a braking manoeuvre. A free-rolling wheel has 0% slip as the wheel speed is identical to the vehicle speed. On the other hand, a locked wheel is operating at 100% slip, given that it has no angular velocity - the tires slides along the road surface.

The value of the coefficient of friction varies according to the percent slip. It increases rapidly with percent slip to a peak value that typically occurs between 10% and 20% slip (critical slip). The coefficient of friction then slowly decreases to reach, at 100%, a value called the coefficient of sliding friction (Figure FT-5).

Antilock brake systems (ABS) prevent the vehicle wheels from locking and reach for a coefficient of friction that is close to the peak value; this tends to minimize the braking distance.

Figure FT-5 Percent slip-friction relationship



Without ABS, it is generally assumed that the driver locks the vehicle wheels during a panic brake, which increases braking distances.

INTERPRETATION OF RESULTS

Several countries have developed guidelines that trigger actions based on friction test results. Some are quite simple while others are more complex. For example:

- in Finland, threshold friction values are based on speed limits. On 80 km/h roads, the minimum friction value is 0.4 as compared to 0.5 at 100 km/h roads and 0.6 at 120 km/h. (Wallman and Astrom, 2001);

- in England, the network is divided into 13 site categories, each of which has a specific site investigation threshold ***(Table SC-4)***.

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SIGHT DISTANCE

Technical study

Patrick Barber and Carl Bélanger

SIGHT DISTANCE

Technical study

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INTRODUCTION

When conducting a site study, analysts have to check if available sight distances are sufficient to allow road users travelling at a reasonable speed to safely stop their vehicle at any point of the road and also to complete all permitted manoeuvres safely. To do so, they have to measure **available sight distances** and compare them with **required sight distances** defined in road design manuals.

Various sight distance criteria must be met, depending on the type of site under study: stopping, manoeuvring, passing sight distances, etc. These criteria are described in the ***sight distance*** technical sheet. This engineering study describes how to measure available sight distances.

WHEN SHOULD SIGHT DISTANCES BE MEASURED

During a safety diagnosis it may be necessary to conduct a sight distance study for the following reasons:

- on-site observations have uncovered sight defects (a qualitative assessment of available sight distances should be carried out in all safety studies);
- the accident analysis has revealed a problem that may be related to a sight restriction (the site visit will confirm the need for a sight study);
- complaints about sight distances have been made (by road users, elected officials, police, etc.).

HOW TO MEASURE SIGHT DISTANCES

Sight distances can be determined using measurements on plans or mathematical equations. These methods are used at the road design stage in order to ensure that the proposed projects satisfy sight distance requirements.

For existing roads, however, sight distance measurements in the field are recommended since they can detect some sight obstructions that may not be identifiable otherwise (e.g. roadside vegetation, new building, etc.).

This engineering study therefore focuses on the description of ***field measurement*** methods.

Measurement methods on plans are described for information purposes.

The equations used for calculating sight distances in horizontal and vertical curves are described in the appendices of the corresponding technical sheets :

Horizontal alignment – Appendix HA-4

Vertical Alignment – Appendix VA-4

FIELD MEASUREMENTS

Measurements may be taken using sighting and target rods or vehicles. The requisite equipment is as follows:

Required equipment

With rods:

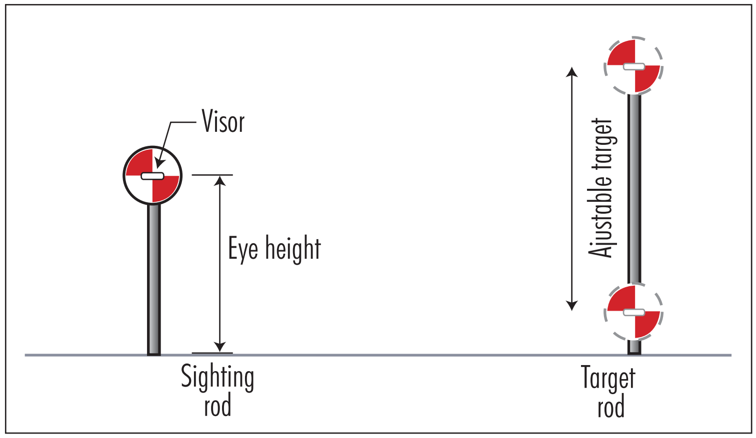
- 2 peoples;
- 2 rods: a sighting rod and an adjustable target rod (Figure SDS-1);
- a measuring wheel;
- a communication system (recommended).

With vehicles:

- 2 peoples;
- 2 vehicles;
- a precision odometer;
- a communication system.

Observers should wear the standard safety equipment (safety hat, vest and boots). Moreover, if required by traffic or sight conditions, additional protection measures should be taken (close lanes, patrol car, etc.).

Figure SDS-1 Example – Target rod and sighting rod



Measuring sight distance with a measuring wheel

Eye and object height

The sight distance being measured may vary significantly according to the height of the eye and the objects being considered.

Eye height

Road design standards define representative vehicles and the corresponding eye heights that should be used for each sight distance criterion. In most cases, the eye height of the driver of a passenger vehicle is recommended, where it is assumed that the higher position of heavy vehicle drivers compensates for the reduced performance of these vehicles (acceleration and deceleration). Some situations, however, require using a heavy vehicle as the representative vehicle (e.g. ***lateral clearance in horizontal curves***). In a study using rods, the sighting rod height must therefore be adjusted in accordance with the eye height recommendations provided in the national standards.

In the case of studies with vehicles, measurements should be taken with vehicles of the appropriate height. For example, pick-up trucks should not be used if the representative vehicle is a passenger vehicle, since it would artificially increase the sight distances being measured.

Object height

The height of the object varies significantly according to the sight distance criterion and country (For example, it ranges from 0 to 0.60 m for the stopping distance and from 1.0 to 1.3 m for the passing distance (Table SDS-1).

Manual measurements are generally conducted with an adjustable target rod that cleary indicates the height of each object height that may be considered. One could also use a number of target rods at different preset heights for each sight distance criterion to be measured. In the case of measurements with vehicles, the height levels should be easy to identify (use additional visual markers if necessary).

Table SDS-1 Height of eye and object

COUNTRY	HEIGHT OF EYE ABOVE ROADWAY SURFACE (m) PASSENGER VEHICLE[1]	HEIGHT OF OBJECT ABOVE ROADWAY SURFACE (m)		
		STOPPING SIGHT DISTANCE (DECISION SIGHT DISTANCE)	PASSING SIGHT DISTANCE (MEETING SIGHT DISTANCE)	INTERSECTION SIGHT DISTANCE
Australia	1.15	0.20	1.15	1.15
Austria	1.00	0.00-0.19	1.00	-
Canada	1.05	0.38	1.30	1.30
France	1.00	0.35	-	1.00
Germany	1.00	0.00-0.45	1.00	1.00
Great Britain	1.05	0.26	-	-
Greece	1.00	0.00-0.45	1.00	-
South Africa	1.05	0.15-0.60	1.30	1.30
Sweden	1.10	0.20	-	-
Switzerland	1.00	0.15	-	-
USA	1.07	0.15	1.30	1.30

Source: Harwood et al., 1995

Measurement procedures vary based on the sight distance criteria being considered and they also vary at intersections and on road sections. The following sections of this technical study describe how to make those measurements.

[1] For heavy vehicles, values range from 1.8 to 2.5 m, according to the country .

PROCEDURE: FIELD MEASURES

TYPE OF SITE: CONVENTIONAL INTERSECTIONS AND ROUNDABOUTS

SIGHT DISTANCE CRITERIA: STOPPING AND DECISION

1. One person stands with the target rod at the position of the rear of a vehicle stopped at the intersection (point 2). This person remains stationary.
2. Starting with the sighting rod from a position upstream from the intersection, a second person advances until he can see the target rod (point 1).
3. The **available sight distance** is then measured on the road by following the traffic lane (Figure SDS-2).
4. At a conventional intersection, the stopping sight distance should be measured on each approach. At a roundabout, it should be measured on each approach, in the ring lane and in the exit (Figure SDS-3). Pedestrian crossings at the exit of roundabouts must be clearly visible from vehicles approaching from the ring.

