Application of Design for Safer Urban Roads and Junctions: Selected Countermeasures

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Application of Design for Safer Urban Roads and Junctions: Selected Countermeasures

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Sammanfattning
Abstract

Road design with focus to safety has been extensively developed in last decades in Nordic and some other EU countries with the main aim to achieve a decrease in a number of accidents and fatalities on the roads. These countries gained many valuable experiences, but they had to sacrifice great effort, expenses, and time to reach the present art-of-state. The purpose of the Master's Thesis is to review some design approaches with focus to safety and discuss the general way that they may be applied.

The Master's Thesis studies safety in three levels: (i) general – design standards, national safety policies and road hierarchy; (ii) local authority and road administrator; and (iii) three specific safety countermeasures – junctions, pedestrian crossings and traffic calming.

The first part of Master's Thesis describes the general road design standards background and their art of state. Furthermore, it discusses the new approaches in road design standard such as Dutch classification of road standards. Safety policies and programs are discussed and the concept of human imperfection is explained. Road safety policy and road hierarchy in Sweden and Denmark is described.

The second part is devoted to the planning process on local authority and road administrator level. The phases of planning process are described. Special attention is paid to ranking process when choosing most effective countermeasures, next to black spot programs and also to public attitudes to safety countermeasures.

The focus of the last part is in specific designs for safer road environment. There are discussed three groups of road facilities and countermeasures; junctions, pedestrian crossings and traffic calming. The cost, effectiveness, suitability, possible side effects and other properties of individual types of countermeasures are discussed.

Nyckelord
Keyword

Traffic, Safety, Design, Standard, Policy, Planning, Attitude, Junction, Pedestrian, Crossing, Calming

PREFACE

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Linköping University, Sweden, Director of Study Department

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1. INTRODUCTION

Road design with focus to safety has been extensively developed in last decades in Nordic and some other EU countries with the main aim to achieve a decrease in a number of accidents and fatalities on the roads. These countries gained many valuable experiences, but they had to sacrifice great effort, expenses, and time to reach the present art-of-state. Countries, which face to similar safety-related problems, have great opportunity to acquire valuable experience from countries with a high level of traffic safety and accelerate their own safety development.

Road design and related engineering countermeasures play a very important (but not only) role in the field of traffic safety. The purpose of the Master's Thesis is to review some design approaches with focus to safety and discuss the general way that they may be applied.

Applicability of measures depends on many factors; cost, effectiveness, legislation, political will, technical conditions and specifications, road users' will and ability to accept alternative countermeasure and will of local authorities to accept alternative countermeasure.

This thesis reflects increased awareness, especially in Scandinavian countries, about vulnerable road users.

General notes and terms:

If not specified, then financial amounts in **$** are considered to be US $ from year 2001.

Vulnerable road users, such as pedestrians, cyclists, moped riders and motorcyclists, are those road users who are not protected by any kind of frame. Therefore, accidents even in relatively low speeds may have serious consequences for them. Vulnerable road users are flexible since they are not limited by traffic way and motor driver can never be sure where to expect a pedestrian or a cyclist. Pedestrians and cyclists can be difficult to see because they are small compared to a car.

Traffic, if not specified, is considered to be **right hand traffic**.

AADT is an abbreviation for the Annual Average Daily Traffic.

2. INSTITUTIONAL AND LEGAL FRAME

This chapter briefly describes the most general level of road safety. It describes the position of design standards, visions, national policies and a road hierarchy in the relation to the road safety.

2.1. Design standards

2.1.1. Design standard purpose

The purpose of design standards is to help engineers to design sound roads. Geometric design standards are generally supported on three main grounds (McLean 1980 cited in Slop 1995):

- *to ensure uniformity among different designs, particularly across administrative boundaries; uniformity makes traffic situations and road user behaviour more predictable, which is believed to be good for safety*
- *to enable the existing expertise in geometric design, which tends to be centred in the major road authorities, to be more broadly applied; and*
- *to ensure that road funds are not mis-spent through inappropriate design, thus making inadequate provision for future traffic growth and current safe operations*

2.1.2. Current design standard practise

Study on European design standards and their relation to safety was presented by Slop (1995). Conclusion of the study is that the relationships between safety and road features are not yet well understood quantitatively. The finding of relationships between road design and road safety is obscured by a variety of factors (driver, vehicle, risk-increasing circumstances, traffic regulations, etc.) and therefore studies often have contradictory results on roadway geometry and related safety effects. This leads to that committees responsible for compiling road design standards rely heavily on their own judgements instead of relying on research results.

According to the same study, not all European countries have road design standards for all types of road. And if they have so, they do not always apply these standards. Even if the standards are applied, different interpretation may lead to different road design even in the same jurisdiction.

Wegman (1996) states that road design standards are in their nature conservative and inert and have low ability to accept new research experience. One reason lies in rapid variability of traffic environment such as design elements, information technology applications, new types and parameters of vehicles, growing congestion etc. Second reason is the lack of interest among researchers. If a researcher is not asked for and the results are not used, no one wants to perform a research in this field. Third reason lies in a difficult transferability from research results to design standards. It implies small will of clients to commission research. Researches are also very costly and road authorities have to face budget cuts. Last reason is the inherent methodology and statistical problem of the researches.

A study of the Danish Road Directorate (1998) states similar problem with implementation of research results to practise and design standards. Committees responsible for compiling road design standards often rely on their own judgement, instead of relying on research results. These committees frequently just use the "best available information". This often means that a limited number of well-known and frequently-cited references are used, for want of more appropriate sources.

2.1.3. New approach to design standards

Design standards, to be able to serve their aims, have a certain degree of coercion. This may, however, lead to diminishing possibilities for the designer to find the right balance between the various criteria since important decisions have been already taken for him.

New road design standards should provide more space for road designer to choose best solution, but they should assist and inform about safety effect of each design decision.

Various standards and rules have different range of rule and are useful for different situations. Some standards are suitable under all circumstances, on the other hand some rules are determined for use under only specific conditions. Some standards are based on broad scientific research, but others are only believed to have a positive safety effect.

In order to determine standard firmness, the background of a standard should be known. Standards based only upon factual figures and relations would be among the firmest, but it appears that these are rare. Most standards are mainly or entirely founded on more or less realistic assumptions.

Dutch classification of standards for roads inside built-up areas was presented by Slop (1995). The facilities described are distinguished by means of a "stars" system as follows:

*****	***regulations*** *to be complied with;*
****	***guidelines*** *from which can be deviated only with a sound motivation;*
***	***recommendations*** *to be preferably followed because it is assumed that their effect is favourable;*
**	***suggestions*** *of which a favourable effect is expected;*
*	***possibilities*** *of which a favourable effect is suspected only.*

Some countries also allow to deviate from recommended value in specified margins, in case of need or emergency. Unfortunately it is not usually specified, what is the measure of "need" or "emergency". Slop (1995) suggest to establish a system of margins allowing designers to depart from certain values, accompanied by a set of well-founded instructions indicating when departures are tolerated.

Besides design standards, road design may be subject of the procedure called "safety audit", which is in some countries (e.g. United Kingdom) required for the design of large road projects. The safety audit ensures "*an independent review of the design process as to guarantee that the highest possible level of safety has been achieved, and that no details are included which could be detrimental to safety"* (Ruyters, Slop & Wegman, 1994*)*. Studies in Denmark and other countries show that almost 25% of traffic accidents could be avoided, if all road installations had been designed for optimum safety from the beginning (Danish Road Directorate - internet source).

2.2. National safety policies and programmes

For many years, the emphasis in traffic safety work has been in trying to encourage the road user to respond, in an appropriate way, typically through licensing, testing, education, training and publicity to the many demands of a man-made and, increasingly, complex traffic system. Traditionally, the main responsibility for safety has been placed on the user to achieve this end rather than on the designers of the system.

This approach, however, does not reflect human imperfection and the fact that human will be always errant. Therefore roads should be designed in such way that human mistakes are "forgiven" and consequences of accidents are reduced. This approach is visible for example in new Swedish and Danish policies.

2.2.1. Sweden: Vision zero

This Swedish long-time plan aims the future in which no one is killed or seriously injured in road traffic. The program acknowledges that traffic accidents cannot always be avoided, since people sometimes make mistakes. On the other hand, it is possible to prevent these accidents from leading to fatalities and serious injuries. Roads and vehicles can be made much safer. People can be made much more aware of the importance of safe behaviour in traffic.

The Vision Zero approach involves an entirely new way of looking at road safety and of the design and functioning of the road transport system. It involves altering the emphasis away from enhancing the ability of the individual road user to negotiate the system to concentrating on how the whole system can operate safely. Also, Vision Zero means moving the emphasis away from trying to reduce the number of accidents to eliminating the risk of fatality or chronic health impairment caused by road accident.

According to Vision Zero, everyone shares responsibility for making road traffic safer: politicians, planners, road maintenance organisations such as the National Road Administration and the municipalities, vehicle manufacturers, transportation companies and everyone else who uses Swedish streets and roads.

2.2.2. Denmark: One accident is one too many

According to Ministry of Transport, Denmark (internet source), in 1988 the Danish Road Safety Commission set a target that the number of people killed and injured in traffic should be reduced by 40-45% before the year 2000. Since this goal has not been reached, the government's action plan “One accident is one too many” was applied.

Participants of the plan are The Road Directorate works, police, the Road Safety Commission, the Danish Road Safety Council, regional and local authorities and other national and international institutions.

The plan operates on four target areas: speed must be lowered, drunken driving must be limited, cyclists must be better safeguarded and the number of accidents at intersections must be reduced.

Speed reduction on urban through-roads is supported by specific instructions for designing environment-prioritised streets that reflect the needs of citizens, pedestrians and bicyclists rather than drivers' need to go fast. They provide markedly improved safety as well as an improved urban environment.

Safety at intersection should be improved by introducing roundabouts, which significantly reduces traffic accidents.

The part of the safety improvement plan is systematic road safety audits for new road installations. The focus is aimed to local communities. The Ministry of Transport has chosen to further this work by setting aside funds to encourage regional and local authorities to work on local road safety plans.

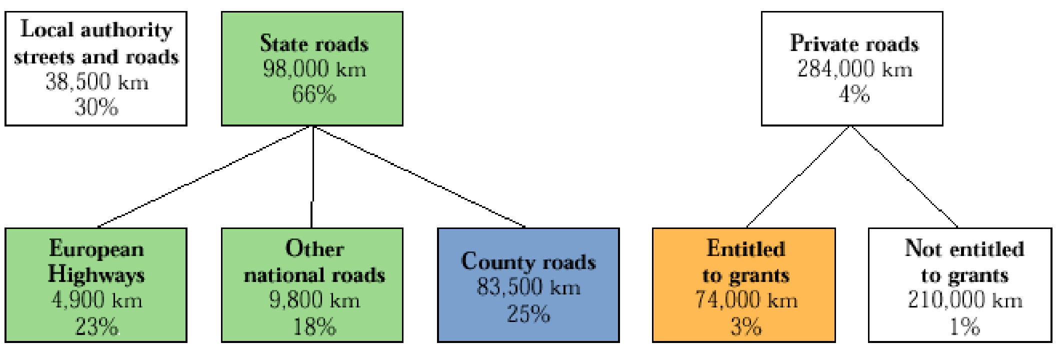
2.3. Road hierarchy and organisation

This thesis presents two different, but both successful models of road hierarchy and organisation in countries with low fatality rate (here fatalities per 100 000 inhabitant). First one, Swedish, comes from a country with high proportion rural roads, while the second one, Danish, comes from a country with majority of urban roads.

2.3.1. Sweden

Road network of Sweden consists of 38 500 km of local authority streets and roads, 98 000 km of state roads and 284 000 km of private roads, which are carrying only 4 % of vehicle mileage (*see Figure 2.1*).

Figure 2.1: The Swedish Road Network



Length of road and distribution of vehicle mileage

Source: SNRA 2000

National roads including European Highways and other national roads cutting through the city are in the ownership and responsibility of the state- owned SNRA (*Swedish National Road Administrator - Vägverket).* As a study made by FHWA (2001) states, the SNRA has a primary goal “to ensure a socio-economically efficient transport system that is sustainable in the long term for individuals and industry throughout the country”. To achieve this goal, five subgoals have been identified, including high accessibility of the system, high transport quality, no fatalities or serious injuries, a good fit in the environment, and promotion of regional development. The most important subgoal among these is the desire to eliminate fatalities and serious injuries (Vision Zero) by 2007, which is a parliamentary objective regarding road safety. A strategic infrastructure plan addresses transportation system needs in a 10-year process with a 4-year planning cycle.

County roads are in ownership and responsibility of Road Associations *(Vägföreningar).* They are responsible namely for maintenance, reconstruction and other physical changes of these roads. Road Associations are independent organisations jointly financed from the local authorities, SNRA and taxes and directly instructed by local authorities. The traffic regulation (such as speed limits) on these roads is in the responsibility of the County Directorate (*Länsstyrelsen*).

Local authorities – the Municipal District Committees (*Kommundelsnämnd*) and/or their technical departments – the Municipal Technical Services Committees (*Tekniska nämnden*) own and are responsible for roads and streets within the area of city. The exception are main roads, mainly throughfares, where SNRA has the responsibility for physical changes. The traffic regulation on roads within cities is in the responsibility of local authorities or technical departments. At some smaller population centres the responsibility for roads belongs to Road Associations.

The geographical boundaries of the responsibility between local authorities (or technical departments) and County Directorate for roads are drawn together. Roads in the responsibility of local authorities comprise urban roads, but in fact even some rural roads, which into some extent belong to the populated area.

By the year 2005, when the new transport policy (*Trafikförordningen*) from the year 1998 will take place, all highways, roads and streets within the city area will be in the responsibility of local authorities.

Road design standards and guidelines are not compulsory for local authorities. However, they discuss with SNRA decisions concerning design and re-design of arterial urban roads. Local authorities are also provided with guidelines and consulting services from Swedish Association of Local Authorities (*Svenska Kommunförbundet*). Local authorities can gain financial support from *SNRA* for safety projects, approved by SNRA. SNRA contribute by 50 % of the costs, others has to be paid by local authorities.

Traffic safety is also a concern of police and non-governmental organisation the National Society for Road Safety *(Nationalföreningen för trafik-säkerhetens främjande, NTF*), which is an umbrella organisation consisting of 24 county road safety federations, 70 national, interest and professional organisations and hundreds of local voluntary associations. Transportation and automotive industries also participate on traffic safety work.

2.3.2. Denmark

According to the Ministry of Transport, Denmark (internet source) the total public road network in Denmark is 71 500 km. The municipalities are responsible for the major part of the Danish roads, almost 60 000 km. The counties are responsible for 10 000 km. The government is responsible for the remaining only 1 650 km of national roads and motorways.

The Road Directorate, as a part of the Danish Ministry o Transport, is responsible for the operation and maintenance of the government roads in Denmark. The tasks include maintenance of pavements, snow clearing and the daily operation of the national roads. The Directorate is also responsible for the maintenance and repairs of the bridges. The Directorate solves these tasks in co-operation with other public authorities and private companies.

The Road Directorate has also a function as a national centre of know-how. It solves a number of tasks for the entire Danish road sector. The Directorate collects and processes road, traffic and accident data. The Directorate also carries out research and development of new materials, management systems for road and bridge maintenance, road safety, environment and traffic informatics. The Road Directorate functions as secretariat to the group which follows up on the road safety action “One accident is one too many”.

Traffic safety is also a concern of few other organisations;

The Road Sector Council provides technical advice to the Road Directorate. The Council ensures that users, road administrations and other authorities can jointly discuss and evaluate the challenges and problems facing the road sector. The Council works with training and education, disseminates knowledge and research, participates in EU cooperation and evaluates the need for new, general themes in road sector, R&D, etc.

The Cooperation Committee of the Road Administrations ensures a co-operation and interfaces between the road administrations, thus ensuring optimum management of the operational activities for the road network. The Committee lays down general guidelines for the co-operation and is involved in the Road Sector Information System, the traffic counting scheme, co-ordination of winter services, road user service, standards for road data etc.