Figure SDS-2 Stopping or decision sight distance at an intersection

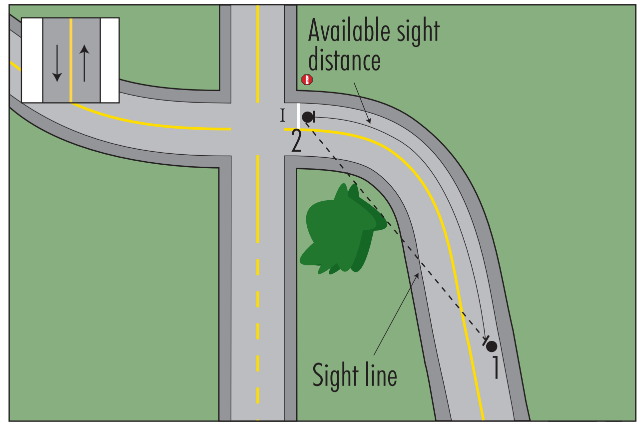
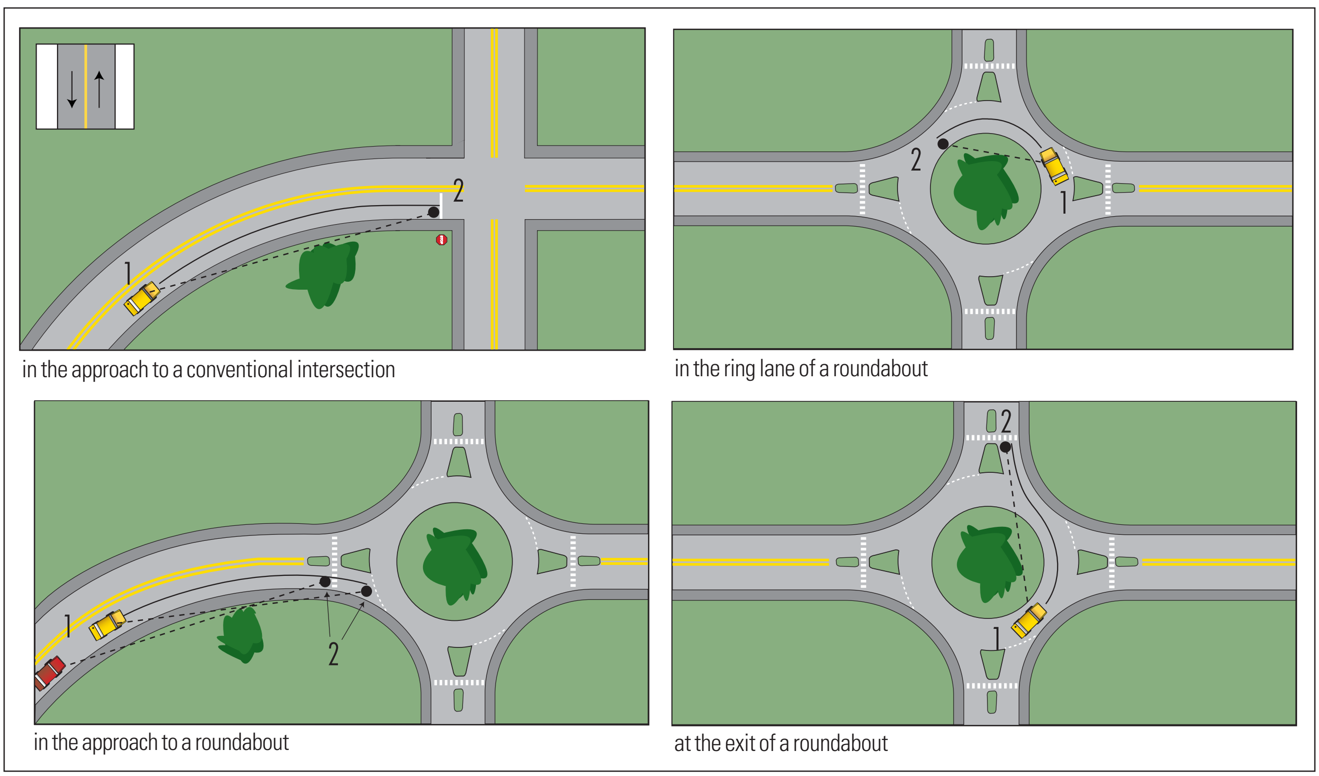


Figure SDS-3 Required stopping sight distances at intersections and roundabouts



Notes

- The method is similar when measuring with vehicles: one is used instead of a sighting rod, the other instead of a target rod.
- **The encroachment of the line of sight on the roadside should take into account temporary or seasonal sight obstructions (parked vehicles, crops, snow accumulations, etc.).**
- In the roundabout lane, the stopping sight distance is measured based on a circular path 2 m from the perimeter of the centre island.

PROCEDURE: FIELD MEASURES
TYPE OF SITE: CONVENTIONAL INTERSECTIONS (NON-PRIORITY MANOEUVRES)
SIGHT DISTANCE CRITERION: MANOEUVRING SIGHT DISTANCE

1. One person stands with the sighting rod at the position of a driver stopped at the intersection (point 1). This person remains stationary.
2. Starting with the target rod from a position in the adjacent approach upstream from the intersection, a second person advances until the person at point 1 can see the target rod. That spot is point 2.
3. The **available sight distance** is then measured on the road, by following the traffic lane (Figure SDS-4).
4. At a conventional intersection, the manoeuvring sight distances should be measured for all permitted non-priority manoeuvres (Figure SDS-5).

Figure SDS-4 Manoeuvring sight distance at an intersection

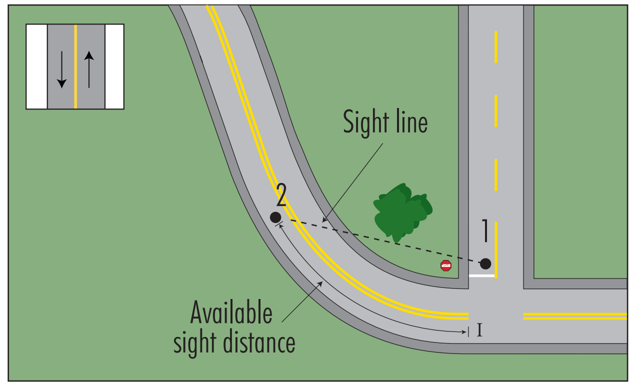
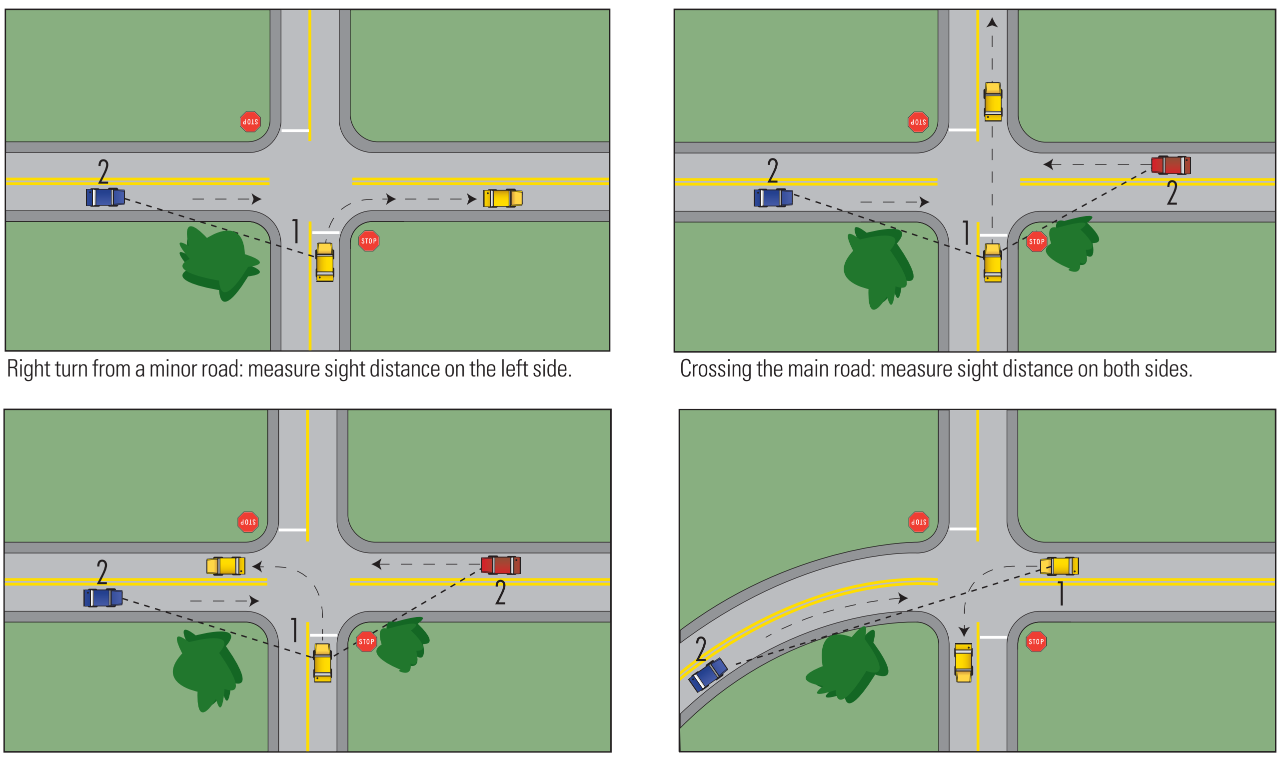


Figure SDS-5 Non-priority manoeuvres at intersection



Right turn from a minor road: measure sight distance on the left side.

Crossing the main road: measure sight distance on both sides.

Left turn from a minor road: measure sight distance on both sides.

Left turn from the major road: measure sight distance in oncoming direction.

Notes

- The method is similar for measurements with vehicles: one is used instead of a sighting rod, the other instead of a target rod.
- **The encroachment of the line of sight on the roadside should take into account temporary or seasonal sight obstructions (parked vehicles, crops, snow accumulations, etc.).**

PROCEDURE: FIELD MEASUREMENTS OF SIGHT DISTANCES
TYPE OF SITE: CONVENTIONAL INTERSECTIONS (UNCONTROLLED OR YIELD), ROUNDABOUTS
SIGHT DISTANCE CRITERION: SIGHT TRIANGLE

1. One person stands with the sighting rod at point 1. and remains stationary. The location of this point depends on the posted speed (the values used in the United States are shown in Tables SDS-2 and SDS-3).
2. Starting with a target rod from a position in the adjacent approach upstream from the intersection, a second person advances until the person at point 1 can see the target rod. This spot is point 2 or 3.
3. The distance D2 or D3 is then measured, as shown in Figure SDS-6.
4. At a conventional intersection (uncontrolled or with yield sign), the sight triangles should be measured in each approach in each direction from which a vehicle could come. At roundabouts, the pseudo-sight triangles should be measured in each approach; one should check the sight distance of vehicles approaching the roundabout in the adjacent upstream approach (D2), and the sight distance of vehicles in the circle itself (D3) (Figure SDS-7).

Figure SDS-6 Sight triangle at an intersection

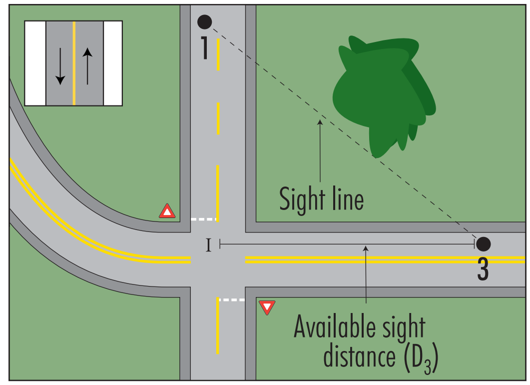
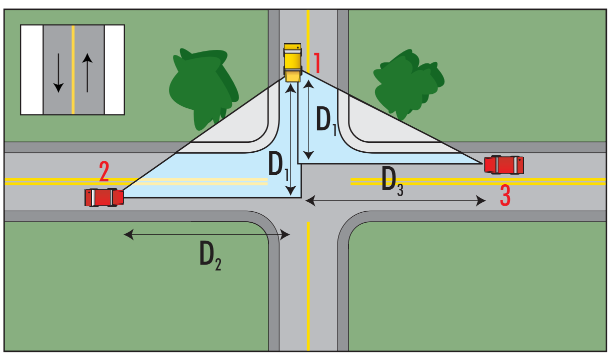
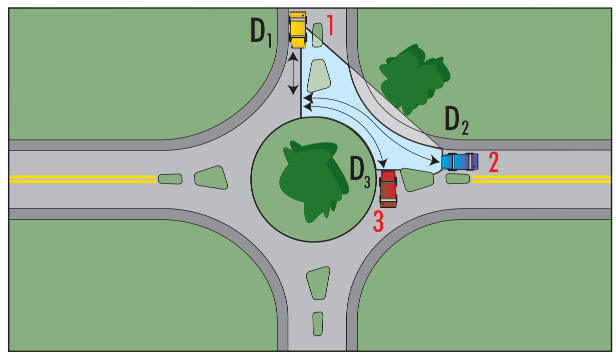


Figure SDS-7 Sight triangles



Conventional intersection:

Vehicle 1 should see the vehicles approaching the intersection in the adjacent approaches (vehicles 2 and 3) sufficiently in advance.



Roundabout:

Vehicle 1 should see the vehicles approaching the roundabout from the upstream adjacent approach (vehicle 2) and the vehicles travelling in the ring (vehicle 3) sufficiently in advance.

Table SDS-2 Sight triangles – Uncontrolled conventional intersections

DESIGN SPEED OF THE APPROACH (km/h)	DISTANCE D_1, D_2 OR D_3 (m)
30	25
50	45
70	65
90	90
100	105
120	135

Source: Association of State Highway and Transportation Officials, 2001

Table SDS-3 Sight triangles – Roundabouts

CONFLICTING APPROACH SPEED (km/h)	DISTANCE D_1 (m)	DISTANCES D_2 AND D_3 (m)
20	15	36
25	15	45
30	15	54
35	15	63
40	15	72

Source: Federal Highway Administration, 2000

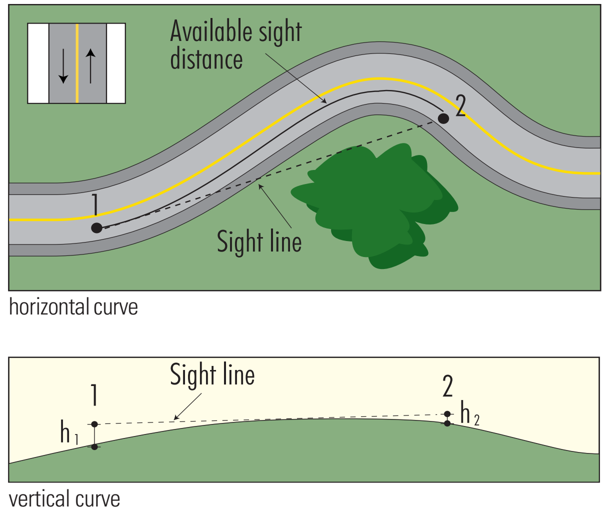
Notes

- The method is similar for measurements with vehicles: one is used as a sighting rod, the other as a target rod.
- **The encroachment of the line of sight on the roadside should take into account temporary or seasonal sight obstructions (parked vehicles, crops, snow accumulations, etc.).**

PROCEDURE : FIELD MEASUREMENTS
TYPE OF SITE: **CONVENTIONAL INTERSECTIONS (UNCONTROLLED OR YIELD), ROUNDABOUTS**
SIGHT CRITERIA: **STOPPING, PASSING, MEETING, DECISION**

1. Two people start at the beginning of the section under study.
2. The person with the sighting rod remains stationary (point 1). The other person moves slowly away with the target rod, until the person with the sighting rod can no longer see the target rod, this being point 2.
3. The **available sight distance** is then measured on the road, following the traffic lane (Figure SDS-8).
4. The person with the sighting rod (point 1) advances a predetermined distance (10 m, 20 m or 50 m, for example) and the same procedure is repeated until the section under study has been completely covered.

Figure SDS-8 Sight distance in horizontal and vertical curves



Notes

- The method is similar for measurements with vehicles: one is used instead of a sighting rod, the other instead of a target rod.
- **The encroachment of the line of sight on the roadside should take into account temporary or seasonal sight obstructions (parked vehicles, crops, snow accumulations, etc.).**
- Measurements should preferably be taken in positions reflecting reality[3] (e.g. for the passing sight distance, the sighting rod should be in the centre of the lane and the target rod in the oncoming lane).

PLAN MEASUREMENTS

Available sight distances may also be measured on detailed plans of the horizontal or vertical alignment of the road[2].

Sight distance measurements using plans are mainly taken at the road design stage in order to check if the proposed alignment meets the recommended sight distance requirements. This type of method may also be used to determine if proposed improvements will correct existing sight distance problems. As mentioned earlier, field measurements of sight distances are recommended on existing roads, since this ensures the detection of sight obstructions that may not appear on plans (e.g. roadside vegetation, new billboard or building, etc.).

Road design softwares now incorporate algorithms for calculating available sight distances of road projects.

Required materials:

- plans for the site under study;
  - plan view for sight distance measurements in horizontal curves;
  - profile view for sight distance measurements in vertical curves.
- ruler.

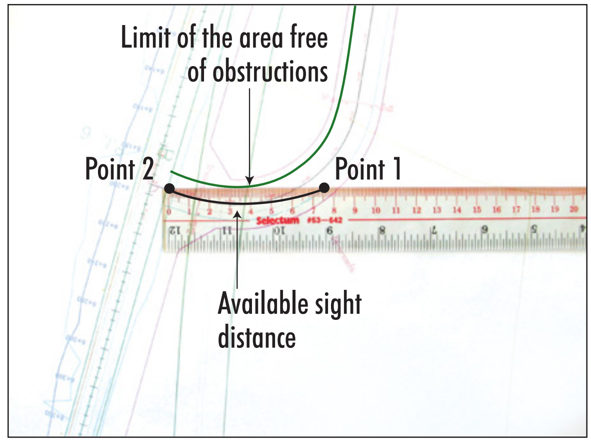
[2] The methods described in this technical study should not be used for combinations of horizontal and vertical curves since the results could be inaccurate.

[3] As always, proper care should be taken to ensure that observation methods do not jeopardize the safety of road users and observers.

PLAN MEASUREMENTS – HORIZONTAL CURVE

1. The locations of points 1 (sighting point) and 2 (target point) are similar to those described in the previous section and they vary according to the sight distance criterion being considered.
2. Place one end of the ruler on the sighting point (point 1).
3. Rotate the ruler around point 1 until it reaches the boundary of the area free of any roadside obstructions.
4. Move away from this point along the ruler until its side is at the location where the target would stand. This is point 2.
5. Measure the available sight distance by following the traffic lane (Figure SDS-9).

Figure SDS-9 Sight distance on a horizontal profile plan



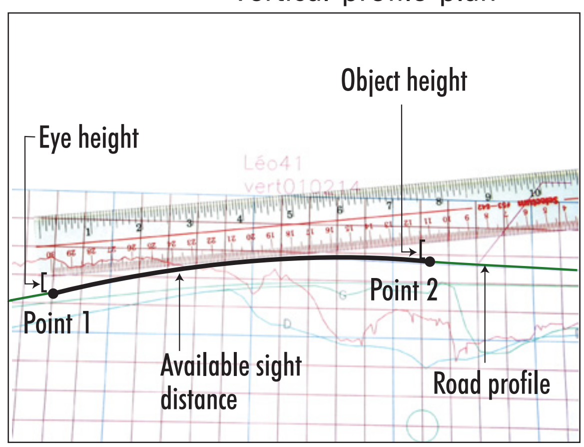
Notes

- **The encroachment of the line of sight on the roadside should take into account potential temporary or seasonal sight obstructions (parked vehicles, crops, snow accumulations, etc.).**
- Measurements should preferably be taken in positions reflecting reality (e.g. for the passing sight distance, the sighting rod should be in the centre of the lanes and the target rod in the oncoming lane).

PLAN MEASUREMENTS – VERTICAL CURVE

1. The locations of points 1 (sighting point) and 2 (target) are similar to those described in the field measurements section and they vary in accordance with the sight criterion being considered.
2. Place one end of the ruler on the sighting point (point 1), at a height representative of drivers' eye height (see ***Table SDS-1***).
3. Rotate the ruler around point 1 until its side reaches the road's profile line.
4. Move away from this point along the ruler until a target at the required height can no longer be seen (see ***Table SDS-1***), this being point 2.
5. Measure the available sight distance (Figure SDS-10).

Figure SDS-10 Sight distance on a vertical profile plan



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Harwood, D.W., Fambro, D.B., Fishburn, B., Joubert, H., Lamm, R. and Psarianos, B. (1995) *International sight distance design practices*, International symposium on highway geometric design practices, Transportation Research Board, Boston, Massachusetts.