The Road Standards Committee advises the Road Directorate on its work with road standards and ensures that the road administrations have the necessary tools such as regulations, guidelines and templates for designing and arranging a safe, environment-friendly, accessible and aesthetically satisfactory road and path network. Committee also ensures that road sector stakeholders provide wide support to road standards.

3. PLANNING

The main scope of this chapter is the description how to plan, choose and implement specified engineering countermeasures on the local level. Therefore this chapter generally describes which procedures local authorities should undertake and which aspects and circumstances should be considered.

3.1. Process

The reasons and problems calling for introducing some countermeasures may be various; it can be high number of accidents in a street, poor level of service of cars or public transport, aesthetically unpleasant road environment or unsightly shopping street in the centre of town.

The experiences and recommendations for communities, how to successfully deal with the planning of countermeasures, are well described by The Swedish Association of Local Authorities (1997). They suggest differentiating 7 stages of the process:

1. *Main focus and goals*
2. *Traffic network analysis*
3. *Basic design and description of consequences*
4. *Order of procedures*
5. *Detail design*
6. *Implementation*
7. *Evaluation*

3.1.1. Main focus and goals

The purpose of the planning stage is to state what quality demands are to be taken into account in the remodelling work, to clarify what importance each demand is to be given and to state the main focus of the project.

Work on setting the objectives should begin with an overall preview of the acute shortcomings and problems as well as of the potential further quality demands that could be set. These should be described in the document and refined and reviewed during each subsequent planning stage.

If planning is limited only on the countermeasure to remove just the problem that is the focus of attention, complications almost always arise: a measure to improve level of service turns out to affect traffic safety and the environment or a traffic safety countermeasure comes into conflict with accessibility. Instead of looking for the answer to the question: “How can we solve this acute problem?” the focus of the work should be checked during all phases of the planning process by asking the question: “How do we – taking into account all demands – want this street to function and work”. Plans are then stimulated towards an goal-oriented method of working, where no apparently acute demands are allowed to dominate before all demands have been tested and weighed up against each other.

3.1.2. Traffic network analysis

The purpose of the planning stage is to identify those parts of the mixed-traffic network where the different categories of traffic have incompatible demands on level of service and traffic safety and then to seek countermeasures that reduce or eliminate these conflicts in the network.

The network is examined for several aspects of various types of traffic; function of road, capacity and intensity, bus-traffic, emergency service traffic, pedestrian and cyclist. There is a network analysis created for each individual type of traffic and presented in maps with preliminary proposals for modified networks. The speed level that best suits the jointly assessed demands of all categories is also evaluated.

Possible remaining quality shortcomings that could not be resolved through the network analyses become basic data for the next planning stage.

3.1.3. Basic design and description of consequences

The purpose of this planning stage is to draw up alternative basic proposals on traffic engineering design and proposals on street space configuration initiatives for all stretches and intersections. This provides a foundation for testing whether the preliminary proposals for network design obtained from the previous stage are suitable. The consequences of alternatives are described, and the best alternatives are selected, taking into account how well the quality demands and planning criteria are met (*see Figure 3.1*).

Figure 3.1: Quality demands and planning criteria

Quality demands	**Planning criteria**
Traffic safety and security Level of service and accessibility Ease of orientation and clarity Environment protection Aesthetic and street design	Participation and endorsement Cost and effectiveness Economical use of resources and preservation consideration

Source: The Swedish Association of Local Authorities 1997

The results of this planning stage are proposals for basic design and configuration for all stretches and intersections.

3.1.4. Order of procedure

In this stage the project is divided into different system parts and it is clarified at what rate the municipality has the possibility and political will to finance[1] the

[1] Alternative sources such as insurance companies, business sector, foundations or governmental subsidies should be also considered.

project. The alternatives of dividing the project are then tested, taking into account the technical planning conditions, the possibility of gaining the acceptance of the users involved, effective achievement of objectives within the quality categories concerned etc.

3.1.5. Detail design, Implementation and Evaluation

Some designs for safer road and junctions are described in the chapter 4 as well as some implementation aspects. Evaluation is the important part of the process. It should be evaluated if the goals from the initial phase were fulfilled, if countermeasures were effective as it was expected, justify the implementation of further programs and accurate assumptions for further programs. Four basic factors, named by Elvik (1996), should not be forgotten or neglected during evaluation. These factors are: (i) changes in traffic, (ii) general trends in the number of accidents, (iii) regression to the mean and (iv) accident migration. The example of evaluation is shown on the *Figure 3.2.*

Figure 3.2: Safety benefits of traffic calming in Vancouver, Canada

Location	Change in collision frequency	Change in injuries	Change in annual collision cost	Payback period
West End	- 18 %	- 6 %	- 10 %	149 years
Mount Pleasant	- 46 %	- 25 %	- 37 %	1.4 years
Willingdon Parker	- 60 %	- 43 %	- 48 %	1.5 months
Kelvin North	- 34 %	- 64 %	- 57 %	1 month
Average	- 40 %	- 35 %	- 38 %	6 months

Source: Geddes et al 1996

3.2. Ranking process

3.2.1. Purpose

Traffic safety can be improved by various means of traffic engineering countermeasures with large scale of safety and other effects, introduction and maintenance costs, but also potential side effect such as increased time delay or emission of exhaust gases. The financial sources are limited and therefore there is a question of optimal allocation of financial resources. In order to choose the proper countermeasure, several different ranking methods have been developed. The most common procedure is called cost benefit analysis.

Cost Benefit Analysis (CBA) expresses all impacts in monetary terms. This method has the advantage that, in theory at least, all impacts can be presented at their "market price", and therefore at a level close to the individuals' real benefit (Australian Department of Transport, 1987).

The two other methods, which are not discussed any further in the text below, are Cost Effectiveness Analysis and Multi-Criteria Analysis. Cost Effectiveness Analysis is usually used for the evaluation of safety countermeasures. The method monitors the effect of an applied countermeasures e.g. in terms of deaths prevented. The method, in contrast to the CBA, does not attempt to estimate the absolute value of benefits achieved in order to compare these with costs.

Multi-Criteria Analysis is based on the "planning balance sheet" approach. All effects of various possible countermeasures are presented in monetary and non-monetary units, enabling decision makers to have appreciate the entire spectrum of impacts.

3.2.2. Data

The quality of the analyses depends on the quality of data. Some data, however, are not available and should be modelled, estimated or measured indirectly.

The data linked to accidents should involve accident rate, severity of accident and injury and fatality rate. Number of accidents at a location is a random variable and the problem with direct accident measurement is that the number of accidents at a specific site is usually small. Small accident numbers go hand in hand with large random variations. Many years of observation have to be included to get a good picture of the situation. This means that many extraneous factors are changed during the period of observation. Another problem is the source of accident records. The police records usually only include serious accidents or accidents with injuries. Insurance companies record accidents with property damage, but these records do not include all important safety-related information about accident circumstances. Moreover, some accidents, solved by road users themselves, are not included in records at all.

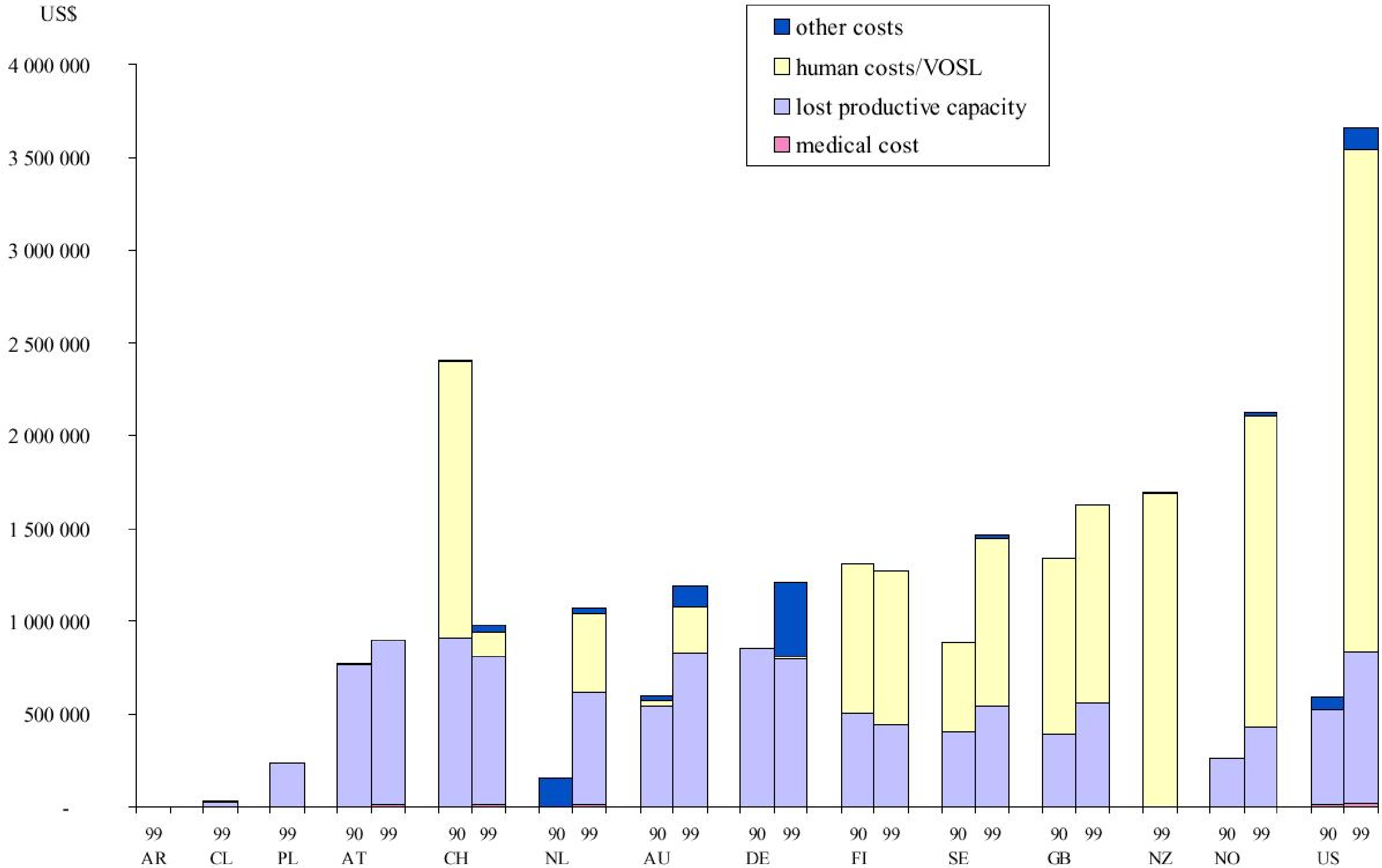
Accident costs refer to damages caused by collisions, and losses caused by the risk of collisions. These include a combination of monetary and non-monetary costs. Monetary costs include damages to vehicles, medical costs, lost productivity due to disabilities and death, emergency services, and expenditures on safety equipment to reduce crash damages. Non-monetary costs include pain, grief and lost quality of life due to crash injuries and deaths, and also reduced mobility to non-motorised modes due to crash risk (Victoria Transport Policy Institute – internet source). In order to measure accident costs for financial analyses, it is necessary to transform consequences of accidents into monetary units. Since these consequences are not possible to transform directly into monetary units another approach has to be chosen. The monetary value of human life or a quality of human life can be expressed in terms of "willingness to pay". The value of a statistical life (VOSL) is for example estimated in hypothetical studies, where individuals give their willingness to pay for a marginal risk reduction of a fatal injury (Trawén, Maraste & Persson, 2001).

The system of accident cost estimations differs from country to country. The difference is likely caused by various considerations of appreciation of human life, costs of medical treatment, economic productivity and others. The international comparison of cost per one fatality is shown on the *Figure 3.3*.

The main costs of measures are connected to the construction and maintenance costs, but also other factors such as private and emergency car delay. The delay of emergency cars may be especially harmful (e.g. heart disease, fires, crime).

Environmental effects of safety countermeasures should be also included into analyses. Some countermeasures may bring increased fuel consumption and emissions of exhaust gases, on the other hand noise emission is usually reduced.

Figure 3.3: Cost per Fatality in 1990 and 1999, US $ 1999



Note: In 1999, VOSL (the value of statistical life) is presented instead of human cost in New Zealand and Norway. The value of lost consumption is included in the VOSL, however, not separated. Therefore, the lost productive capacity presented for Norway refers to net costs only, and the part lost productive capacity is not comparable with the other countries, where the cost refers to gross costs.

Source: Trawén, Maraste & Persson 2001

3.2.3. Methodology

As was mentioned above (3.2.1), the costs and benefits of countermeasures are usually measured in terms of monetary units. The principle behind the B-C methodology is that benefits associated with safety improvements should be greater than the costs associated with that improvement. Benefits are coming from reduced accident frequencies, severity, or both. Costs are associated with a safety improvement include increases in the cost for initial installation, normal maintenance, and repair of damages from accidents that are attributable to the improvement. The B-C methodology is formulated in terms of incremental benefits and incremental costs, thus allowing for several safety alternatives to be evaluated concurrently.

The formulation of the B-C methodology is as follows:

$$BC_{2-1} = \frac{(B_2 - B_1)}{(C_2 - C_1)},$$ *(Source: Mak 1995)*

where

BC_{2-1} is B-C ratio of alternative 2 compared to alternative 1;
B_1 is annualised safety benefits of alternative 1;
B_2 is annualised safety benefits of alternative 2;
B_1 is annualised direct costs of alternative 1; and
B_2 is annualised safety costs of alternative 2.

3.3. Black spots

At some locations on existing road network, accidents occur more frequently than at the rest of road network. Higher accident frequency may be the consequence of drivers' misunderstanding or underestimating of the traffic situation e.g. because of unclear marking, faint visibility or high traffic volume. It seems reasonable to identify, diagnose and treat these locations and therefore to decrease significantly accident frequency. Financial resources used for the improvement of these sites may, if properly used, bring large benefits in terms of saved accident losses. The choice of these sites and proper treatment is, however, a complicated matter since accident occurrence has a random character and is influenced by many factors. For the purpose of the identification of these sites, called "hazardous locations" or "black spots", were used several approaches and developed several methods.

3.3.1. Black spot programs

The will to deal with the most risky areas on road networks led many countries to introduce programs focused on identification, assessment and treatment of those sites with the highest accident rates. The emphasis in these programs is on cost-effectiveness of measures, i.e. to choose that kind of treatment on that site, which will bring the biggest effect compare to its cost.

These programs typically consist of these phases:

1. *Accident and traffic data collection, recording of an accident history*
2. *Identification and diagnosis of black spot according to criteria*
3. *Identification of potential countermeasures to treat black spots*
4. *Selection and prioritisation from countermeasures of the preferred option, optimally based on maximising the safety benefits at minimal costs*
5. *Implementation of countermeasures*
6. *Evaluation of applied countermeasures with feedback for improvement to standards and practises*

Sources: Australian Department of Transport 1987, Gaca & Pietrucha 1999, de Mello & Chequer 1996

According to a study elaborated for Australian Department of Transport (1987), black spot treatment programs may be distinguished into two types; mass-action programs are ones where proven treatments are installed "en-masse" (e.g. fully controlled right[2] turns at all major signalised intersections). On the other hand, area-wide programs are ones which tackle an area (e.g. residential precint) identified as having safety problems rather than an isolated location (or black spot).

3.3.2. Accident data collection and black spot identification

Black spot identification

Black spot identification means the process of the selections the weakest places on the city road network ("black spots"). It is possible to distinguish at least two levels in the evaluation of road network safety. In the lowest level the black spot is considered a single junction, short road section or another specific traffic element such as a pedestrian crossing. In the higher level the black spot may be whole arterial road in a village or town or one part of a village, town or city.

One of the most common methods used in practise for identification "black spot" is to compare accident rate at the site with some critical number of accidents. The site is considered to be a "black spot" if accident rate exceeds mean accident rate over all sites in the region plus multiple of the standard deviation of the site accident rates within that region during given period (Higle & Witkovsi, 1988). Such methods are based on the concepts of confidence intervals within the context of classical statistics. The multiple used depends on the degree of confidence desired, for each location.

[2] There is a left-hand traffic in Australia.

Because of random variations typical for accident phenomena, historical accident data do not always reflect long-term accident characteristics accurately. A site with a low accident rate (in long term) may still have a high accident rate over a short period of time, and vice versa. Moreover, the vast differences in an accident history that exist among various sites imply that the random variables used to describe the accident rates should differ from site to site.

To overcome some of these difficulties, Bayesian analysis approach could be used instead. Bayesian analysis provides a framework enabling to include both regional accident characteristics and site-specific accident histories resulting in a coherent method by which the random variables representing the accident rates at the various sites may be mathematically defined. Therefore a Bayesian identification technique makes possible to determine the probability that accident rate exceeds some level.

Criteria for black spot identification process

The proposed criteria should not be limited only on the number of accident at given location, but should consider more factors (e.g. section length, traffic volume, accident seriousness, proportion of child accidents and others). Therefore various accident indexes are used instead only simple number of traffic accidents (*see Figure 3.4*). It should be also noted that it is possible to compare only similar types of traffic locations. It is not possible to compare e.g. a pedestrian crossing with a road section or a road section with a junction or a motorway with an urban road sections etc. since every element is characterised by other parameters.

Figure 3.4: Accident and gravity index used on Greek road network

Accident index expresses the proportion between number of accidents, traffic volume and, in case of a road, length of the examined road segment. The formula is:

$$r = \frac{N * 10^6}{Q * L * T},$$

where N is the number of accidents during period T, Q is the traffic volume (usually per 1 year), T is the time period (usually 1 year) and L is the length of the examined segment.

Another index, ***gravity index***, is of similar form as the previous index, but instead of N – the number of accidents, is used C which expresses the severity of an accident. The formula for C is:

$$C = N * f_1 + H * f_2 + S * f_3,$$

where N is the number of deaths, H and S are the numbers of serious and light injuries respectively and f_1: f_2: f_3 are weight coefficients for deaths and serious and light injuries.

Source: Pitsiava-Latinopoulou, Tsohos & Basbas 1999

The design of Greek accident index, however, supposes the number of accidents to be proportional to the traffic volume. This does not reflect the fact that safety requirements set on a high volume road should be higher than in the case of a low volume road. Generally, if the certain countermeasure is applied to the high volume road, the benefits in terms of the reduced numbers of accidents are higher than in the case of the low volume road. Therefore it may be useful to use more comprehensive indicators, expressing the compromise between the number of accidents and accident index above. The example is an index (*see Figure 3.5*) used for black spot identification in Polish cities Bydgoszcz, Inowroclaw and Chojnice. A dangerous place on the city road network is in this case called “black spot” if the place (junction or 50 meters long road section) has the value of below described safety indicator greater than the critical value.

Figure 3.5: Safety indicator used in Bydgoszcz, Inowroclaw and Chojnice

$$W_j = \frac{\frac{X_j}{Q_j}}{\frac{1}{n}\sum_{i=1}^{n}\frac{X_i}{Q_i}} + \frac{X_j}{\frac{1}{n}\sum_{i=1}^{n}X_i} + \frac{YP_j + YR_j}{\frac{1}{n}\sum(YP_j + YR_j)}$$

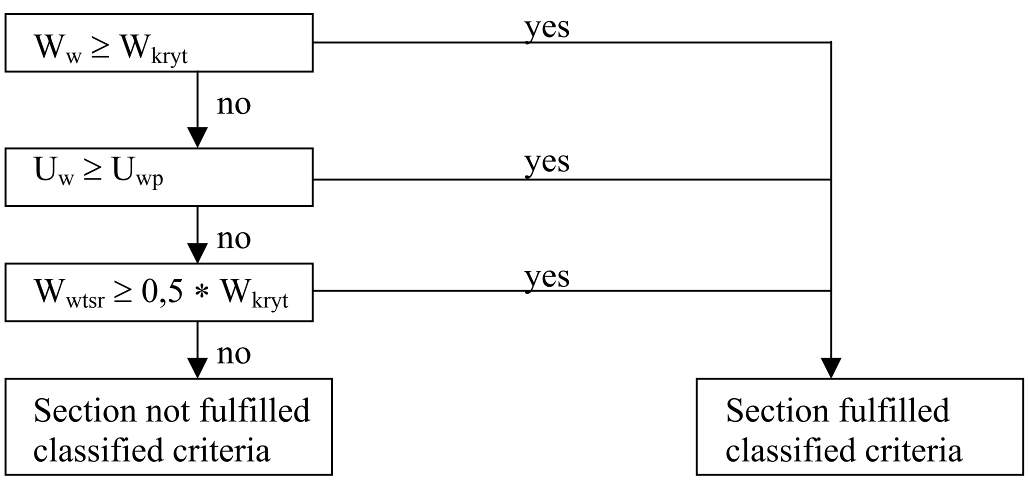
j,i	indexes of an estimated element,
X_i	number of equivalent road accidents, that is the equivalent number of road collisions equivalent (in relation to costs) to the number of all road accidents that have happened on the network element i for two last years,
n	number of road network elements of the same type in the whole city, where at least 1 accident and 3 collisions happen every year,
Q_i	average daily traffic volume on the element i of the road network
YP_i	number of road accidents with pedestrians on the element i of the road network (for last two years)
YR_i	number of road accidents with cyclists on the element i of the road network (for two last years)

Source: Szczuraszek, Kempa, Bebyn & Chmielewski 1999

Black spot diagnosis

After the preliminary identification of black spots, which should be periodically repeated (e.g. every year), all sites should be checked if they fulfil criteria for being supposed to be a black spot. In result it is obtained the shorter list of black spots for further analysis. It is also possible to steer the size of the black spot set by changing the values of criteria. For example, this system is also used nowadays in Poland on national road network (*see Figure 3.6)*.

Figure 3.6: The final qualifying algorithm for black spots sections identification procedure



Legend:

W_w	Average annual accident number
U_w	Relative accident factor considering the seriousness of accidents
W_{wtsr}	Average annual number of the same kind (type) of accidents
W_{kryt},U_{wp}	Criteria values

Source: Gaca & Pietrucha 1999

The presented procedure consists of three steps. In the first step sections are filtered with the number of accidents lower then the given criterion. In the second step more factors such as seriousness of accidents, section length, traffic volume and others are considered. The third step of the procedure was chosen for taking into consideration sections, where the same types of accidents happened.

The above described scientific methods, however, are influenced also by non-traffic interests. There is a necessary to take into consideration local societies and self-governmental bodies opinions by selection of black spots sections to remedy measures application.

3.3.3. Countermeasures at black spots

The suitability and effectiveness of black sport treatment programs depends on the specific spot or location and countermeasure and treatment that are implemented. As was mentioned above the chosen countermeasures should bring maximal possible safety benefits for given or available amount.

The range of possible countermeasures is wide and for illustration some of them are listed below:

- *Prohibitions of the movements which were mainly responsible for the accidents at each intersection*
- *Redesign of intersection layout with the addition of traffic safety islands and facilities for left turn movements. Roundabout construction. Staggered T-junctions instead X-junction.*
- *Measures for improving the safety level for the pedestrians (i.e. pedestrian crossings) optimally with a central refuge island. Special lighting at pedestrian crossings. School crossings*
- *Installation of the necessary vertical and horizontal signs. Warning signs.*
- *Reconsideration of speed limits, speed reduction in peak hours.*
- *Use of rumble strips, speed humps and speed bumps.*
- *Traffic islands at city gateways.*
- *Lighting installation.*
- *Slippery conditions improvements especially at critical points-junctions, pedestrian crossings, at sections with a high longitudinal inclination.*

- *Inclinations improvements.*
- *Reconsideration of the traffic lights programmes.*
- *Visibility improvements.*
- *Strict speed enforcement.*
- *Traffic management countermeasures – full or half road closures, diverters and others.*
- *Roadside improvement. Removing obstacles such as poles or trees from roadside or installation barrier cushions.*

Source: Pitsiava-Latinopoulou, Tsohos & Basbas 1999, Australian Department of Transport 1987

The use of an appropriate treatment for a particular accident problem is largely based on professional judgement. It implies that improved staff training and research may cause better evaluation and proper choice of countermeasures in future.

3.3.4. General efficiency of black spot treatment programs

Black spot treatment programs should include a monitoring part to evaluate continuously the effectiveness of programs, to update and improve identification procedures and to adopt a flexible approach to the introduction of new countermeasures.

A number of studies have evaluated the effectiveness of these programs and showed them to be highly cost-effective and generally the costs of treatments are recouped by accident savings within a year with high benefit-cost ratios being achieved (Camkin, 1984 in Australian Department of Transport, 1987).

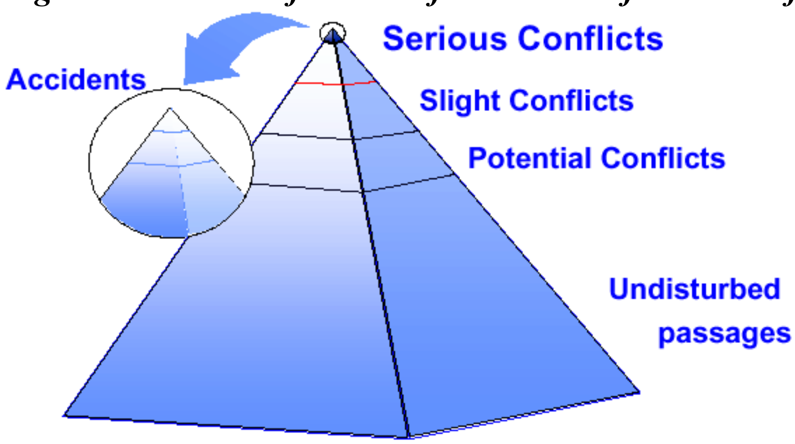
On the contrary, Elvik (1996) in his meta-analysis of black spot treatment evaluation studies mentions that studies did not consider all factors such as (i) changes in traffic, (ii) general trends in the number of accidents, (iii) regression to the mean and (iv) accident migration. He discovered that "the more confounding factors studies controlled for, the smaller were effects attributed to black spot treatment". While large reductions in the number of accidents, generally 50-90 % were found in studies not controlling for any confounding factors, studies simultaneously controlling for general trends, regression to the mean and accident migration did not find any statistically reliable effect of black spot treatment on the number of accident.

The problems with application of black spot treatment programs are connected with many practical problems causing that the full potential of programs is not used. Szwed (1986 cited in Australian Department of Transport, 1987) names some of them:

- *Limited or inadequate resources*
- *Inadequate forward or strategic planning*
- *Inability to accelerate funding*
- *Long lead times after the initial identification of a site*
- *Lack of expertise for identifying, evaluating and implementing appropriate treatments*
- *Shortcomings with the existing black spot identification procedures – for example, sites at the top of the black spot list are being treated whilst sites further down the list remain untreated, even though low-cost treatments may be available at the latter sites which may be more cost-effective*
- *Lack of innovation*

An alternative or a supplement to the black spot programs is the Conflict Technique developed by Lund University in Sweden (*see Figure 3.7*). This method makes possible to identify black spots within very short time. The method is based on a direct observation of conflicts defined as events when road users have to take an evasive action to avoid an imminent accident. The idea is to measure the number of serious conflicts, which are in close relation to the number of accidents. The explanation is that the process of a serious conflict is almost identical to that of a serious accident, with the exception of collisions occurring less frequently and that no one is injured.

Figure 3.7: The conflict classification used for the Conflict Technique



Source: Department of Technology and Society, Lund University

3.4. Attitude of road users towards safety countermeasures

3.4.1. Importance of road user opinion

The acceptance by the local community is necessary to countermeasure functions effectively and public opinion and attitude toward safety measures should not been neglected for several reasons;

- *Public disagreement may lead to safety countermeasure being altered or removed consequently after introduction.*

- *Angry driver irritated with safety measures can behave aggressively, may try to over-speed in order to reduce time-loss. In turn it may cause that safety measure may on contrary produce additional risk.*

- *Decision-making about safety countermeasures is often in responsibilities of regularly voted local authorities and discontent population can influence elected politicians to change the decision about safety measure.*

- *Discontent and bad understanding of safety measures can also lead to vandalism*.

In order to minimise the likelihood of negative public attitude it is important to understand public reaction to schemes.

3.4.2. Public attitudes to safety measures

A study (Webster, 1998) reviewed 40 UK and 5 non-UK surveys on public attitude towards various safety countermeasures. Most of surveys indicate that the majority of the respondents approved of safety measures. The general finding is that the average percentage of respondents expressing approval across all the UK surveys was 65.

Schemes with speed humps has been on average approved by 72 % (ranging from 47% to 93%) and there was little difference between public perception of schemes in 20 mph and 30 mph zones. The round-top humps were more popular than flat-top humps (78 % against 64 %). The speed humps were on average approved better by residents (78 %) than non-residents (66 %).

The percentage of respondents expressing overall approval for the schemes with speed cushions was 53%. The lower approval with measure could be explained by lower regarded effectiveness at reducing speed than road humps.

Attitudes towards chicanes in particular were very variable. Negative attitude was present e.g. for one-way chicanes with high volume of traffic. The negative attitude led to consequent removal of chicane. Boyd and Noon (1997 cited in

Webster 1998) described a survey in Edinburgh which showed that chicanes were the least popular measure with 74% of residents living close to one being dissatisfied with them. Chicanes were disliked because they were said "to make driving conditions difficult and to encourage bad driving".

Road closures may cause strong public oppositions. Road closures should not be scattered "randomly" around an area unless they are overwhelmingly supported. Residents are not able to understand random closures and they can split a community. The popularity of road closures is very dependent on the area and the degree of access required (Webster 1998).

The public attitude to mini-roundabouts was described only in few studies, but generally was poorly accepted especially in smaller rural townships. There was sometimes confusion at mini-roundabouts by elderly drivers and also by drivers who drove in the wrong direction or over the roundabout. Roundabouts are accepted quite positive and the studies (described at NCHRP 1998) show that public acceptance of roundabouts improved after the installation (*see Figure 3.8*). It could be concluded that if well-designed safety countermeasure can change road users' approach to countermeasures to safety problems.

Figure 3.8: Public attitude toward roundabout before and after construction

Attitude	Percent	
	Before Construction	After Construction
Very negative	23	0
Negative	45	0
Neutral	18	27
Positive	14	41
Very positive	0	32

Source: NCHRP 1998

According to the survey study (Webster 1998) from York City in United Kingdom, the most effective measures perceived by respondents were round-top road humps (75 % effective), which although criticised on a number of issues, were felt to be more acceptable than other forms of traffic calming. Speed cushions and flat-top road humps were felt to be next best (50 %) in terms of effectiveness, followed by chicanes (45 %) and mini-roundabouts (41 %) in descending order. As follows from mentioned above the perceived efficiency links strongly to public approval of safety countermeasure.

The aesthetic improvement connected to the safety countermeasure may also influence overall attitude to safety countermeasures. Mackie (1989 cited in Webbster 1998) reports that a more integrated approach combining safety, environmental and land use planning objectives could gain better public support and provide more financial justification for schemes which may not be viable in either safety or environmental objectives separately. The alarming fact is that average perceived effect on environment, expressed by percentage of respondents who thought that area was from aesthetic standpoint better before introduction safety countermeasure was 48 %. This number is very high and indicates that road planners did not consider aesthetics factor properly or neglected at all.

The interesting fact is that respondents underestimated the effectiveness of safety countermeasures (*see Figure 3.9*). Although personal injury frequency was reduced by, on average, 63%, the proportion of respondents who thought that safety had improved was only 53 %. There was also no linear relationship between changes in mean speeds, traffic flows or accidents and the percentage of people who thought these things had improved.

Figure 3.9: Comparison of changes in accident frequency at schemes and perceived effect

Type of measures installed	Reduction in accident frequency (%)	Respondents who thought that safety	
		Improved (%)	Same (%)
Humps	61	43	-
Humps	100	22	-
Humps, chicanes	53	47	39
Humps, narrowings	61	37	39
Humps	50	48	31
Humps, narrowings	47	50	34
Humps, narrowings, chicanes	100	82	-
Cushion, raised junctions	100	74	-
Humps	56	67	-
Humps	56	52	-
Humps	70	62	-
Round-top humps	73	85	-
Flat-top humps	84	69	-
2-way chicane	74	46	-
1-way chicane	54	17	55
Gateway, chicane, miniroundabout, speed camera	20	40	-
Gateways, 30 kph on road	13	68	-
Average all surveys	63	53	-

Source: Webster 1998

3.4.3. Tools to increase countermeasures acceptance

In order to increase the acceptability of safety countermeasures should be considered if an appropriate countermeasure is chosen and/or if its design is not redundantly restrictive.