Travel time and delay

Technical study

Patrick Barber and Carl Bélanger

TRAVEL TIME AND DELAY

Technical study

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INTRODUCTION

This engineering study describes how to measure the travel time between two points on a road and the stopped time delays at an intersection. Both measurements are aimed at determining if road users are facing excessive delays. In addition to impeding traffic flow, delays may have an adverse impact on road safety as they increase frustration, leading to hazardous behaviour: choice of unsafe traffic gaps, failure to stop at red lights, hazardous passing manoeuvres, etc.

Delays can be estimated from field observations or, more theoretically, with equations or simulation programs. This engineering study describes two simple field observation methods. For more comprehensive coverage of the subject, the reader should refer to traffic engineering manuals.

Definitions

The main indicators for quantifying lost time are travel time (or travel speed), running time (or running speed) and delays:

Travel time time required for a vehicle to make a run (road segment).

Travel speed distance travelled divided by the travel time.

Running time time during which a vehicle is in motion during a run (or moving faster than a pre-established minimum speed).

Running speed distance travelled divided by running time.

Delay time lost by a vehicle due to traffic problems. Several types of delays have been defined[1], including:

travel time delay: difference between the travel time measured in a survey and the travel time for a run made at average traffic speed, during uncongestionned conditions.

stopped time delay: time during which a vehicle is stopped in traffic.

WHEN SHOULD A DELAY STUDY BE CONDUCTED

A delay study may be justified during a safety diagnosis for the following motives:

- field observations have uncovered delay problems ***(site observation checklists)***;
- the ***accident analysis*** has highlighted safety problems that can be related to delays ***(accident tables)***;
- users have complained of excessive delays;
- remedial actions have recently been taken to reduce delays and their effectiveness needs be verified (a delay study should be conducted before and after intervention).

[1] Other definitions of delays are described in the section ***Intersection delays***

Observation Period

Observations should be made when delays are expected to the longest. This is generally during the morning or evening rush hours, although it may sometimes be at other times: at the end of a major sports or cultural event, the closing of a shopping mall, etc.

If the accident analysis reveals a time-related pattern that may result from excessive delays, the study should be conducted when the problems are most likely to be observed.

HOW SHOULD A DELAY STUDY BE CONDUCTED

Several methods have been developed for conducting field measurements of delays experienced by road users. This section describes two simple methods, one for road segments, the other for intersections. The results obtained will vary according to the type of site under study (Table TD-1).

Table TD-1 Delay measurement methods described in this study

COMPONENT	METHOD	RESULTS
Segment	Test vehicle (floating vehicle or average vehicle)	travel time running time travel speed running speed delays (location, duration, cause)
Intersection	Manual	total delay average delay per vehicle average delay per stopped vehicle percentage of stopped vehicles

ROAD SEGMENT – TEST VEHICLE

Description

This method can be used to measure the travel time and travel speed, the running time and running speed, and delays (location, duration, cause). Two variants are described, the *floating vehicle* and *average vehicle*.

Floating vehicle

The test car driver is asked to “float” in traffic, i.e. to try and pass as many vehicles as pass the test car so that its travel time is representative of the average user’s travel time (while complying with traffic rules and avoiding any hazardous manoeuvres).

Average vehicle

The test car driver is asked to travel at a speed which seems to him representative of the average traffic speed, without the previous passing requirement.

Equipment

1 vehicle
2 observers
2 stopwatches
data capture forms

Number of runs

To achieve an acceptable level of statistical reliability, several runs over the segment under study should be conducted in both travel directions. The exact number of runs depends on the average range in running speed (R), as measured at the site, and the speed estimation error deemed acceptable (Table TD-2).

The value of R is calculated by initially making a few runs over the segment under study, following the ***procedure*** described below (two to four runs). The difference in running speed between each consecutive run pairs made in the same direction is then calculated (e.g. the difference between the first and the second run, between the second and the third run, etc.). The value of R is equal to the average of these differences.

For example, if the value of R is 20 km/h and the tolerated error is 5 km/h, at least six runs are required (at a confidence level of 95%). Assuming that three runs were made to determine the value of R, three additional runs are required.

The same procedure should be followed in both travel directions.

Table TD-2 Minimum number of runs required[a]

AVERAGE RANGE IN RUNNING SPEED R (km/h)	MINIMUM NUMBER OF RUNS FOR PERMITTED ERRORS (km/h)				
	2	3.5	5	6.5	8
5	4	3	2	2	2
10	8	4	3	3	2
15	14	7	5	3	3
20	21	9	6	5	4
25	28	13	8	6	5
30	38	16	10	7	6

[a] confidence level of 95%

Source: Institute of transportation engineers, 2000

Procedure

Observers should determine in advance the exact boundaries of the segment under study and choose a number of control points in the segment, generally at intersections or major accesses. The identifier of each control point should be entered on the ***travel time study form*** before the runs start.

The test car driver should start his run upstream from the segment under study so as to reach the average traffic speed before the run's starting point. He should then make the run following the selected driving strategy (floating vehicle or average vehicle).

The second observer starts one stopwatch at the segment's starting point. This stopwatch is used to mark the elapsed time at each control point and at the end point. This same person uses the second stopwatch to measure the delays occurring when the vehicle has to stop or travel at a very low speed (5 km/h or less). The location and causes of these delays are noted (the use of pre-established delay codes accelerates this data collection).

This data may be collected on paper forms similar to that in ***Figure TD-1***. A variety of equipment and software may also be used to facilitate data collection and processing (laptop computer or specialized equipment for this type of survey).

Figure TD-1 Example – Travel time and delay study

Segment – Travel time and delay study

Municipality: *Quebec City* Date: *2002/02/10*

Route: *no. 175* Time from: *8:00* to: *8:15*

Direction: *North* Trip No: *1*

Observer: *S.Langlois* Weather: *sunny*

Starting point: *intersection of route 224* End point: *intersection of route 256*

Comments:

CONTROL POINTS			STOPS OR SLOWS		
No	LOCATION	TIME	LOCATION	DELAY (s)	CAUSE
1	start	00:00	access to Esso	5	LT
2	Durand	01:24	Bertrand	22	TS
3	Bertrand	02:55	store	7	LT
			Shell	3	LT
4	Dutil	04:21			
5	Georges	05:23			
6	Labbé	06:42	Fauteux	49	TS
7	Dufresne	08:57			
8	end	10:07			

Delay cause

TS = traffic signal SS = stop sign LT = left turn P = parking cars

PED = pedestrian I = incident B = bus stopping C = congestion

Trip length: *6.45 km* Trip time: *10 min 07 s*

Total stopped time: *86 s* Running time: *8 min 41 s*

Calculations

Travel times and travel speeds, running times and running speeds, and delays are calculated using the average results obtained in the different runs:

$$\bar{T} = \frac{\sum T_i}{N}$$

where:
$\bar{T}$ = travel time (s)
T_i = travel time for run i (s)
N = number of runs made

$$\bar{Tr} = \frac{\sum Tr_i}{N}$$

$$Tr_i = T_i - Ts_i$$

where:
$\bar{Tr}$ = running time
Tr_i = running time as measured in run i (s);
$Tr_i = Ti - Ts_i$
with Ts_i = sum of stopped times during run i (s)

$$\bar{V} = \frac{3600\ NL}{\sum T_i}$$

where:
$\bar{V}$ = travel speed (km/h)
L = length of segment under study (km)

$$\bar{S} = \frac{3600\ NL}{\sum Tr_i}$$

where:
S = running speed (km/h)

$$\bar{D} = \frac{\sum D_i}{N}$$

where:
$\bar{D}$ = delay (s) at a point in the segment
D_i = delay as measured at a point in the segment during run i (s)

INTERSECTION – MANUAL METHOD

Description

This method may be used to calculate user delays at an intersection: total delay, average delay per vehicle, average delay per stopped vehicle and percentage of stopped vehicles.

One of the main problems with this type of study consists in determining when a vehicle is stopped. If wheels are locked, the situation is clear, but this is less so when vehicles are in the process of stopping and a standard treatment is required. The Institute of transportation engineers (2000) recommends considering vehicles travelling at a speed slower than a slow walk (about 5 km/h) as stopped.

Equipment

Typically, an intersection delay study requires two observers, each equipped with a stopwatch and data capture forms: one person counts the number of stopped vehicles while the other counts the number of vehicles travelling in the approach ***(procedure)***.

Once again, a variety of equipment and software may be used to facilitate data collection and processing (laptop computer or specialized equipment).

Number of observations

The minimum number of observations may be determined with the following equation:

$$N = \frac{(1 - p)\chi^2}{pd^2}$$

where:

N = number of observations (vehicles)

p = proportion of vehicles having to stop in the approach to the intersection (%/100)

χ^2 = value of chi-square at desired confidence level (table TD-3)

d = maximum error permitted (%/100)

Table TD-3 χ^2 values

CONFIDENCE LEVEL	χ^2 VALUE
90.0	2.71
95.0	3.84
97.5	5.02
99.0	6.63
99.5	7.88

The value of p (percentage of vehicles having to stop at the intersection) may be estimated during the study or be based on previous studies conducted under similar conditions.

Procedure

An intersection delay study is generally conducted on an approach-by-approach basis. Observers are posted alongside the intersection at a location where they do not obstruct traffic but where they have a clear view of all vehicles that may be stopped in the approach.

One observer counts the number of stopped vehicles in the approach at regular intervals (from 10 s, 15 s or 20 s) . It is assumed that the vehicles remain stopped throughout the entire interval. The total approach delay is then calculated by multiplying the total number of stopped vehicles counted during the study by the selected sampling interval.