Citizens should understand that safety problematic concerns themselves and that safety measures are not introduced in order to "to bully car drivers", but on the contrary prevent road users from traffic accidents. Citizens should be informed through media and campaigns in easy to understand the way about planned and realised safety countermeasures in the context of accident situation. These campaigns can be also connected with general promotion of safer traffic.

The important component of safety countermeasures planning process should be also public consultations. Consultation at an early stage in the process is useful in determining the perceived problems in an area, and in defining the objectives of the safety countermeasures. Following on the consultation process may be used to seek local views on the proposed works and resolve any conflicts that may arise. The proposal of safety countermeasures should be discussed with such bodies as the Police, Fire and Ambulance services and bus operators since some countermeasures (especially traffic calming techniques) may cause delays to emergency vehicles.

Possible ways to inform citizens:

- ***Regional TV and radio broadcasting, newspapers.*** *Articles, discussion, interviews, accident maps and statistics, children programme.*

- ***Reports, leaflets and brochures*** *distributed to households.*

- ***Public meetings and consultations***

- ***Programmes of co-operation between local authority and citizens.*** *Citizens may have possibility to propose treatments.*

- ***School education*** *Responsible approach to traffic safety should be formed in early age.*

Safety countermeasures are not perceived equally by all road users. According to Lehner (1999) study on road users opinion on acceptability of speeds and speed limits in 6 European countries, pedestrians prefer efficient measures that have a direct impact on car drivers' speed choice, while car drivers prefer measures that leave the decision to themselves. However, some countermeasures e.g. roundabouts may have positive effect toward safety and also driving comfort due to reducing travel times.

4. SELECTED SAFETY COUNTERMEASURES

4.1. Junctions

4.1.1. Problem definition

Driving through a junction is a complicated matter and usually involves complex manoeuvres during which motorists must continuously assess the positions, speeds and intentions of other road users. Examples from France and Denmark show that approximately 40 % of all accidents occur at junctions (Danish Road Directorate, 1998).

The comparison of accident rates for various types of intersections is shown in the *Figure 4.1*. The example shows the situation in Norway. The figure shows very low accident rates for roundabouts. The accident rate is on the contrary high for priority junctions, especially for X-junction with strong turning traffic or high vehicle speed.

Figure 4.1: Accident rates at junctions on Norwegian road network

Type of control	**Junction type**	**Speed limit (km/h)**	**Accident rates (acc./million vehicles) by percentage of traffic coming from the side road**		
			0-14,9	**15-29,9**	**>30**
Grade-separated junctions					
	Double T-connection		0,08		
	Half cloverleaf intersection		0,08		
	Diamond intersection		0,11		
	Trumpet intersection		0,04*		
	Combined Diamond/Cloverleaf int.		0,08		
	Combined Trumpet/Cloverleaf int.		0,13		
	Combined Trumpet/Diamond int.		0,07*		
Total			0,085		
At-grade junctions					
Give way (major / minor)	T-junction	80 or 90	0,06	0,12	0,26
		60 or 70	0,07	0,11	0,14
		50	0,08	0,11	0,11
	X-junction	80 or 90	0,07	0,27	0,58
		60 or 70	0,12	0,19	0,28
		50	0,07	0,10	0,31
Right hand rule	T-junction	50	0,07	0,07	0,13
	X-junction	50	0,10	0,19	0,18
Signal control	T-junction	60	0,07		
		50	0,05		
	X-junction	60	0,11		
		50	0,10		
Roundabout (small / medium)	3-road	all	0,03		
	4-road	all	0,05		
Total	all	all	0,10		

Remark: **** Accident rate is based on low number of observations.***

The shapes of grade separated junctions are illustrated in the Figure 4.14: Schema of the different intersection types.

Source: Johannessen 1998

4.1.2. Factors influencing junction safety

An accident is often caused by a combination of factors affecting a situation in which man, vehicle, road design and condition, and traffic situation all play a part. In order to avoid human errors or mistakes, and thus to avoid accidents, it is essential that road users, whether they are pedestrians, cyclists, or car, bus or lorry drivers, are given proper time for information acquisition, are never subjected to unexpected situations, are given sufficient time to make correct decision, and preferably need only make one decision at a time. Accident factors may be sorted into four groups (Brüde et al, 1998):

- ***Human factors****, such as information acquisition, decision-making ability, reaction and decision time, disabled persons, road user attitudes, behaviour and habits.*

- ***Physical elements****, such as function of connecting roads, number of arms, vertical and horizontal alignment of the connecting roads, presence of cycle lanes and tracks, sight distance, conflict area, traffic control device, lighting, roadside and surroundings.*

- ***Traffic considerations****, such as design hourly traffic volumes and turning movements, vehicle speeds, size and operating characteristics of vehicles, pedestrian and cycle traffic and accident experience.*

- ***Economical and other factors****, such as construction and maintenance costs, delays and time costs, energy consumption and emissions.*

4.1.3. Junction design principles and junction location

A junction should be preferably established in a concave vertical curve (sags) for both roads. This should be applied at least for the secondary road. A junction is best constructed on a straight section, and under no circumstances on a sharp horizontal curve. Joining on the inner side of a curve may result in poor visibility of other vehicles. Joining the outside of a curve with super-elevation may impede the secondary road users' perception of the junction, and create problems with an inappropriate transverse inclination for turning cars.

A junction should be located so that the physical conditions permit the establishment of visibility splays. The normal way of doing this is to arrange free sight within so called sight triangles.

Design should make a driver attentive to the junction at a suitable distance for him to start preparing for the necessary changes in his driving. Road users on the secondary road need information on priority conditions early enough for them to give way, and also the road users on the primary road must be given a clear warning of the priority conditions in due time. A junction and its surroundings should be designed to be visually clearly distinct from a free road section. This is mainly achieved by suitable interruptions of the optical alignment, by the provision or discontinuation of planting, by the well-considered siting of posts and also by application of road signs and marking. The indication may be stressed by discontinuation of kerbstones, the provision of traffic islands and narrowing of the carriageway lanes.

Also priority conditions should be unambiguous. Therefore, the secondary road should have an interrupted course and therefore misleading kerbstones, planting and illuminators continuing unchanged after the junction, giving a wrong impression of free road, have to be avoided. This is particularly important if the frontages on both sides of the junction look alike. When priority of a road is changed, the alignment of the formerly through road should be changed so that the new priority conditions are clearly apparent.

If it is necessary to reduce speed on the priority road, elements such as narrowing, staggering, central traffic islands, ramps, raised carriageways, humps, changed road surface or traffic-actuated signals may be used. The most effective speed reducers are raised areas of different designs. Unfortunately, they are also known to create problems for emergency transport and buses. At areas, where conflicts between vehicles and pedestrians and cyclists are expected, speed should not exceed 30 km/h (e.g. Wramborg, 2001). Speed reducers must be designed and marked in a way that enables road users to observe them without diverting their attention from the traffic situation and the task of passing through the junction.

Because of safety and functionality of the junction several others requirements are set on the design of the junction:

- *Only few and easily recognisable elements should be used in order to make layout of the junction simple and easy to recognise and understand.*

- *The angle of the junction between the secondary and the primary road should be as close as possible to a right angle and secondary road users in the stop position should be waiting approximately at right angles to the primary roads.*

- *Anywhere at a junction, road users should have adequate visibility ahead so that they can choose the correct lane. Road markings, road signs, and any traffic lights must be seen and understood in due time by the target road users.*

- *Road equipment (signs, guard rails, crash barriers, telephone poles, shelters, lamp, posts, planting etc.) must not impair visibility.*

- *The junction design must provide adequate length for carrying traffic streams into the entry lanes of the junction and for sign-posting.*

- *There must be adequate space for waiting vehicles, which would otherwise interfere with other junctions along the road.*

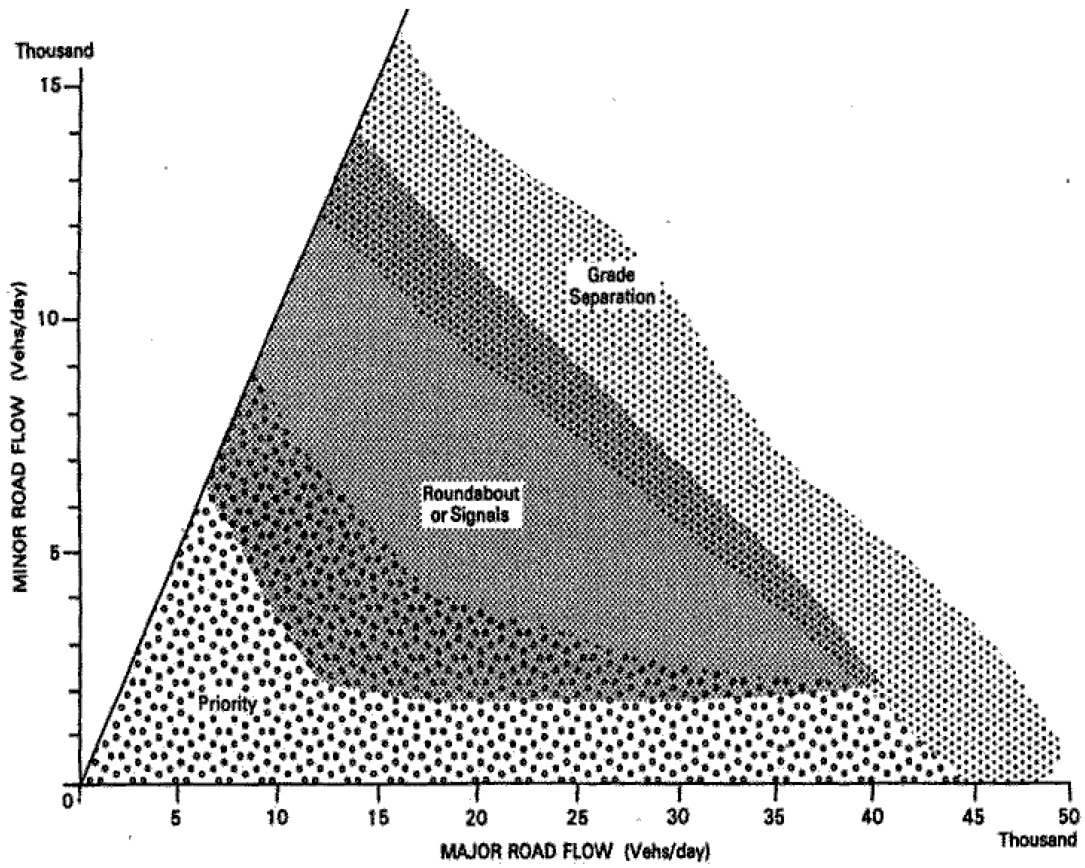
Source: Brüde et al 1998, Danish Road Directorate 1998

4.1.4. The choice of a junction type

The choice between different types and designs of junctions is normally made with regard to the capacity required, safety, environment and uniformity. Besides these also spatial limitations, topographical conditions and construction costs have to be considered. Most countries have different ways of appraising the various elements and factors and of setting and applying monetary values to the various costs and benefits, including the costs of fatalities and injuries. This results in different ways of choosing the appropriate junction type.

In many countries, a sample diagram has been developed to indicate the appropriate type of junction with regard to capacity and traffic safety. The figure below shows an example (*see Figure 4.2*) from the UK. Similar way is also used in the Czech Republic.

Figure 4.2: Types of junction appropriate to different traffic flows, AADT in two directions. An example from the UK.



Source: Brüde et al 1998

In Sweden, there are different diagrams for the safety and the capacity. *Figure 4.3B* below shows a diagram taking into an account the capacity at a 3-way junction with a speed limit of 50 km/h, and *Figure 4.3C* below shows a diagram taking into account traffic safety. *Figure 4.3D* and *Figure 4.3E* below show capacity and safety criteria for 4-way junctions with a speed limit of 50 km/h. Junctions of category I are represented by signalised crossing or roundabout, while category II is represented by priority junction.

Figure 4.3: Types of junction appropriate to different traffic flows in Sweden

B,D: Types of junction appropriate to different traffic flows considering capacity, an example from Sweden.

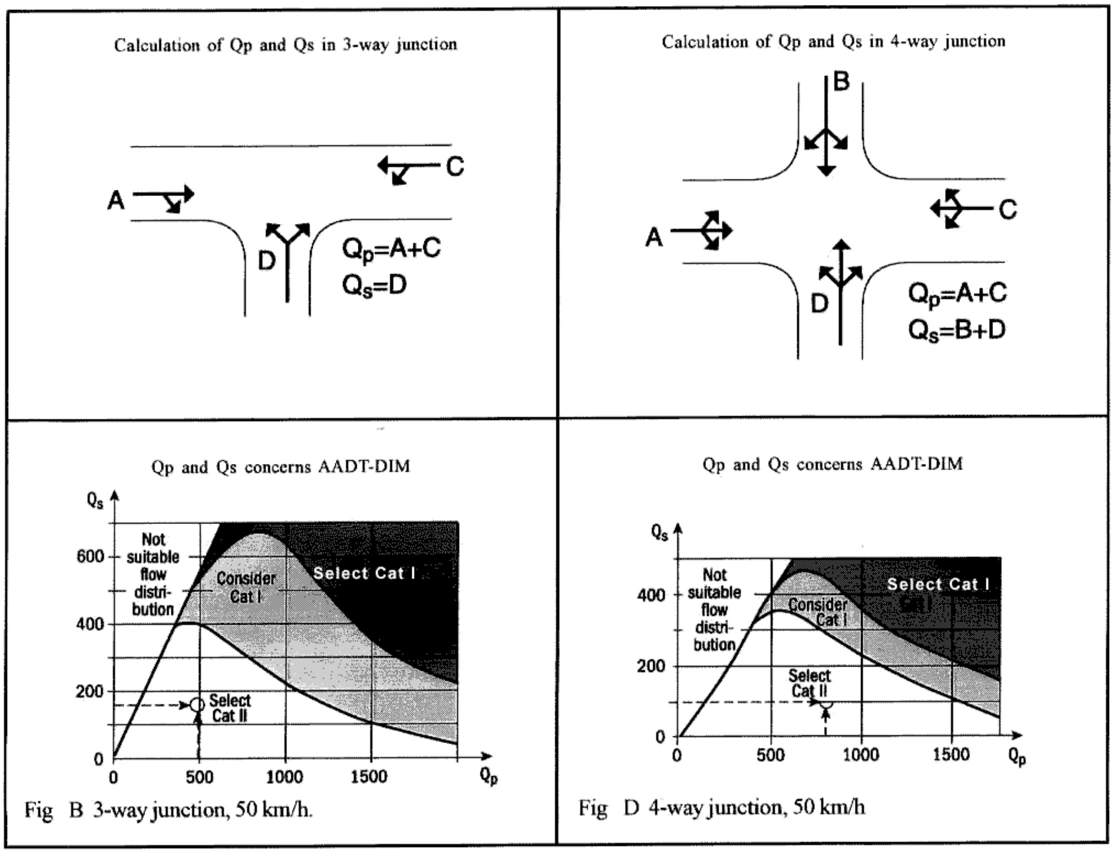


Fig B 3-way junction, 50 km/h.

Fig D 4-way junction, 50 km/h.

C, E: Types of junction appropriate to different traffic flows considering safety, an example from Sweden.