In order to calculate the average delay per vehicle – which is the most useful information obtained in a delay study – the number of vehicles travelling through the intersection also has to be counted. This is done by a second observer or with automatic counting equipment ***(traffic count)***. Whatever method is used, there should not be any significant difference between the number of vehicles approaching and leaving the intersection during the observation period. This is to ensure that the calculated delay per vehicle accurately reflects reality. A common problem is related to the formation or elimination of a queue of vehicles during the observation period (the number of vehicles queued at the intersection approach must be equivalent at the beginning and end of study).

A computation of the percentage of vehicles having to stop at the intersection may also be useful, since it is an indicator of traffic flow efficiency (to obtain this information, observers need to count the total number of vehicles having to stop at the intersection). This figure can also be used to calculate the average delay per stopped vehicle. An example is shown in Figure TD-2.

Finally, it may also be useful to estimate the delays associated with specific manoeuvres, such as a specific turning manoeuvre, which requires counting the delays and traffic flows for this specific movement.

The number of observers depends on the required delay and traffic flow measurements, the geometric configuration of the site, the need to collect traffic flow data, and the equipment used.

A simple stopwatch that can be programmed to emit a sound signal at each selected time-interval facilitates data capture. Once again, a variety of electronic equipment is now available to facilitate data capture and processing.

Forms similar to that shown in Figure TD-2 may be used to summarize the information collected during a delay study. As previously mentioned, one observer counts the number of stopped vehicles at each selected interval while the second observer counts the number of vehicles traveling in the approach and the number of vehicles having to stop. A blank form is included in ***Appendix TD-1***.

Figure TD-2 Example - Delay study at intersection

Intersection - Delay study

Municipality: *Quebec city* Date: *2002/02/10*

Intersection: *route 256 and route 224*

Approach: *North* Time from: *8:00* to: *8:15*

Observer: *S.Langlois* Weather: *Sunny*

Comments:

HOUR:MINUTE STARTING AT	TOTAL NUMBER OF VEHICLES STOPPED IN THE APPROACH AT TIME						APPROACH VOLUME	
	+0 sec	+20 sec	+40 sec				NUMBER STOPPED	NUMBER NOT-STOPPED
08:00	0	0	2				8	10
08:01	2	0	4				10	9
08:02	3	4	6				12	15
08:03	4	8	7				10	8
08:04	0	2	4				5	11
08:05	8	5	7				15	12
08:06	1	3	5				10	17
08:07	6	2	0				9	8
08:08	4	5	1				11	13
08:09	0	2	7				8	16
08:10	8	3	0				10	10
08:11	5	2	6				10	15
08:12	0	5	7				12	8
08:13	5	1	3				10	15
08:14	0	2	0				5	7
SUBTOTAL	46	44	59				145 (B)	174
TOTAL						(A) 149		319 (C)

$$\text{Total delay} = (A) \times \text{sampling interval} = 149 \times 20\text{ sec} = 2{,}980 \ (D) \text{ veh-sec.}$$

$$\text{Average delay per vehicle} = \frac{(D)}{(C)} = \frac{2{,}980}{319} = 9.34 \text{ seconds/veh.}$$

$$\text{Average delay per stopped vehicle} = \frac{(D)}{(B)} = \frac{2{,}980}{145} = 20.55 \text{ seconds/veh.}$$

$$\text{Percentage of stopped vehicles} = \frac{(B)}{(C)} = \frac{145}{319} = 45 \ \%$$

Average delays for the entire intersection are obtained by combining the delays on each approach.

PRESENTATION OF RESULTS

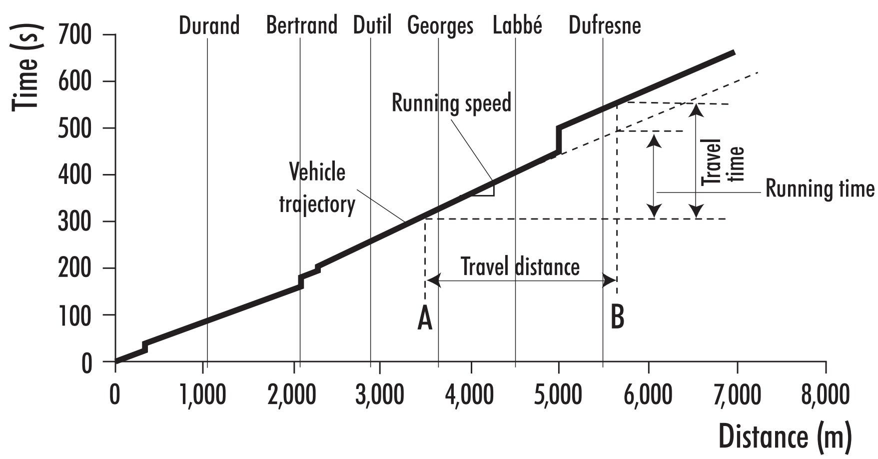
The type of presentation depends on the scope and detail of the study.

For a typical intersection delay study, the completed forms in ***Figure TD-2*** are generally adequate. For travel time and delay studies on road segments, however, summary tables or graphs make it easier to identify the problem areas. The values of interest are the average speed per road segment and stopped time delays. Examples of summaries are shown below.

Table TD-4 Average travel speed and stopped delay

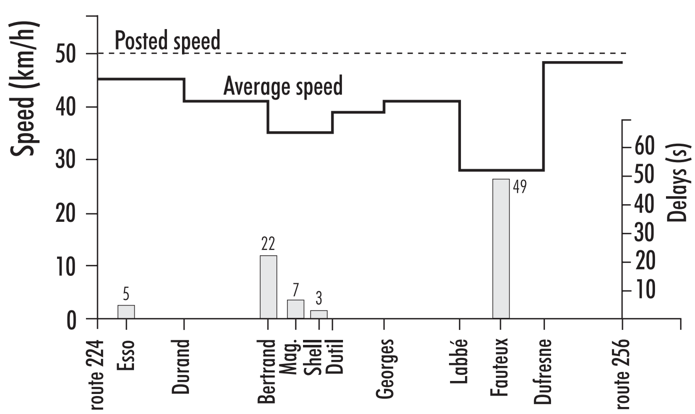
SEGMENT	LENGTH (m)	TIME (s)	POSTED SPEED (km/h)	TRAVEL SPEED (km/h)	DELAY (s)	RUNNING SPEED (km/h)
route 224-Durand	1,050	84	50	45	5	48
Durand-Bertrand	1,030	91	50	41	22	54
Bertrand-Dutil	840	86	50	35	10	40
Dutil-Georges	670	62	50	39	0	39
Georges-Labbé	880	79	50	40	0	40
Labbé-Dufresne	1,050	135	50	28	49	44
Dufresne-route 256	930	70	50	48	0	48

Figure TD-3 Travel time measurements



Example of graphical determination of the travel time and running time between A and B.

Figure TD-4 Graphic summary of a delay and travel time study



REFERENCE

Institute of Transportation Engineers (2000) *Manual of transportation engineering studies*, pp. 52-68, Institute of Transportation Engineers, Washington, DC.

Appendix TD-1

Blank forms

Segment – Travel time and delay study

Municipality:	Date:
Route:	Time from: to:
Direction:	Trip No:
Observer:	Weather:
Starting point:	End point:
Comments:	

CONTROL POINTS				STOPS OR SLOWS		
No	LOCATION	TIME		LOCATION	DELAY (s)	CAUSE
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						

Delay cause

TS = traffic signal SS = stop sign LT = left turn P = parking cars

PED = pedestrian I = incident B = bus stopping C = congestion

Trip length: __________ Trip time: __________

Total stopped time: __________ Running time: __________

Intersection - Delay study

Municipality: Date:

Intersection:

Approach: Time from: to:

Observer: Weather:

Comments:

HOUR:MINUTE STARTING AT	TOTAL NUMBER OF VEHICLES STOPPED IN THE APPROACH AT TIME						APPROACH VOLUME	
							NUMBER STOPPED	NUMBER NOT STOPPED
SUBTOTAL							B	
TOTAL	A							

C

Total delay = A × sampling interval = × = D veh-sec.

Average delay per vehicle $= \frac{D}{C} = \quad = \quad$ seconds/veh.

Average delay per stopped vehicle $= \frac{D}{B} = \quad = \quad$ seconds/veh.

Percentage of stopped vehicles $= \frac{B}{C} = \quad = \quad$ %

TRAFFIC CONFLICTS

Technical study

Carl Bélanger and Patrick Barber

TRAFFIC CONFLICTS

Technical study

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INTRODUCTION

In most road safety studies, analysts use the information contained on accident reports to identify and understand failures of the road system and then propose appropriate corrective actions.

While these analyses are essential, it is well recognized that accident data suffer from a number of shortcomings and need to be complemented by field observations in order to improve the accuracy of safety diagnoses. This has been discussed in detail in Chapter 5 ***(identification)*** and Chapter 6 ***(diagnosis)***.

Over the years, different tools have been proposed to assist safety analysts in making these field observations and formalized techniques have been developed (e.g. traffic conflict techniques, positive guidance and, more recently, road safety audits).

In a traffic conflict study, trained observers watch the traffic and note the frequency and types of conflicts that occur at a specific location. Traffic conflict studies are primarily conducted at urban intersections, where these events are more frequent. Since conflict studies imply direct observations of road users' behaviour, they help in identifying manoeuvres that are particularly hazardous and in finding improvements that could alleviate these problems (these can be related to the road component of the ***safety system*** or to other components).

It should be noted that the introduction of traffic conflict techniques initiated a long-standing debate concerning their validity as an accident estimator. A clear answer to this question has yet to be found but research has shed some interesting light on the topic ***(Are traffic conflicts good estimators of road accidents?)***.

Definition

The traffic conflict technique (TCT) was originally developed by researchers from the General Motors Laboratories who wanted to investigate whether GM cars were driven differently than others (Perkins and Harris, 1968). Since then, several variants of the original TCT have been proposed. Almost all traffic conflict techniques take into consideration the need, for at least one road user, to take evasive action in order to avoid a collision (braking, swerving, accelerating or a combination of these manoeuvres). Several measurements have also been proposed to characterize traffic conflicts. They include: time to collision (TTC), deceleration rate (DR), encroachment time (ET), post-encroachment time (PET), etc. (Gettman et Head, 2003). These measurements can be used to determine the severity of a traffic conflict objectively. An example is described below ***(conflict severity)***.

A well-accepted definition of traffic conflict is:

> *"An observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged."*
>
> Amundson and Hyden, 1977

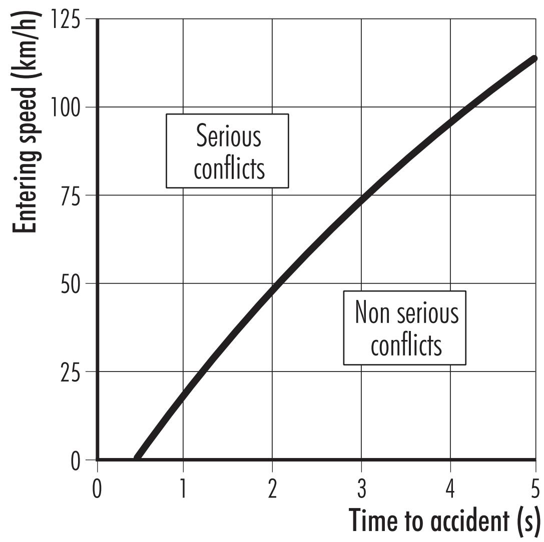
Conflict severity

Most traffic conflict techniques (TCTs) categorize conflicts based on their severity (e.g. serious or non serious).

Some TCTs use subjective criteria to determine conflict severity; for example, the American manual developed by Parker and Zegeer (1989) identifies serious conflicts based on an array of observations that include vehicle front-end-diving when braking, squealing brakes, etc.

Other TCTs determine conflict severity by using more objective criteria (that may, however, be more difficult to measure); for example, the Swedish traffic conflict technique combines the TTC[1] and the vehicle speed to distinguish serious and non-serious conflicts (Figure TC-1).

Figure TC-1 Serious and non-serious conflicts



Source: *(http://www.tft.lth.se/rapporter/Conflict1.pdf)*

Are traffic conflicts good estimators of road accidents?

This is a question that has been debated since the introduction of traffic conflict techniques (TCT). While everybody agrees that a higher conflict rate is an indicator of a lower level of safety, it is much more difficult to determine, without ambiguity and controversy, whether traffic conflicts are good estimators of accidents or not.

However, one should not be surprised to find low correlations between the total number of accidents and the total number of conflicts observed during a traffic conflict study. After all, these datasets are generally quite different in terms of events and periods considered. To make these datasets more comparable, the group of accidents should exclude all events that are not pertinent to conflict observation conditions. This includes:

- accidents involving only one vehicle (keeping in mind that a small proportion of these accidents may result from conflicts between two vehicles);
- accidents involving other accident types that have not been observed during the conflict study;
- accidents that have occurred during periods when conflicts were not observed (traffic conflict studies are generally conducted during the daytime on weekdays under dry conditions).

In a landmark study aimed at verifying the correlation between accidents and conflicts, Migletz, Glauz, and Bauer (1985) completed this matching exercise. In so doing, they had to reduce the total number of accidents that had been reported to the analyzed intersections, from 1,292 to 319. Their conclusion remains probably the most accurate answer to this question:

"Overall, traffic conflicts of certain types are good surrogates of accidents in that they produce estimates of average accident rates nearly as accurate, and just as precise, as those produced from historical accident data. Therefore, if there are insufficient accident data to produce an estimate, a conflict study should be very helpful."

Migletz, Glauz and Bauer, 1985

[1] The time to collision (TTC) is the time before two road users collide if they remain at their same speed and on the same path; it is derived from estimates of speeds and distance between two road users when the evasive action begins.

Types of traffic conflicts

- As in the case of accident analyses, it is quite useful to subdivide traffic conflicts into different categories, based on their type. This allows the preparation of summary tables, graphs and diagrams that facilitate the interpretation of results (comparisons with sites having similar characteristics and detection of deviant types of traffic conflicts).
- Glauz and Migletz (1980) defined 12 types of conflicts between two vehicles and 4 types of secondary conflicts involving 3 road users (Figure TC-2)[2]. However, some of these conflicts have very low rates of occurrences, which reduces their usefulness *(Table TC-1)*.
- The number of conflict types rises quickly when those that may occur between motorized and non-motorized road users are added to the list (pedestrians, cyclists, others).
- The list of conflict types that may be observed at a site depends upon its prevailing traffic rules and geometric characteristics; this list should be determined prior to initiating the study.
- It is not necessary to observe all traffic conflicts that may occur at a site in all conflict studies. If, for example, the objective is to compare the performance of two left-turn treatments at intersections, it might very well be sufficient to collect conflicts that are related to this manoeuvre.

WHEN TO CONDUCT A TRAFFIC CONFLICT STUDY

A traffic conflict study can be used:

- to make progress in a safety diagnosis. Traffic conflict studies are particularly useful when accident data suffer from strong limitations (accident reports may be unavailable, the information may be insufficient or unreliable);
- to evaluate the effectiveness of a safety treatment. The main advantage of conflict studies over accident studies is that it is not necessary to wait several years before gathering sufficient data to complete the evaluation. A conflict study can be conducted soon after work has been completed and negative can be made quickly if anticipated benefits have not been achieved (or if unexpected side effects have been created). In these studies, traffic conflicts need to be observed before and after the implementation of the treatment;
- to compare the safety performance of different road features or traffic rules (e.g. compare safety at signalized intersections with and without an exclusive left-turn phase).

[2] The concept of secondary conflict is used to describe those situations where the evasive action of a second driver places a third one in danger of a collision. Some examples are shown in Figure TC-2.

Figure TC-2 Traffic conflict types at intersections[1]

[1] Right-hand-side driving

Source: Glauz and Migletz, 1980

HOW TO CONDUCT A TRAFFIC CONFLICT STUDY

A number of elements need to be considered in the planning of a traffic conflict study:

- ***personnel training***
- ***observation technique***
- ***observation period***
- ***observation details***

Personnel training

The validity and usefulness of a traffic conflict study are greatly influenced by the degree of consistency of observers. Two basic requirements must be satisfied:

- the same observer must record conflicts consistently;
- different observers must record the same conflicts consistently.

Traffic conflict training procedures and guidelines have been developed in several countries, which include Great Britain, Sweden, the USA, Germany and France (Muhlrad, 1993).

Observers' training period varies from one to two weeks but ideally, it should be based on the time it takes to attain consistency of observations. This can be determined by comparing counts of traffic conflicts made by experienced and inexperienced observers at the same location or by comparing corresponding video recordings and manually recorded conflicts. Very high consistency levels should be attained (Hyden, 1987; Parker and Zegeer, 1988).

Observation technique

Personnel

The required number of observers (or the study duration when observations are made sequentially) depends on the number of conflict types to be observed, the average rate of occurrence for each conflict type, the traffic volumes, the number of intersection legs and the need for a traffic count[3].

Average conflict rates may vary significantly, depending on the TCT used. For example, averages of 3 conflicts per hour are considered to be high for the Swedish TCT (Almquist and Hyden, 1994) while average rates of up to 90 conflicts/hour have been obtained by Migletz et al., 1985, with the American TCT.

When all traffic conflict types need to be collected at a busy intersection, one observer will generally be able to watch only one intersection leg at a time.

Equipment

The equipment needed to conduct a traffic conflict study is fairly simple:

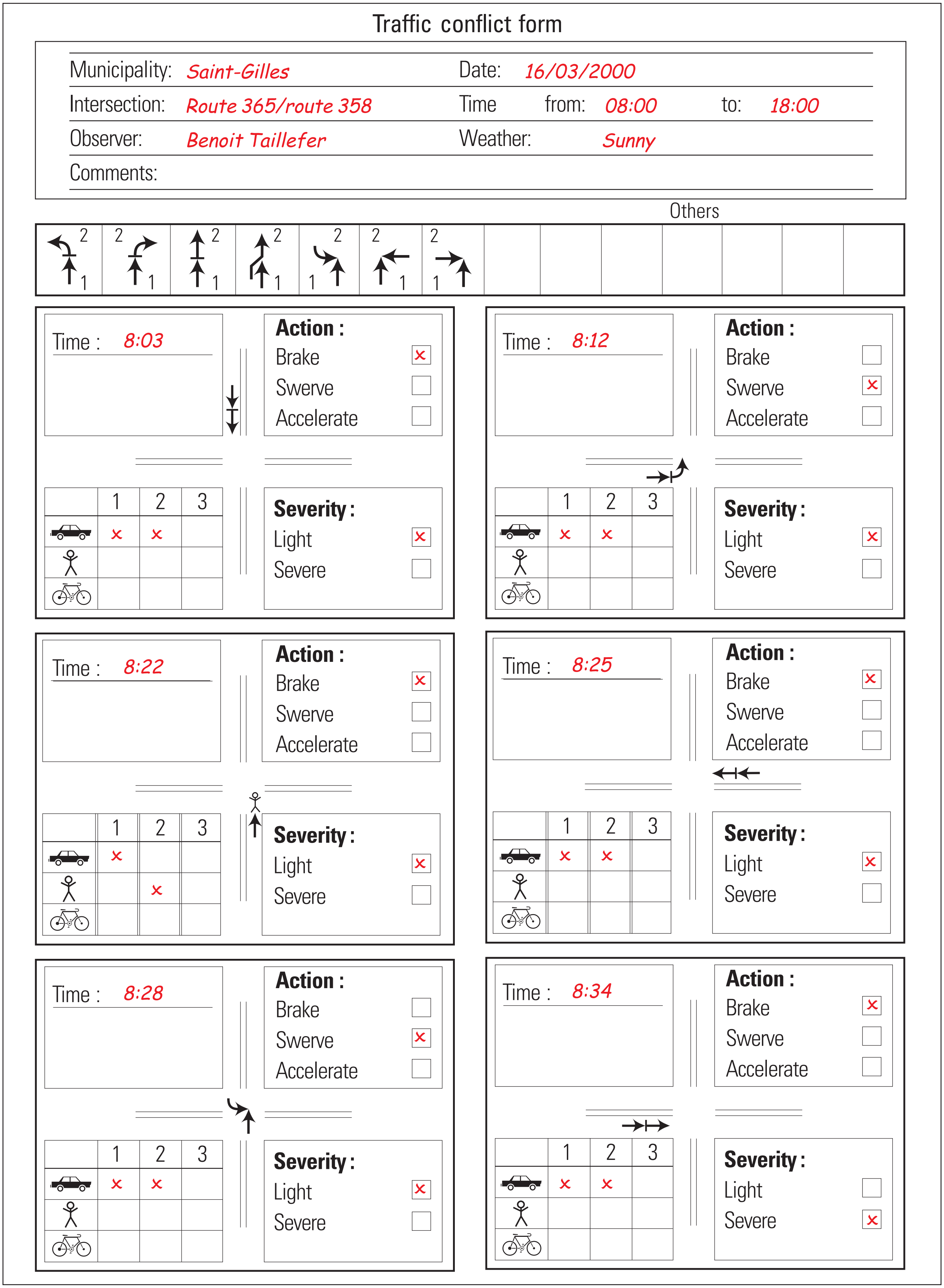
- traffic conflict forms (see Figure TC-3 and ***Appendix TC-1*** for blank form);
- watch and stopwatch.