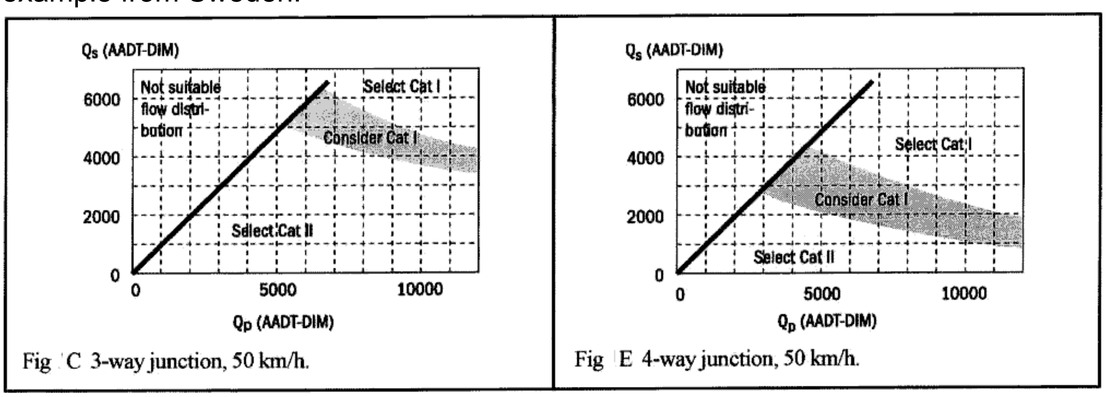


Fig C 3-way junction, 50 km/h.

Fig E 4-way junction, 50 km/h.

Source: Brüde et al 1998

In France, the choice of type depends on classification of both involved roads as shown on the *Figure 4.4*.

Figure 4.4: French table for type of road and type of junction

	Motorway A	Motorway B	Urban artery	Distribution road	Local road
Motorway A	motorway interchange	– motorway interchange – road interchange	– road interchange	– partial road interchange – on side roads with give-way or stop sign	
Motorway B		– road interchange – signalised junction – roundabout	– road interchange – signalised junction – roundabout	– signalised junction – give-way or stop sign	– on side roads with give-way or stop sign
Urban artery			– road interchange – signalised junction – roundabout	– signalised junction – roundabout – give-way or stop sign	– on side lane with give-way or stop sign
Distribution road				– signalised junction – roundabout – give-way or stop sign	– signalised junction – give-way or stop sign
Local road					– give-way to traffic from right – give-way or stop sign

Source: Brüde et al 1998

In Denmark, the choice of junction type is based on the desired speed on the major road (*see Figure 4.5*).

Figure 4.5: Relationships between type of junction and desired speed on the major/primary road. An example from Denmark.

Type of junction	Speed class			
	10–20 km/h	30–40 km/h	50 km/h	60–70 km/h
Signalised		x	x	x
Priority, X-type		(x)	(x)	(x)
Priority, T-type		x	x	x
Raised side-road junction	x	x	x	(x)
Roundabout		x	x	x
Uncontrolled	x	(x)		
Relations marked by (x) are not advisable and should therefore not be used for new construction projects.				

Source: Brüde et al 1998

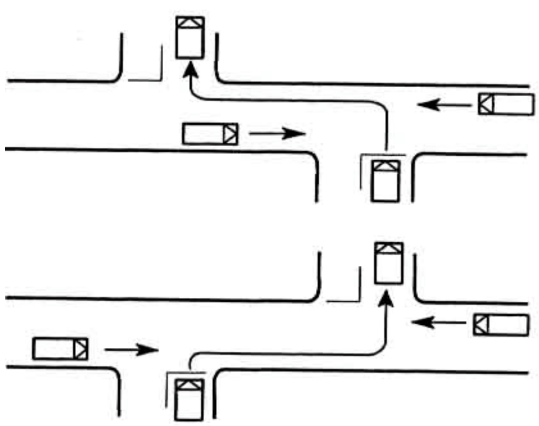
4.1.5. Priority junctions

Priority junctions are junctions controlled by either stop or give-way lines or signs. There are three main types of priority junctions: T-junction (3 ways), X-junction (4 ways) and the staggered junction (two immediately following altering T-junctions).

Priority junctions are appropriate where the traffic flows on minor roads and the overall numbers of turning manoeuvres are relatively low. Junctions carrying heavy traffic require other types of control because when the traffic volume increases, the risk of accidents at priority junctions increases. As delays in traffic flow increase on the minor road, motorists may attempt to use unsuitable gaps to break into the major traffic stream.

The number of accidents and their severity is normally considerable greater at 4-way junctions than at 3-way junctions. Therefore, two staggered T-junctions (*see Figure 4.6*) are normally safer than a single X-junction. A Swedish study (Brüde, 1991) recommends to use a left-right stagger in a rural environment and a right-left stagger in an urban environment. In rural environments, left turns from the primary road are most dangerous. In urban environments, however, left turns from the secondary road are most dangerous. Bared & Kaisar (2001) states that expected reduction in total accidents when two staggered T-junctions are used instead of 4-arm priority junction in rural areas, is 20 to 30 % for 2x2 lanes and 40 to 60 % for 2x4 lanes intersections. For urban signalised intersections with 2x2 lane, the reduction of accidents is about 20 % and also a noticeable reduction in travel time is noted at high flows.

Figure 4.6: Example of right- and left- staggered junction. The first case is suitable for rural roads, the second case is suitable for urban areas.



Source: Danish Road Directorate 1998

Priority junctions are normally safer without extra left- and right- turning lanes because the junctions are easier to survey and the traffic situation is not so complex. Vehicles turning in lanes can create sight problems because of shadows. However, left-turning lanes may increase safety, where left-turning and through traffic flows are high.

Traffic islands (channelisation) usually increase safety, particularly where entering and turning movements are frequent and where pedestrians and cyclists cross the road, since they have to pay attention only to one direction of traffic at a time and crossings are shorter.

4.1.6. Junctions with give-way to traffic from the right

Junctions without any designed priority are generally safer than priority junctions, but their capacity is reduced. The explanation is that vehicles approaching from all directions have to considerably decrease their speed.

4.1.7. Signalised junctions

Signalised junctions are safer and more suitable than priority junctions in case of higher volume on both the major and the minor road, numerous vulnerable road users, roads having three or more marked lanes on the free sections, insufficient overview on single-lane sections or the junction being in a location with many accidents expected. French and Danish studies showed that given identical traffic conditions, signalised junctions are safer than priority junctions. Only increase was experienced in front-rear collisions, but mostly with minor injuries (Danish Road Directorate, 1998). Traffic signals can also provide the possibility of giving priority, e.g. to ambulances and public transport, when needed. The disadvantage of traffic-signal control is that it can increase delays and operating costs in uncongested conditions. In some countries, the traffic lights are set to flashing amber at night. Several studies showed that flashing amber at night increases the number of accidents. The same effect has been observed for deactivated lights.

Traffic signals require special layout to provide traffic islands for channelling turning vehicles. Junction layout should reflect traffic volumes and patterns, as well as pedestrian needs. Traffic lanes should ideally be allocated for each of the vehicular movements allowed, but lane sharing will often be necessary at restricted sites. Lanes that are too narrow can cause safety problems for large vehicles, which approach the kerb and pavement too closely. Traffic signals installations must not be placed so close to each other that road users can misunderstand the traffic areas to which they apply.

The allocation of green-time to each direction can be implemented by using one of two implemented fundamental principles; time-controlled signalling and/or vehicle-actuated signalling. The first type usually has several settings for morning, evening, off-peak or weekend traffic situations. Vehicle actuated signals can dynamically react to the current traffic situation and they can automatically change their own program. Signal systems may also be co-ordinated in order to create "green waves". A green wave means that a driver, once he has passed or started at green light at the first junction, will be able to pass through the following junctions without stopping again if he drives at the intended speed for the wave. The disadvantage is that the green wave optimised for cars is not usually optimised for cyclists or pedestrians.

4.1.8. Roundabouts

Roundabouts have existed as a part of the road system since the beginning of the century. The traffic circulating in a roundabout was obliged to give way to incoming traffic, which was satisfactory until traffic intensity became excessively high in the 1950s. In the 1970s, it once again became common practise in European countries to construct roundabouts as a result of changes in right-of-way regulations, which gives a priority to circulating traffic over incoming traffic. The roundabouts are practical and effective solution to improve traffic safety and their use is increasing nowadays. Therefore this topic is discussed more into the depth in the Master's Thesis.

The studies about safety, environmental and operational effects of roundabout use were summarised by Martens, Comte & Kaptein (1997). They states that roundabout is an effective speed management tool, but its effectiveness is mediated by the extent to which drivers are forced into an actual roundabout manoeuvre. A large roundabout, used to mark the entrance to a small town was successful at reducing traffic speeds. Roundabouts also decrease straightness of the road as perceived by drivers.

Some studies show that roundabouts have accident rates almost 50 % lower than junctions with traffic signals, others states that the accident rate is approximately the same, but the severity of accidents is reduced because of low speeds (20-30 km/h). It is supposed to be due to small collision angles and reduction in the number of collision points (*see Figure 4.7*).

Figure 4.7: Conflict points at roundabouts and 4 way junction

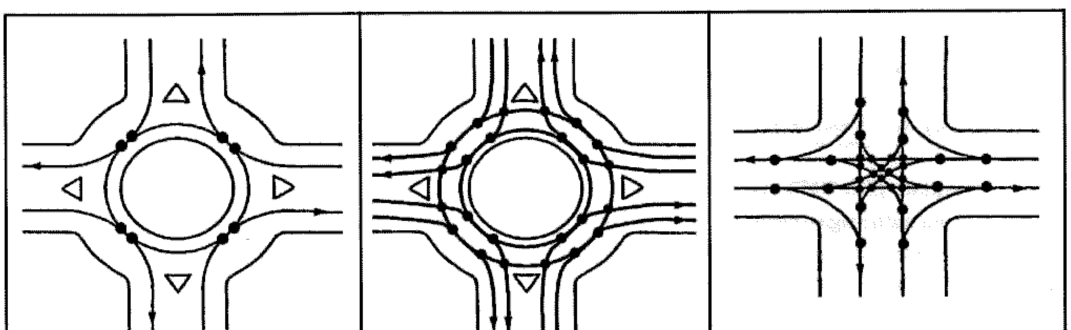


Fig A. Single lane roundabout, 8 conflict points	Fig B. Two-lane roundabout, 24 conflict points	Fig C. 4-way junction, 32 conflict points

Source: Brüde et al 1998

Most studies summarised by Martens, Comte & Kaptein (1997) reported improved safety and interplay between road users and traffic noise reduction. At mini-roundabouts fuel consumption and emission increased somewhat. According to Dagersten (1992) roundabouts has generally higher capacity than intersections controlled by traffic light. Total time delay on roundabout is decreased by 60 to 97 %. In the case of replacement priority junction by mini-roundabout time delay for car on former major road rose, but dropped for cars on minor roads (Várhelyi 1993).

Roundabout design

Design criteria differ significantly from country to country, but general pre-requisites and conditions for the introduction of roundabout are:

- *high proportion of traffic on minor road*
- *the need to reduce speed on the intersecting roads*
- *the requirement for more equal distribution of waiting periods between two roads*
- *the requirement for smoother traffic flow and a lower noise level*
- *high fluctuation of traffic flow*
- *improved aesthetics*
- *more than 4 arms of the junction*
- *irregular angles of arms*
- *high number of accidents*

Roundabouts can be classified as mini, small and normal according to the size of the central island. Mini-roundabouts have a radius of less than 2 metres and the central island normally consists only of road markings. Large trucks are permitted to cross the central island or even to make turns on the wrong sides of the island. This type of roundabout is a relatively cheap solution and is useful for example at residential areas, but it is not very suitable for cyclists.

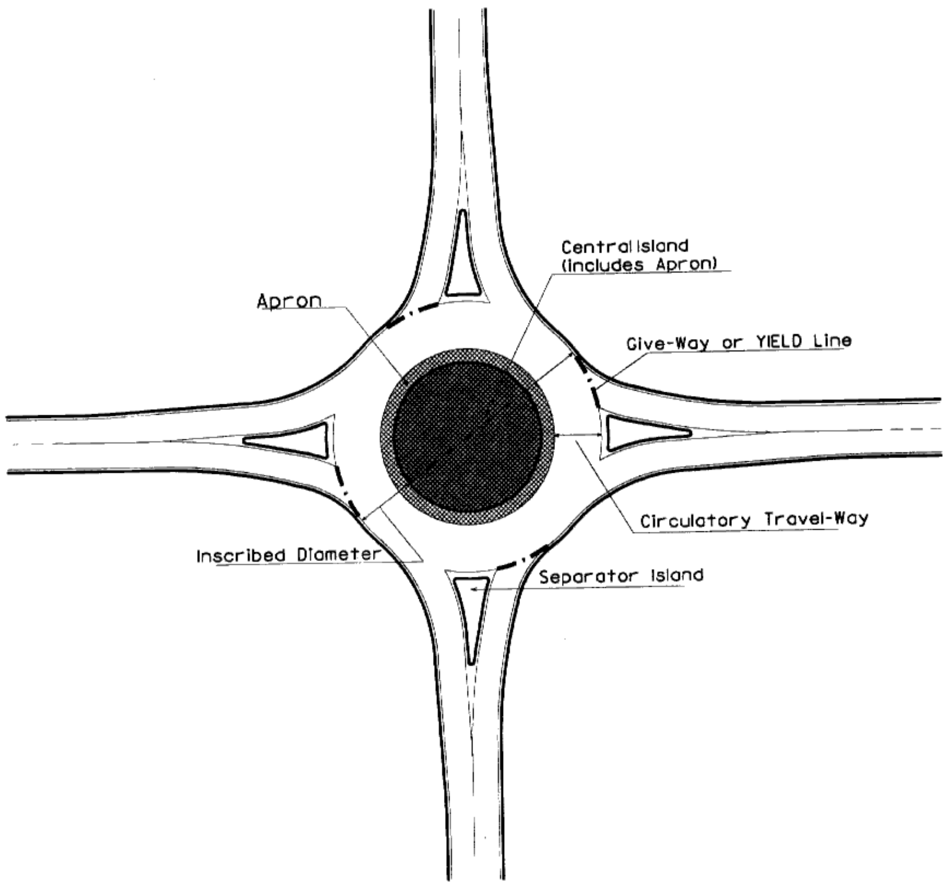
At small roundabouts, the central island often forms two circles, the inner one having a radius of 4-6 m and the outer one a radius of 8 – 10 m. The area between the circles can be used as a short cut by large trucks, but should cause discomfort when driving through this area due to changed texture or elevation.

At normal, major urban roundabouts, the central island usually has a radius of at least 10-15 m, which allows large trucks to drive around the island. The width of the circulating area must then be adjusted, often to 6 –10 m, to provide sufficient space for large trucks.

Design elements

A study with an international comparison of design elements of roundabouts was carried out by Bared, Prosser & Esse (1997). Among others they found followings; Typical modern roundabout and its entries and exits consist of design elements such as central island (with apron), circulatory roadway, give-way or yield line, separator island (*see Figure 4.8*). The basic considerations for the proper design of roundabouts are design speed, sight distance and deflection from direct trajectory.

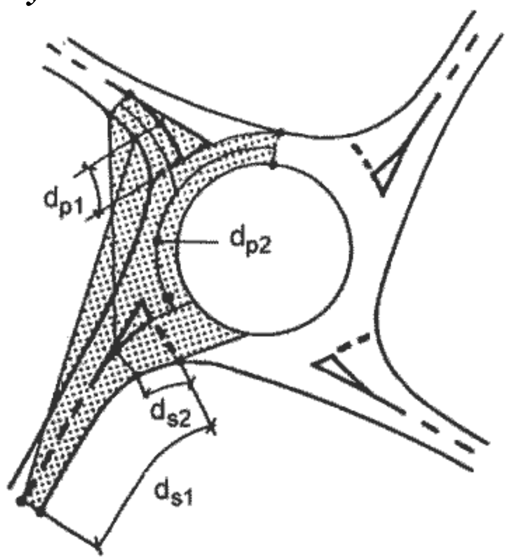
Figure 4.8: Typical roundabout terminology



Source: Bared, Prosser & Esse 1997

Site visibility is an important concern in designing roundabouts and stopping sight distance to separator island should always be ensured. Other required sight distances are left-side visibility of the circulatory travel-way and visibility of the left-side approach at 5 to 10 m from the yield line of an entry, because a driver approaching the roundabout or waiting at the yield line should be able to observe both the traffic in the roundabout and the traffic in the roundabout in the entrance to his left (*see Figure 4.9*).

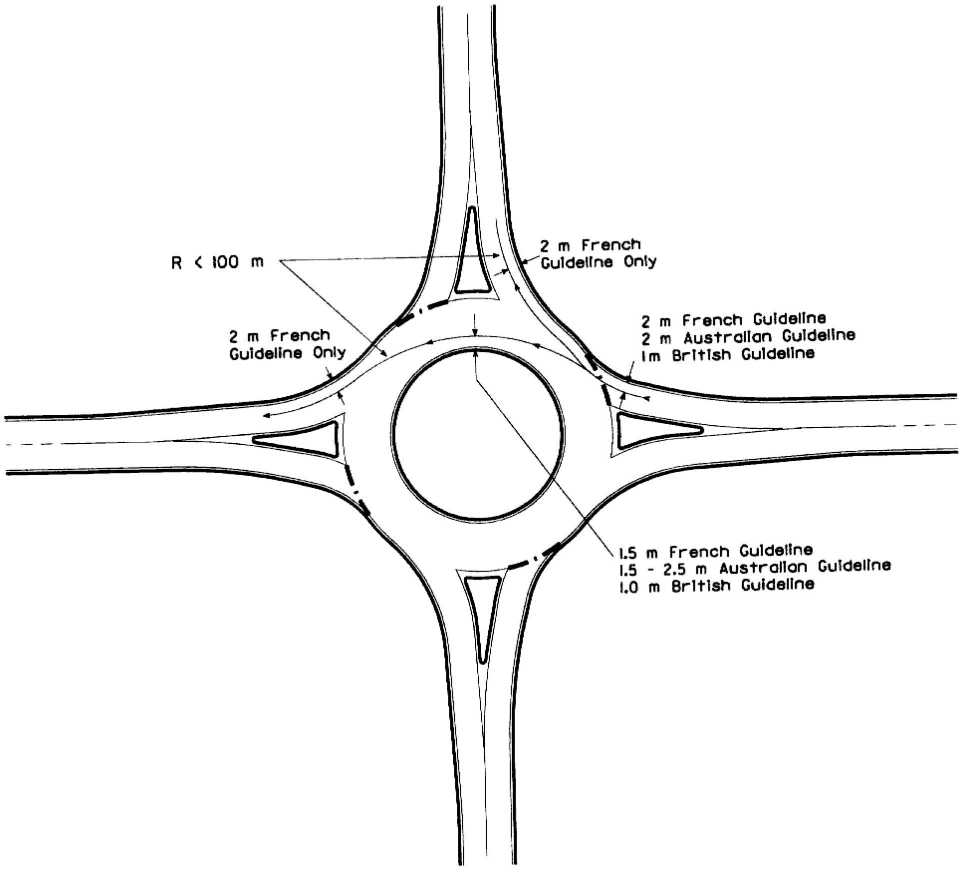
Figure 4.9: Sight triangles at a roundabout where entering traffic has to give way



Source: Brüde et al 1998

The features of the roundabout cause that even cars going in through direction, otherwise on priority junction going straight, have to deviate from straight trajectory. This movement is called **deflection** (*see Figure 4.10*). The purpose of deflection is to reduce speed for through direction at a roundabout. The single most significant feature of a modern roundabout is to provide entry, through and the exit deflections. Each deflection should be developed with an individual radius not exceeding 100 m, linked to design speed 40 or 50 km/h. To guarantee speed in the range 30 km/h or less, radii should be less than 50 m in the connecting curves between the circulation area and the entrance or exit lanes (Brüde et al, 1998).

Figure 4.10: Schema of deflection at a roundabout



Source: Bared, Prosser & Esse 1997

A **central island** consists of a raised, often landscaped, nontraversable area and truck apron. The central island should be visible from all directions at a distance. This could be obtained by making the island elevated in comparison with the carriageways and by providing it with "soft" objects, e.g. bushes. The shape of the central island should be circular (not oval) in order to prevent speeding and to provide skewed entry angles. Irregular radius of a circulatory area could also cause problems in drivers' radius estimation. Wider inscribed circles do not increase capacity considerably, but provide necessary deflection. When a nontraversable central island is small, swept paths for articulated vehicles require a mountable paved area of apron of 1,5 to 2,5 m. The mountable area or apron cross slope should be steeper than that of the circulatory roadway (4 to 5 %) to provide faster drainage and discourage passenger vehicles from driving on it. Central islands should be clear of hard objects other than breakaway devices.

The **approach width** at entries depends on the roadway width and the design vehicle. The widening of a single lane entry to two lane may increase capacity, but there are some indices that the safety level is decreased. At high approach speeds, it is advisable that vehicle speeds gradually be reduced by means of horizontal reversed curves according to the principle of design consistency (*see Figure 4.11*).

Figure 4.11: Three reversed curves at a roundabout approach

Source: Bared, Prosser & Esse 1997

Roundabout approaches can be designed in two ways: radial or staggered. Staggered approaches accentuate deflection at entries. British guidelines recommend an entry angle of between 20 and 60 degrees, with the best angle being 30 degrees. Auxiliary right turn lanes should be considered when right-turn traffic flow is more than 50 % of the entry flow or more than 300 vehicles during peak hour.

Splitter islands should be provided on roundabouts approaches in both rural and urban areas. The objectives of the splitter island comprise:

- *The allow drivers to perceive the upcoming roundabout and reduce entry speed, and they provide space for a comfortable deceleration distance.*
- *They physically separate entering and exiting traffic and prevent wrong-way movement.*
- *They control entry and exit deflection.*
- *They provide a refuge for pedestrians and bicyclists and a place to mount traffic signs.*

The variety of roundabout design standards is shown on the *Figure 4.12*.

Figure 4.12: Design Elements Stated by Three Guidelines

Description	British	Australian	French
Central island diameter (at the non-mountable curbs)	Minimum 4 m	Minimum 5 m Recommended >10 m Typical 20-30 m	Minimum 7 m
Width of circulatory travel-way (curb to curb)	Maximum 15 m		Minimum 6,5 – 8,5 m Maximum 9 m
Inscribed circle diameter	Minimum 15 m Maximum 100 m		
Cross-Section of circulatory travel-way	Adverse and crowned x-section Recommended 2 – 2,5 %	Adverse x-section Minimum 2,5 – 3 %	Adverse x-section Recommended 1 – 2 %
Entry width (curb to curb)	Minimum 4 m Maximum 15 m	Minimum 5 m	Recommended 5 m for 1 lane approach 8 m for 2 lane approach
Entry radius	Minimum 6 m Recommended 20 m		Recommended 10-15 m Entry radius < inscribed radius
Exit width (curb to curb)	Recommended 7 – 7,5 m	Minimum 5 m	Recommended 5 - 6 m for 1 lane 8 m for 2 lanes
Exit radius	Minimum 20 m Desirable 40 m		Minimum 15 m Maximum 30 m Exit radius> Central Island Radius
Length of separator island	20 – 50 m	Comfortable deceleration length (high speed)	Equal to radius of inscribed circle
Lighting	Required	Required	1. Required if approach is already lighted 2. Otherwise not required in rural areas

Source: Bared, Prosser & Esse 1997

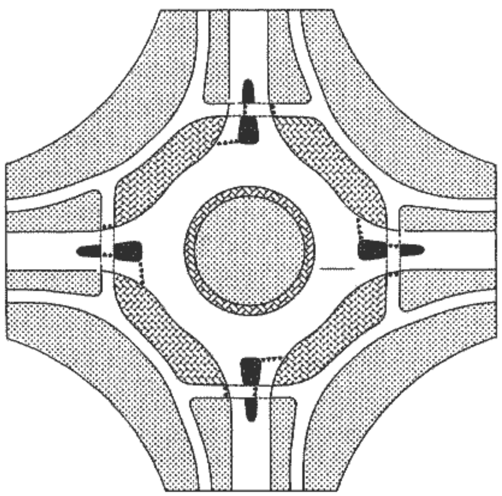
Safety and other considerations

The capacity depends on the total number of incoming vehicles from the entry arms, the number of crossing pedestrians, the number of cyclists in the roundabout, the width of the central island, the width and the number of lanes in the circulating area and the distance between the entry lanes. Single lane roundabouts can provide a traffic capacity up to AADT 15-24 000. There is not a general agreement about capacity benefits of two-lanes roundabouts. The cost of a roundabout varies widely and can range from $ 45 000 - 150 000.

From the safety point of view, roundabouts should preferably be designed small with only one lane, in the entrance, exit and circulating areas. This solution is most friendly to vulnerable road users. Small roundabouts, however, provide smaller capacity. Low speed is of special interest where pedestrians and cyclists are crossing the entrance and exit lanes.

Cycle tracks and lanes at roundabouts create special problems. Basically, three principally different designs may be used. The simplest design, no extra facility for cyclists, may only be used where cycles are not separated from cars before and after the roundabout. The second design, cycle lanes at roundabouts, is not proved to provide improved safety for cyclists. Studies indicate that third design, with a separate track with an ordinary cycle crossings (*see Figure 4.13*) is the safest design except grade-separation of cyclists. The crossing should be recessed by 2-5 m from the roundabout in order to avoid congestion in the circulation area and to provide a driver sufficient time to react.

Figure 4.13: Example of roundabouts with separated cycle tracks



Source: Danish Road Directorate 1998

Safety problems at roundabouts

Brown (1995) summarises the most common problems affecting safety at roundabouts. A basic problem is excessive speed at the entry or within the roundabout. The factors mostly affecting safety at roundabouts are:

- *Inadequate entry deflection;*
- *A very small entry angle which encourages fast merging with circulating traffic;*
- *Poor visibility to the give-way line;*
- *Lack of lighting;*
- *Poorly designed or positioned warning and advance signs;*
- *"Reduce Speed Now" signs where provided being incorrectly sited;*
- *More than four entries leading to a large configuration;*
- *Low level of skidding resistance on the approaches to roundabouts and on the circulatory carriageways;*
- *Abrupt and excessive superelevation in the region of the entry region;*
- *Excessive entry width*
- *Improper type of central island kerb*

Low merging angles force drivers to look over their shoulder or to use their rear-view mirror. It decreases attentiveness and evokes higher entry speed. The opposite - high entry angles - produce excessive entry deflection and can lead to sharp braking at entries accompanied by "nose to tale" accidents. Brown recommends an entry angle of 30 degrees.

Signing at roundabouts should not be overused. According to several studies the number of direction and warning signs on the approach had no significant effect on accident frequency of any type. In dangerous entries, however, chevrons, give-way or reduce speed signs may improve safety. Some studies also indicate that a lack of a consistency in destination signing could lead to confusion and possibly generate accidents.

Furniture of the central and deflection island should be minimised and together with lighting columns, should be located clear of over-run paths and visibility envelopes. Chevrons and right(left)-turn signs should be set back from the central island kerbline to reduce obstruction to visibility.

One example of a successful design element is a continuous highly visible chevron marking applied at roundabouts in Oxfordshire, UK. The marking consists of reflectorised black and white concrete black paving in chevron pattern sloping inwards from the central island kerb. The treatment enhances the driver's perception of the presence of the junction and is claimed to reduce overrunning. The advantage is that it does not obstruct circulatory visibility as much as a chevron board.

An improper type of central island kerb, e.g. with high profile, can be a danger to vehicles over-running the entry. These kerbs may result in loss of control or overturning of vehicles.

4.1.9. Grade separated junctions

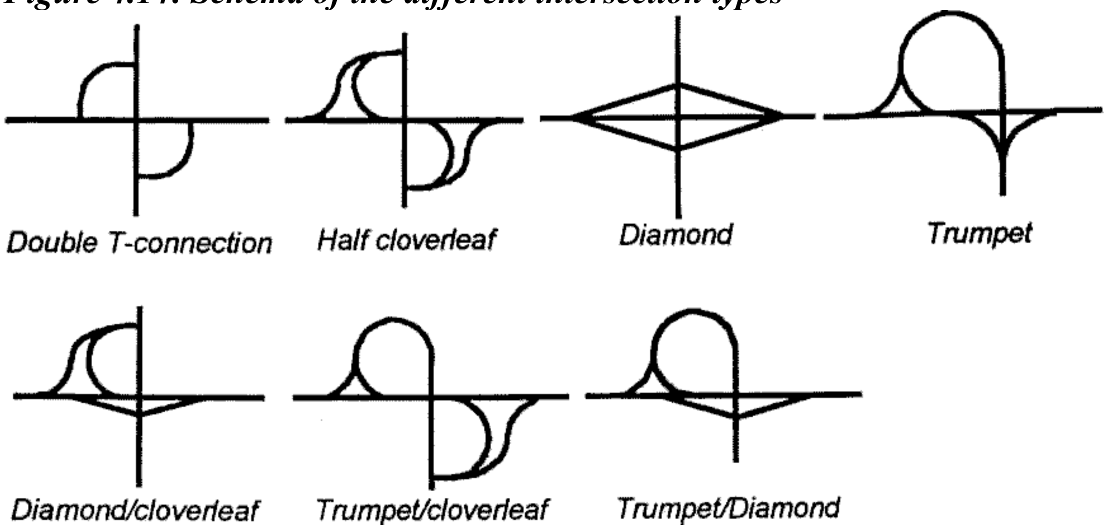
Grade-separated intersections are suitable for main roads, where high capacity, a good traffic performance and high traffic safety standards are important criteria. Grade-separated intersections are especially suitable when high travel speeds are necessary and when there are short distances between the junctions.

The average traffic risk level for grade-separated intersections is fairly low, and below most empirical accident rates for ordinary at-grade junctions (compare the *Figure 4.1*). In contrast to at-grade junctions, grade-separated junctions are relatively safe even for higher driving speeds and for higher proportion of vehicles coming from the secondary road.

The disadvantages of grade-separated junctions are high construction costs and large area requirements. Grade-separated junctions can also influence drivers to increase speed, which may in turn increase accident rate at adjacent road sections.

There are several basic types of grade-separated junctions (*see Figure 4.14*).

Figure 4.14: Schema of the different intersection types



Source: Johannessen 1998

According to Norwegian study (Johannessen 1998) most of the accidents on grade-separated intersection occur at the primary road link within the intersection and at intersection of the secondary road and the ramp. Accidents at primary road links are typically accidents at high speed with serious consequences or fatalities. It seems to be a good solution to use a roundabout for the secondary road connections (*see Figure 4.15*). On the primary roads, the risk at entries is generally higher than the risk at the exits. From the safety standpoint, the direct entry without parallel accelerating lane to the primary road is not favourable.

Figure 4.15: Funnel-shaped roundabout in Slovenia, Tomacevo

Source: Tollazzi 2001

4.1.10. Individual elements at junctions

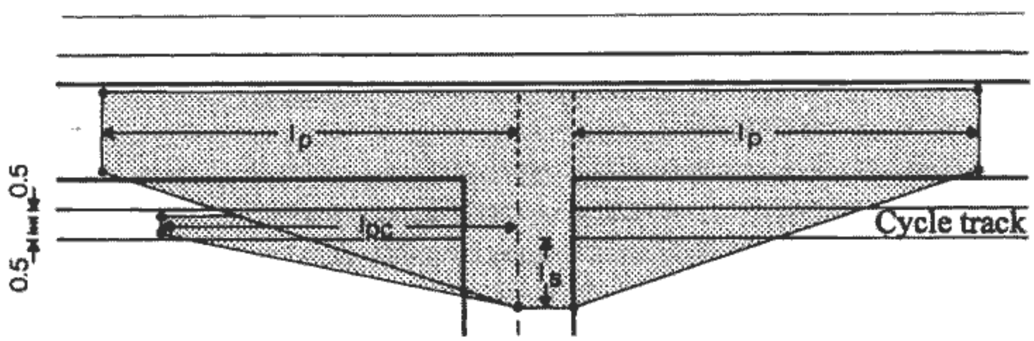
Sight distance

It is essential for a safe interaction between road users at junctions that they can see each other in good time before the junction. The visibility is usually ensured by a visibility splay. The visibility splay at a junction is the triangular area which enables a road user to survey the junction adequately and safely. The stopping sight distance is the distance which is needed to react and stop safely and depends on the speed of the vehicle.

The shape and size of a sight triangle will depend on the type of junction, the speeds on the intersecting roads and the mode of control. The sight triangles must be free from sight obstacles. In the design of sight triangles at junctions with more than one lane in each direction, e.g. left or right turning lanes, it is necessary to have in mind that there is always a risk of an approaching vehicle in the nearest lane concealing a vehicle in the adjacent lane.