<u>Optional:</u>

- mechanical or electronic counting devices (to facilitate data collection);
- video camera, recording media and batteries (the recording of traffic conditions while conducting a conflict study is useful in later validating questionable conflicts or completing observations).

[3] A traffic count is required when rates of traffic conflicts per vehicle are to be estimated or when the study's objective is to evaluate the effect of a measure that has an influence on traffic conditions (a traffic count study needs to be conducted before and after the treatment).

Figure TC-3 Example – Traffic conflict study form



Traffic conflict form

Municipality:	Saint-Gilles	Date:	16/03/2000
Intersection:	Route 365/route 358	Time from: 08:00	to: 18:00
Observer:	Benoit Taillefer	Weather:	Sunny
Comments:			

Others

Conflict 1

Time : 8:03

Action : Brake [x] · Swerve [ ] · Accelerate [ ]

	1	2	3
Car	x	x	
Pedestrian			
Bicycle			

Severity : Light [x] · Severe [ ]

Conflict 2

Time : 8:12

Action : Brake [ ] · Swerve [x] · Accelerate [ ]

	1	2	3
Car	x	x	
Pedestrian			
Bicycle			

Severity : Light [x] · Severe [ ]

Conflict 3

Time : 8:22

Action : Brake [x] · Swerve [ ] · Accelerate [ ]

	1	2	3
Car	x		
Pedestrian		x	
Bicycle			

Severity : Light [x] · Severe [ ]

Conflict 4

Time : 8:25

Action : Brake [x] · Swerve [ ] · Accelerate [ ]

	1	2	3
Car	x	x	
Pedestrian			
Bicycle			

Severity : Light [x] · Severe [ ]

Conflict 5

Time : 8:28

Action : Brake [ ] · Swerve [x] · Accelerate [ ]

	1	2	3
Car	x	x	
Pedestrian			
Bicycle			

Severity : Light [x] · Severe [ ]

Conflict 6

Time : 8:34

Action : Brake [x] · Swerve [ ] · Accelerate [ ]

	1	2	3
Car	x	x	
Pedestrian			
Bicycle			

Severity : Light [ ] · Severe [x]

Observers' location

- Observations are generally made upstream from the location of the traffic conflicts of interest, in order to see vehicles' braking lights. Observers' exact location is influenced by the space availability, the presence of visibility obstructions, the types of conflicts to be observed and the traffic speed. A distance of 30 m or more from the point of interest is usually adequate in urban areas (100m or more in rural areas).
- Observers should try to be inconspicuous to drivers to avoid modifying their behaviour. Appropriate locations include legal parking spaces, sitting behind a utility pole or a tree, etc. When allowed by the site configuration, observations should be made from an elevated point (e.g. the roof of a building) to avoid some visual obstructions (group of pedestrians, parked vehicles, etc.).
- When the observation period extends over several days, observers should try to maintain the same position throughout the study.
- When similar conflict studies need to be conducted at different sites, observers should try to use equivalent positions.

Observation period

- In most cases, traffic conflict studies are conducted in daylight under dry weather conditions;
- observations should not be made under unusual conditions, such as road works or special events that interfere with normal traffic patterns, unless justified by the need of the analysis.
- If accident analyses reveal a time-related pattern, observations should be planned when problems are the most likely to be observed (rush-hour periods, weekends, etc.).
- The observation period may vary from a few hours to several days, depending on the time needed to collect sufficient data. Typical observation periods range between two and five days. Statistical methods have been developed to determine a study duration that will ensure a selected level of statistical reliability (Institute of Transportation Engineers, 2000).
- In order to help observers maintain a high level of concentration, a conflict study must be planned around sequences of observation periods and breaks. Parker and Zegeer (1988) recommend 20 or 25 minutes observation periods followed by breaks of 10 or 5 minutes (using constant 30 minute periods simplifies the management of the study); others prefer longer observations and breaks periods (e.g. Almquist and Hyden, 1994; Sayed and Zein, 1998).

Observation details

Before initiating the analysis, the observer must complete all the information on the traffic form heading to ensure that the location and observation conditions will be readily recognized in the future: municipality, intersection, approach, date, time, weather conditions, other comments.

Forms that have been developed to collect traffic conflict data vary significantly. For example, the Swedish technique uses a separate sheet for each traffic conflict and records detailed information on each of these events while American forms record several conflicts on the same sheet. A model of traffic conflict form is suggested in Figure TC-3 and in ***Appendix TC-1***.

For each observed conflict, the following information can be recorded on the form:

- time of occurrence;
- manoeuvres involved (and their location);
- types and numbers of vehicles involved (TTC or equivalent);
- estimate of severity;
- primary or secondary conflict;
- other comments.

PRESENTATION OF RESULTS

Once observations have been completed, data must be reduced and summaries prepared. Results are presented either in summary tables or in traffic conflict diagrams (Table TC-1 and Figure TC-4).

Summary tables allow comparisons of conflict rates between the site being analyzed and sites with similar characteristics, which is useful in detecting deviant patterns. The logic behind these analyses is similar to that of the ***accident pattern analysis*** described in Chapter 5.

Traffic conflict diagrams are quite similar to the ***collision diagrams*** described in Chapter 6. They facilitate the identification of repetitive conflict patterns that are concentrated in some travel directions and intersection areas.

Table TC-1 Daily conflict rates for signalized high-volume intersection

CONFLICT				PERCENTILE[1]	
NO.	TYPE	MEAN	VARIANCE	90th	95th
1	Left-turn, same direction	83.6	11,613.7	265.0	360.0
2	Slow vehicle	669.1	23,994.7	870.0	940.0
3	Lane change	18.2	160.6	35.0	43.0
4	Right-turn, same direction	218.6	7,587.5	470.0	510.0
5	Opposing left turn	22.0	377.7	48.0	60.0
6	Left-turn from left	0.6	0.8	1.7	2.5
7	Cross traffic from left	0.1	0.1	–	–
8	Right turn from left	0.1	0.0	–	–
9	Left turn from right	0.4	0.3	1.1	1.4
10	Cross traffic from right	0.3	0.2	–	–
11	Right turn from right	2.6	2.3	4.6	5.4
12	Opposing right turn on red	0.2	0.1	–	–
1-4	All same direction	989.5	67,198.4	1,340.0	1,460.0
7+10	Through cross traffic	0.4	0.3	1.1	1.5