Consideration has to be paid to vulnerable road users. Visibility to and from the cycle track must be ensured (*see Figure 4.16*). To be able to cross a carriageway at a junction safely, also cyclists must have a sufficient overview of the traffic on the road to be crossed. They should be able to estimate the distance and speed of the traffic. The necessary sight distance depends on the approaching speed of the crossing traffic. The time a cyclist needs to be able to cross the carriageway from the stop position depends on the physical condition of the cyclist. The elderly and children need more time for this than healthy cyclists do.

Figure 4.16: Danish Road Guidelines - Sight triangles at a junction with a cycle track parallel to the primary road.



Source: Danish Road Directorate 1998

The visibility length l_s in the *Figure 4.16* above should be 2,5 m and visibility length along the primary road l_p depends on desired speed on the primary road as shown on the *Figure 4.17*.

Figure 4.17: Danish Road Guidelines - Visibility distance along the primary road

Desired speed (km/h)	70	60	50	40	30
Sight distance l_p (m)	145	120	95	75	55

Source: Danish Road Directorate 1998

Vehicle lanes

Lanes are intended to provide the various road user categories with a defined area to use. All types of motor vehicles, however, use most vehicle lanes, but in some cases lanes may be designated for specific categories, e.g. buses. Normal widths with more than one lane in each direction are 3-3,5 m (for 50-70 km/h) for the primary road and at least 3,5 m with one lane in each direction on the secondary road. Excessively narrow lanes can create safety problems, particularly with heavy vehicles.

Generally, the use of extra lanes at junctions is doubtful from the safety aspect since each additional lane makes it more difficult to survey the junction, to understand its function and to control the situation. Moreover vehicle in one lane may conceal vehicle in another lane. Often, extra lanes lead to increased speeds, which gives the road user less time to make right decisions and makes accidents more severe. If left turn lane present then it should be single lane. From the safety point of view, secondary roads should preferably have only one entrance and one exit.

At junctions, where cars and cycles both use the traffic lanes, extra lane for traffic turning from the primary road should be normally avoided. There is a risk of dangerous conflicts between turning cars and cycles travelling straight ahead. Where there is a cycle track along the road, however, a lane for turning cars can act as a speed change lane and thereby reduce rear-end collisions between through traffic and turning vehicles. It can also provide a queuing area for turning vehicles that have to yield or stop before a cyclist or pedestrian crossing in the secondary road.

Cycle tracks and lanes

A cycle track or a cycle lane is an area along a carriageway reserved for cyclists, usually with a width of 1,0 – 2,2 m (one-way) or 2,5 m (two-way) over. A cycle track, in contrast to a cycle lane, is separated from the carriageway by means of a kerb and usually also from any pedestrian pavement by the same means. A cycle lane is an area on a carriageway reserved for cyclists by marking which consists of a line along the edge of the carriageway (Brüde et al 1998).

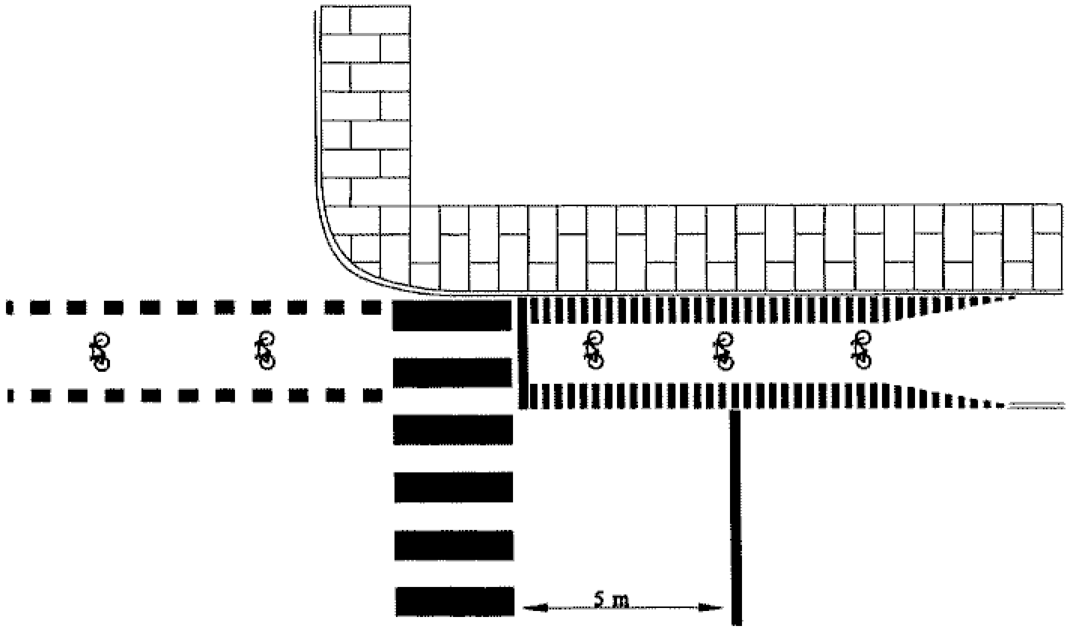
A cycle lane can be used for one-way traffic, but cycle tracks can be used for both one-way and two-way traffic. In some cases, cycle lanes are used for contra-flow traffic on one-way streets, although this usually requires special design of the junctions. It is normally considered that cycle lanes should be used only where speeds are 50 km/h or less and the proportion of heavy traffic is small.

Cycle tracks are considered safer for cyclists travelling straight ahead at a signalised junction than cycle lanes within junctions. Especially cyclists on cycle lanes are often involved in collisions with cars turning right. It is generally agreed that there must be a good interaction, which requires visual contact in advance, between cyclists and drivers of turning vehicles before they arrive at the potential conflict point.

There are several improvements to make junctions safer for cyclists, which differs according to the type of a junction.

A successful solution for **signalised crossings** is shown on the Figure 4.18. The cycle track is truncated, but combined with a more narrow cycle lane on the last 30-50 m up to the junction. Cyclist drive at the same vertical level as motorists, but are separated from them by a 30-cm-broad, white, profiled marking. The cycle lane across the junction is intended to increase the attentiveness of motorists to cyclists, and to show them how far into the junction they can drive without inconveniencing the cyclists.

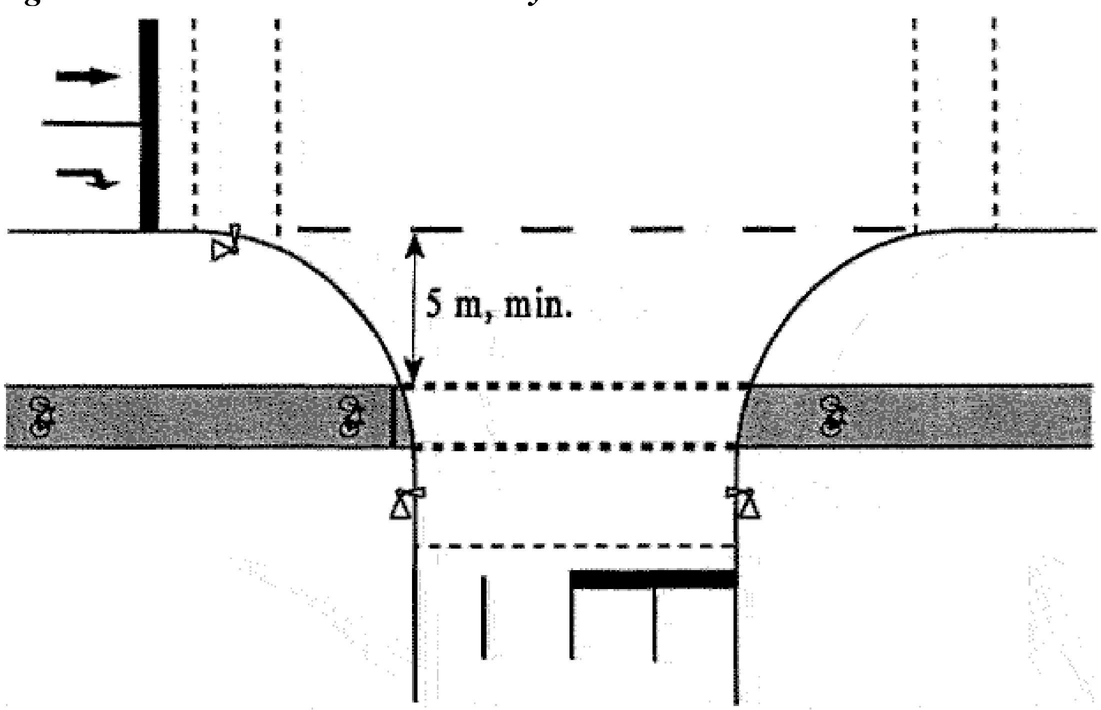
Figure 4.18: Junction with recessed stop line, truncated cycle track and cycle lane across the junction



Source: Danish Road Directorate 1998

Another design example for signalised crossing is a junction where the cycle track has been recessed by 5 m from the vehicle lane (*see Figure 4.19*). This allows turning motorists to stop in front of the cycle track without interfering with through traffic. This solution is suitable for high intensity traffic on the primary road and may be applied also to dual cycle tracks.

Figure 4.19: Junction with recessed cycle track

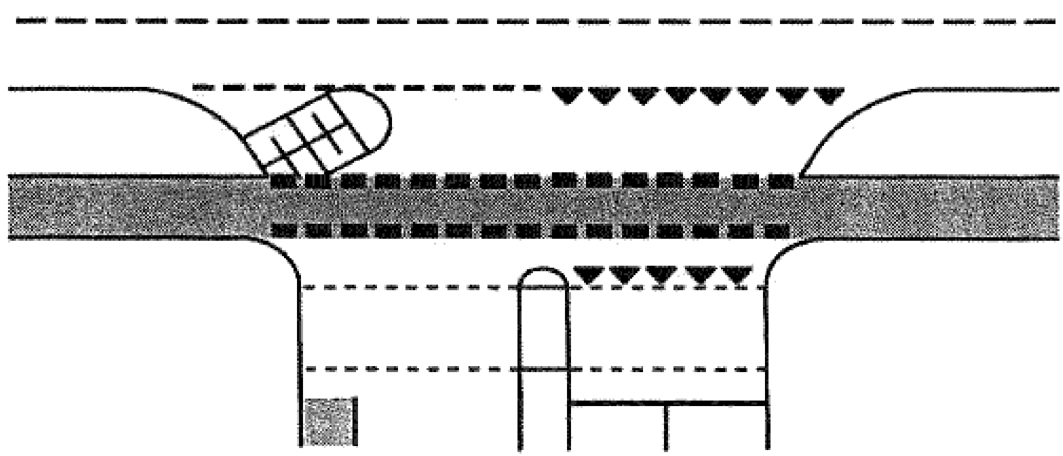


Source: Danish Road Directorate 1998

Where **priority control** is applied to major urban junctions, the geometry of the junction is often an elaborate channelisation for motorists, cyclists and pedestrians. It is often considered useful to interrupt cycle tracks at some distance from the junction give-way line. This makes it possible for right-turning vehicles to merge with through cyclists and, thus, avoids right-turning accidents. Although this solution is clearly inconvenient, it is safer for cyclists.

Another possibility is to recess the cycle track from the road and/or raise all cyclist crossings. The conflicts between right-turning vehicles and cyclists may be reduced by a so-called "Hague Hill", which is a small speed-control hump between the main carriageway and the cycle crossing (*see Figure 4.20*).

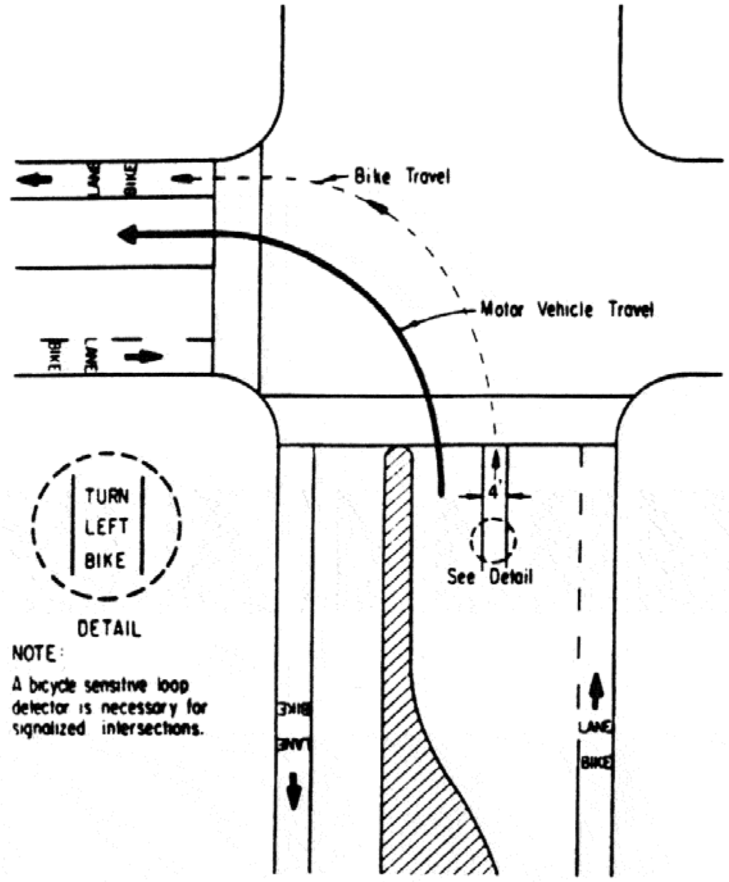
Figure 4.20: The Hague Hill measure



Source: Danish Road Directorate 1998

Many solutions have been tried to make junctions safer for **cyclists turning left** from the primary road, e.g.: a specially marked area on the carriageway of the secondary road, where cyclists can wait before they turn left or separate area for cyclists in front of the lanes for motorists. Another possibility is to use a separate turning lane for cyclists (*see Figure 4.21*).Such a lane can provide for a more orderly flow of bicycles and motor vehicles in the turning movement, especially for roads with a high volume of cyclists turning left.

Figure 4.21: Bike left turn lane



Source: ITE 1997

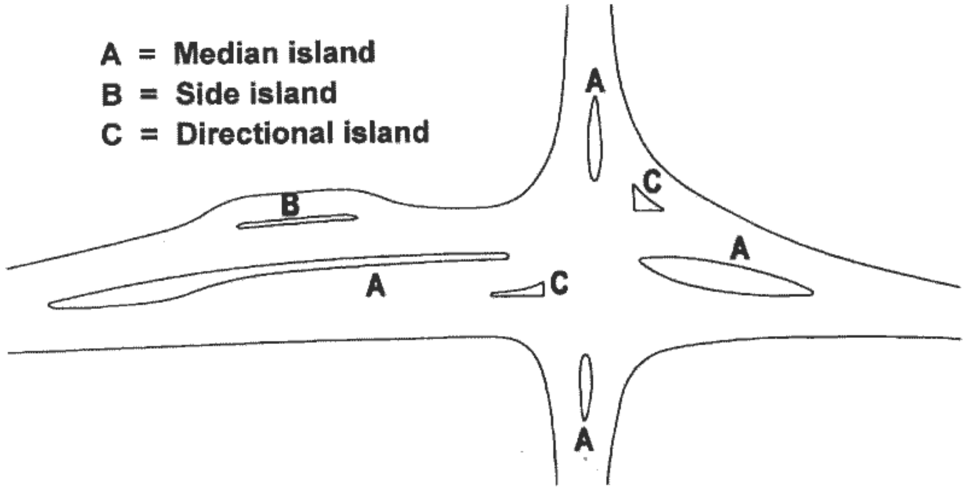
Traffic islands

An island is an area in the junction used for control of traffic movements. Traffic islands at junctions are generally established in order to:

- *Separate and regulate traffic streams and determine their location*
- *Control conflict points and angles*
- *Reduce excessive carriageway area*
- *Protect pedestrians and cyclists (on refuges) and enable them to cross in two stages*
- *Permit turning vehicles to wait clear of through-traffic lanes*
- *Provide space for road equipment*
- *Reduce speeds*
- *Facilitate the overview and comprehension of the junction*

Islands should be located and designed to offer little hazard to road users, while they still should be commanding enough so that motorists will obey them and not to drive over them. Islands can be divided into different categories as shown on the Figure 4.22.