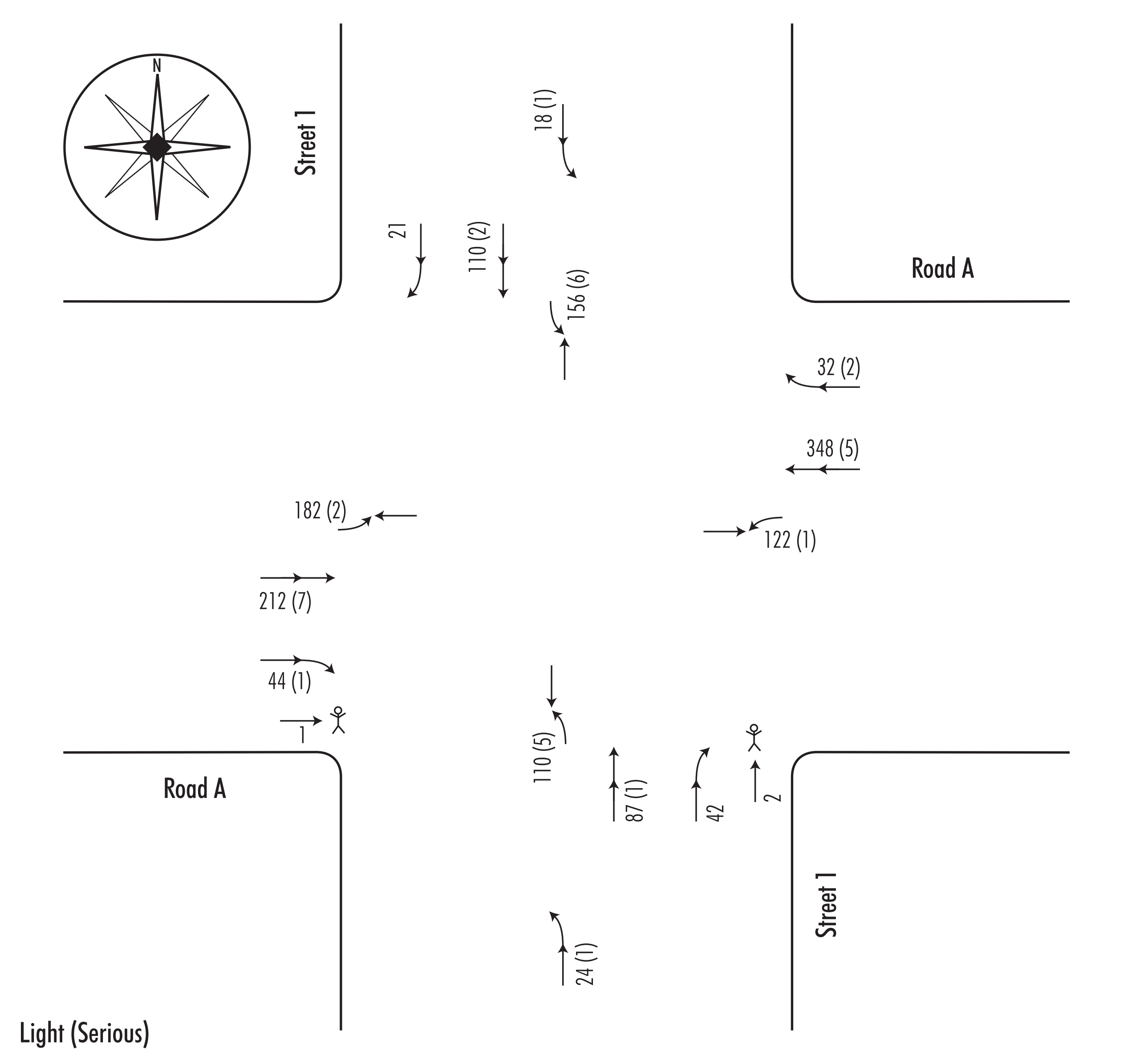
[1] For the rarest types of conflicts, no values are given; any observed conflicts should be viewed with suspicion. Otherwise, values given suggest limits, at two levels, for normally expected conflict rates.

Source: Glauz et al., 1985

Figure TC-4 Example – Traffic conflict diagram

Traffic conflict diagram

Municipality:	Saint-Gilles	Date:	16/03/2000		
Intersection:	Route 365/route 358	Time from:	08:00	to:	18:00
Observer:	Benoit Taillefer	Weather:	Sunny		
Comments:					



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APPENDIX TC-1

Blank forms

Traffic conflict form

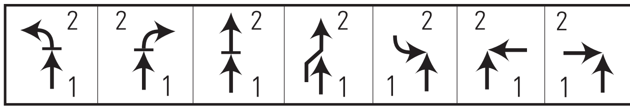
Municipality: Date:

Intersection: Time from: to:

Observer: Weather:

Comments:

Others



Time :

Action :
Brake ☐
Swerve ☐
Accelerate ☐

	1	2	3

Severity :
Light ☐
Severe ☐

Time :

Action :
Brake ☐
Swerve ☐
Accelerate ☐

	1	2	3

Severity :
Light ☐
Severe ☐

Time :

Action :
Brake ☐
Swerve ☐
Accelerate ☐

	1	2	3

Severity :
Light ☐
Severe ☐

Time :

Action :
Brake ☐
Swerve ☐
Accelerate ☐

	1	2	3

Severity :
Light ☐
Severe ☐

Time :

Action :
Brake ☐
Swerve ☐
Accelerate ☐

	1	2	3

Severity :
Light ☐
Severe ☐

Time :

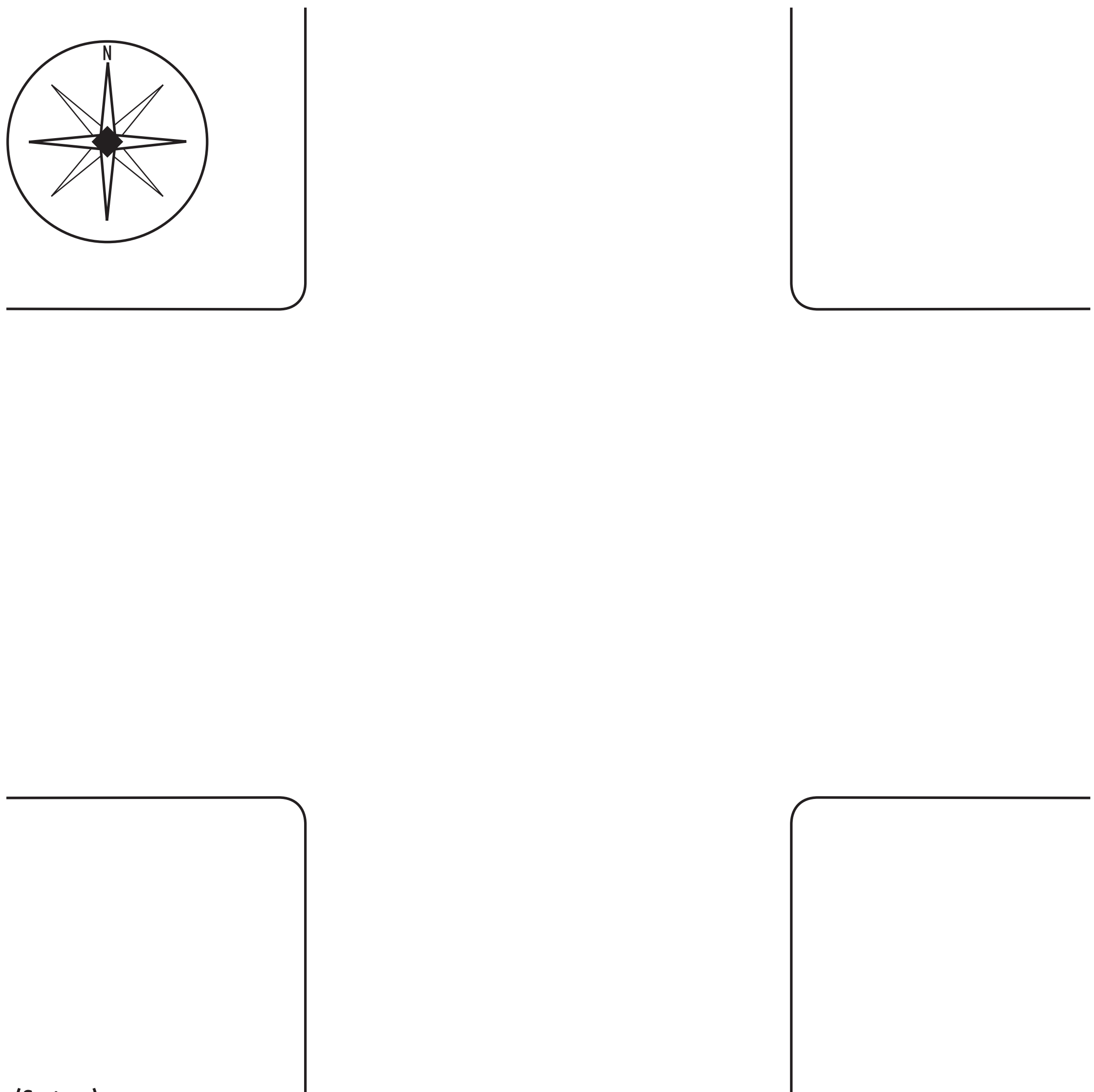
Action :
Brake ☐
Swerve ☐
Accelerate ☐

	1	2	3

Severity :
Light ☐
Severe ☐

Traffic conflict diagram

Municipality:	Date:
Intersection:	Time from: to:
Observer:	Weather:
Comments:	



Light (Serious)

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The following calculators are provided on the electronic version of the manual.

CALCULATORS

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  - Critical accident rate
  - EPDO index
  - Binomial test
  - Poisson test
  - Confidence interval
  - Regression to mean
  - Before - after tests (individual site)
  - Before - after test (group of sites)
- **Horizontal curves**
  - Speed differentials
  - Overturning speed
  - Braking distance (curve)
  - Basic equations
  - Road width
  - Lateral clearance
- **Others**
  - Grade analysis
  - Economic assessment
  - Spot speed study
  - Distribution tests
  - Braking distance (tangent)
  - Motion equations

Instructions for installation

The CD-ROM that accompanies this manual contains the electronic version of the manual, in Adobe Acrobat® Reader (.pdf) format, and several calculators. To install the files on your computer, take the following steps:

1. Insert the Road Safety Manual CD-ROM into the CD-ROM drive.
2. If the installation program does not start automatically in a few seconds, take the following steps:
   a. Choose “Run...” on the “Start” menu of the Windows® taskbar.
   b. Type **X:\setup.exe** (replace **X** with the letter of your CD-ROM drive) then hit “Enter”.
3. The installation program will guide you through the installation process for the Road Safety Manual.

This manual, written by experts of the World Road Association (PIARC), is a basic reference for all transportation engineers concerned about road safety problems.

In more than 600 pages, the work presents, in an easy-to-read, easy-to-consult format, an up-to-date summary of the accumulated knowledge of the last several decades.

The work is divided into four parts. The first part introduces the reader to the road safety field. The second part describes a complete safety analysis process (from data collection to assessment). The third part explains in detail the relationship between various components of the road and safety (horizontal alignment, vertical alignment, etc.). The fourth part describes all the steps required to complete technical studies (sight distances, spot speed, etc.).

Included with the manual is a CD-ROM containing the French and English versions of the text. It also contains several programs that make it easier to use the calculation methods described in the manual. It runs on a personal computer.

Québec

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