Figure 4.22: Different islands categories



Source: Brüde et al 1997

Islands could be made and delineated either by a raised kerbstone or by paint, i.e. ghost island. Raised islands may sometimes constitute a hazard and be difficult to see at night. They should therefore be made visible in advance either by installing fixed street lighting or by suitable delineation such as road markings or stud and delineator posts. Special caution should be taken with raised islands in the primary road where approaching speeds are relatively high. Ghost islands should be used particularly where approach speeds are relatively high, where pedestrians do not need protection while waiting to cross, where street lighting is not provided and where posts and columns are not needed on the islands.

Hazardous poles and columns should not be placed on small islands. If it is necessary to place a pole on such an island, it should be of a deformable/energy-absorbing type.

In order to improve the overview from a left-turning lane over oncoming vehicles, the establishment of a wedge-shaped ghost island, a so-called "tie" is recommended. The width of lanes must be of sufficient size to permit cars to avoid driving over boundaries of the ghost islands.

In signalised junctions, special islands may be needed for each traffic stream regulated by its own traffic signal phase, e.g. for left turns.

At pedestrian crossings, special refuges ought to be used if the crossing is "longer" than 2 lanes, or for signalised 3 lanes. If a refuge at a pedestrian crossing is designed for pedestrians to wait, the refuge should preferably be more than 2 m wide. This also allows to wheel-chaired and cyclists safely wait on the refuge.

Bus facilities

Bus facilities, such as bus lanes, bus signals and the location of bus stops, are often used at or near junctions in urban areas to improve trafficability for buses. The width of a bus lane should be 3.0 – 3,5 m, but where cycles use the same lane, the width should be increased by 1 m.

Bus lanes are often doubtful from the safety aspects as speeds are higher than in adjacent vehicle lanes. Experience shows that crossing pedestrians can misunderstand a situation with serious injuries as a result (Danish Road Directorate, 1998).

Contra-flow bus lanes, which allow bus traffic against the car flow in one-way streets, may create safety problems as buses approach from an unexpected direction for other road users.

For safety reasons, bus stops should normally be located after the junction, normally at least 10 m, in order to avoid conflicts in the entrance lane (Danish Road Directorate, 1998). After dismounting, passengers should preferably use the pedestrian facilities at the junction.

Bus stops can be designed with or without bus lay-bys. Where the vehicle flow is given higher priority, a bus lay-by should be constructed. On the contrary, where the priority of the buses and the comfort and the safety of the passengers is of the highest priority on road sections, bus lay-bys should not be constructed and a bus at a bus stop should stop or slower vehicle traffic.

Pedestrian facilities

The layout of pedestrian crossings depends on the junction type. Generally the width of a pedestrian crossing should be 3 m or more and should, especially in heavy flows, be applied together with median islands (refuges) in order to allow pedestrians to cross in two stages.

Some countries do not use zebra crossings at signalled junctions. At Danish signalised junctions, pedestrians should always have a separate pedestrian traffic signal over all the arms of the junction. An audible signal makes it easier for the blind and people with impaired vision to locate the crossing area at a signalised junction and different sounds indicate green and red signal.

At prioritised junctions, pedestrians should not cross more than 2 lanes especially when traffic is high (AADT more than 5000) respectively more than 3 lanes at signalled crossings (Danish Road Directorate 1998 or Wramborg 2001). In cases, where there are no separate turning lanes, the pedestrian crossing should, from the capacity standpoint, be recessed by 4-5 m, so that a turning vehicle can wait in front of the pedestrian crossing without blocking the through traffic.

Many studies mention that the pedestrian crossings at roundabouts should be recessed at least 5-6 m from the circulating area located adjacent to any cycle tracks.

Lighting

The primary function of street lighting is to enable persons on or near a road to see road users, any obstacles, the road itself and the nearest surrounding even at night. In addition, lighting can help to emphasise the road alignment and to indicate junctions. In urban areas, all junctions should be provided with lighting.

Many studies have shown that the number of accidents at unlighted junctions during the darkness can be reduced by 20-40 % by installing street lighting. Moreover, lighting reduces especially vulnerable road users accident rate, i.e. to those subject with the most serious consequences in case of an accident.

Lighting columns are, however, dangerous for drivers. Therefore, such posts should be placed either at a safe distance from the carriageway or designed as break-away or deformable/energy-absorbing structures.

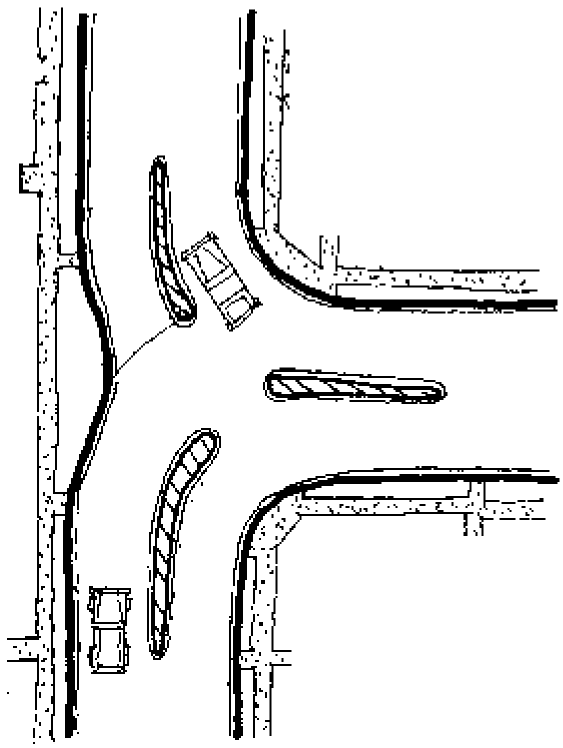
It is also important to avoid dazzling or misleading lights from nearby business, e.g. a petrol station.

4.1.11. Examples of safety improvements at junctions

Modified T-junction

A modified T-junction may be used at priority junction on minor roads, e.g. in residential zones as a speed reducer for through traffic. It involves a gradual curb extension or bulb at the top of the T so that vehicles are deflected slightly as they pass straight through the intersection (*Figure 4.23*). If not properly designed, it can create confusion regarding priority of movement. The costs of modification of T-junction varies from $ 30 000 – 60 000.

Figure 4.23: The layout of modified T-junction



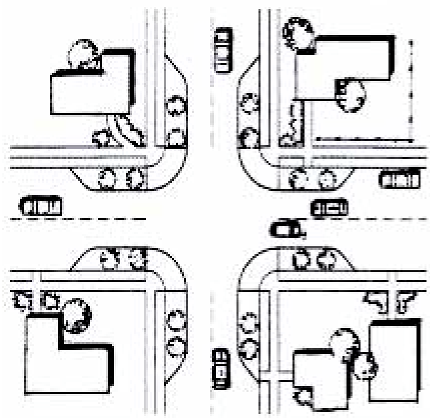
Source: PBIC, 1-internet source

Curb extensions

Curb extensions extend the pavement or curb line out into the parking lane, which reduces the effective street width. Curb extensions significantly improve safety level at pedestrian crossings by reducing the pedestrian crossing distance, improving the ability of pedestrians and motorists to see each other, and reducing the time that pedestrians are in the street. Curb extensions placed at an intersection essentially prevent also motorists from parking in or too close to a crosswalk or from blocking a curb ramp. Turning speeds at intersections are reduced with curb extensions.

The turning needs of larger vehicles such as school buses need to be considered in curb extension design. Curb extensions cost from $2 000 to 20 000 per corner, depending on design and site conditions. Drainage has to be considered for costs.

Figure 4.24: A layout of road narrowing at intersection



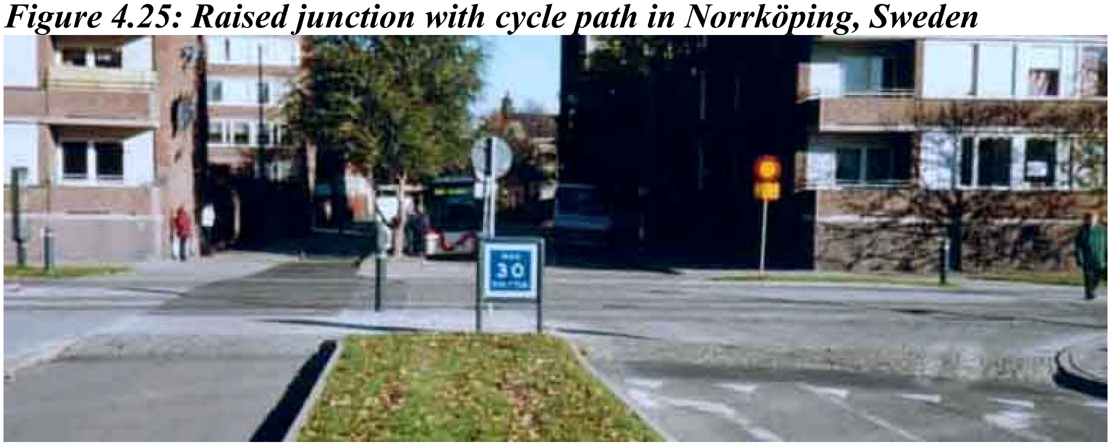
Source: Fehr & Peers Associates, 1- internet source

Raised junctions

A raised junction is essentially a speed table for an entire intersection. The construction involves providing ramps on each intersection approach and elevating the entire intersection to the level of the pavement. They can be built with a variety of materials, including asphalt, concrete or textured material. The crosswalks on each approach are also elevated as a part of the treatment, to enable pedestrians to cross the road at the same level as the pavement.

The cost of a raised intersection is highly dependent on the size of the roads. The cost varies from $25 000 to $70 000.

Figure 4.25: Raised junction with cycle path in Norrköping, Sweden



4.2. Pedestrian crossing facilities

4.2.1. Problem definition

The aim of introduction of pedestrian crossing facilities is to provide pedestrians and often also cyclists with safe and comfortable crossing the road. Well-designed pedestrian crossings increase driver's awareness of pedestrians and cyclists. Pedestrian crossings have to be adjusted to pedestrians and cyclists needs and limitations.

Pedestrians (together with cyclists) belong to a group called vulnerable road users, which is more exposed to traffic risk than other road user groups. It is because they have no protection from any kind of frame and therefore any collision in higher speed has for them serious consequences. For example, European pedestrians and cyclists have 7-10 times higher probability to be killed per travelled kilometre than car drivers and passengers (Rumar, 2000). The share of vulnerable road user fatalities on all traffic-related fatalities is world-wide between 10 and 50 % (Trnka & Sanca, 2000).

Especially some vulnerable road users, such as elderly or children, are due to their specifics more endangered. Young children do not understand well traffic environment, they tend to behave unpredictably and their ability to judge traffic event is limited. Children height causes visibility problems and therefore children can be hidden behind obstacles such as parked cars or some traffic signs. Pubescents are influenced by their older peers and an unfavourable consequence of this influence may lead to risky and irresponsible behaviour.

Elderly or disabled can have both physical and mental limitations. Their speed is limited, senses may be affected by a partial loss of function and they make misjudgement of traffic situation. Moreover there are also conflicts between needs of different groups of disabled persons. For example, blind people wish to have a kerbstone as a border between the pavement and the crossing to indicate the beginning and direction of the crossing. On the Persons using wheelchairs want no kerbstone at all, with the pavement and the crossing on the same level so that no ramps are necessary. Usually, the result is a compromise with a 2-3 cm high kerbstone (Brüde et al, 1998).

4.2.2. Interaction driver – pedestrian at pedestrian crossings

Towliat (2001) summarised results of current studies about pedestrian and driver behaviour at pedestrian crossings. He found that many serious conflicts are caused on by another vehicle travelling in the same direction (overtaking or passing).

Ekman (1988 cited in Towliat 2001) states that cars with an initial high speed did not reduce speed when passing a signalised crossing. Drivers with an initial high speed of less than 50 km/h reduced their speed somewhat, but the reduction was negligible.

A survey (Trafikkontoret i Goteborg, Rapport nr. 10:1994 cited in Towliat 2001) studied pedestrian safety and behaviour at eight non-signalised pedestrian crossings on road stretches and junctions. Speed measurements showed that vehicles approaching the crossings did not reduce speed to any appreciable extent, and that the speeds were 10 to 15 km/h lower at raised crossings. The mean of the 85 percentile speed at four raised crossings was about 30 km/h.

A Finnish investigation (Himanen & Kulmala, 1988 cited in Towliat 2001) studied various factors that affected pedestrian and driver behaviour. They confirmed that the higher the speeds of drivers the less they give way to pedestrians. The critical factor for safety was that drivers' speeds did not matter much for pedestrian behaviour, possibly because pedestrians could not judge the speeds. Pedestrians were more inclined to give way to lorries and buses or a queue of cars than a single car.

4.2.3. Formal rules

Legislation is an important factor for safety on pedestrian crossings. A pedestrian priority on pedestrian crossings should be clearly defined in traffic rules. Problems due to unclear definition of pedestrian priority before the change of appropriate rule were experienced in Sweden. According to Towliat (2001) the original rule was: *"a driver who approaches a non-signalised pedestrian crossing must adapt his speed so that he does not constitute a danger to pedestrians who are either on or about to step onto the crossing. If necessary, the driver must stop to give the pedestrian an opportunity to cross*". Current Swedish legislation has not been able to regulate interactions between drivers and unprotected road users from a safety point of view and thus from May 1 2000 a new rule compels drivers to give way at pedestrian crossings. According to the new rule: "*At a non-signalised pedestrian crossing the driver is obliged to give way to pedestrians who are on or about to step onto the crossing*". The rule for pedestrians was the same in both cases: "*The pedestrians must only set foot onto a non-signalised pedestrian crossing with the due care demanded by the distance and speed of the vehicle approaching the crossing. Away from the pedestrian crossings, the pedestrian can cross the road only if this can be done without constituting a danger or inconvenience to traffic".*

4.2.4. Safety principles

The crucial factor for accident risk and accident consequences is a vehicle speed. Supposed dry conditions and reaction time 1,5s the braking distance is 17m, 33m and 55m for the speed 30 km/h, 50 km/h and 70 km/h respectively and the braking distance may be even up to several times longer for wet or ice/snow conditions. Accident consequences depend on collision speed. If this exceeds 45 km/h, the likelihood for a pedestrian or cyclists to survive a crash is less than 50 per cent but if the collision speed is less than 30 km/h more than 90 per cent of those struck will survive (ETSC 1999). For these reasons the vehicle speed on pedestrian crossings should be limited to 30 km/h.

Very important factor is visibility and adequate sight distance both for motorists and pedestrians. Sight distances must not shortened by on-street parking, street furniture (mailbox, utility poles), landscaping or vegetation. Visibility should be also improved by lighting, especially if night-time crossings are common. According to Danish study (Jensen 1998) the installation of better lighting at zebra crossings give a 30% reduction in the number of pedestrian accidents occurring in darkness. Different colour of lighting in place of pedestrian crossing may bring increased awareness of drivers.

Towliat (2001) suggests three safety principles for pedestrian crossings:

- ***Low speed:*** *The safety can be improved by reducing the speed of all vehicles that pass an interaction point. According to Swedish "Vision Zero", speed of car on streets or locations where there is risk of collision between car and pedestrian or bicycle is reduced to 30 km/h.*

- ***No obvious priority:*** *All road users must, in so far as it is possible, feel equal and avoid obvious feelings of priority*

- ***Improved and relevant information to motorists about the presence of pedestrians and cyclists at intersection points:*** *Provision of such information can increase drivers' awareness.*

Pedestrian crossings should be designed in order to minimise crossing distance for pedestrians. As was mentioned above (see 4.1.10 över, pedestrian facilities) pedestrians should not cross at non-signalled crossing more than 2 respectively more than 3 lanes at signalled crossings at once. Swedish current practise is even more strict; at non-signalised crossing pedestrian should cross only one lane respectively 2 lanes at signalled crossings.

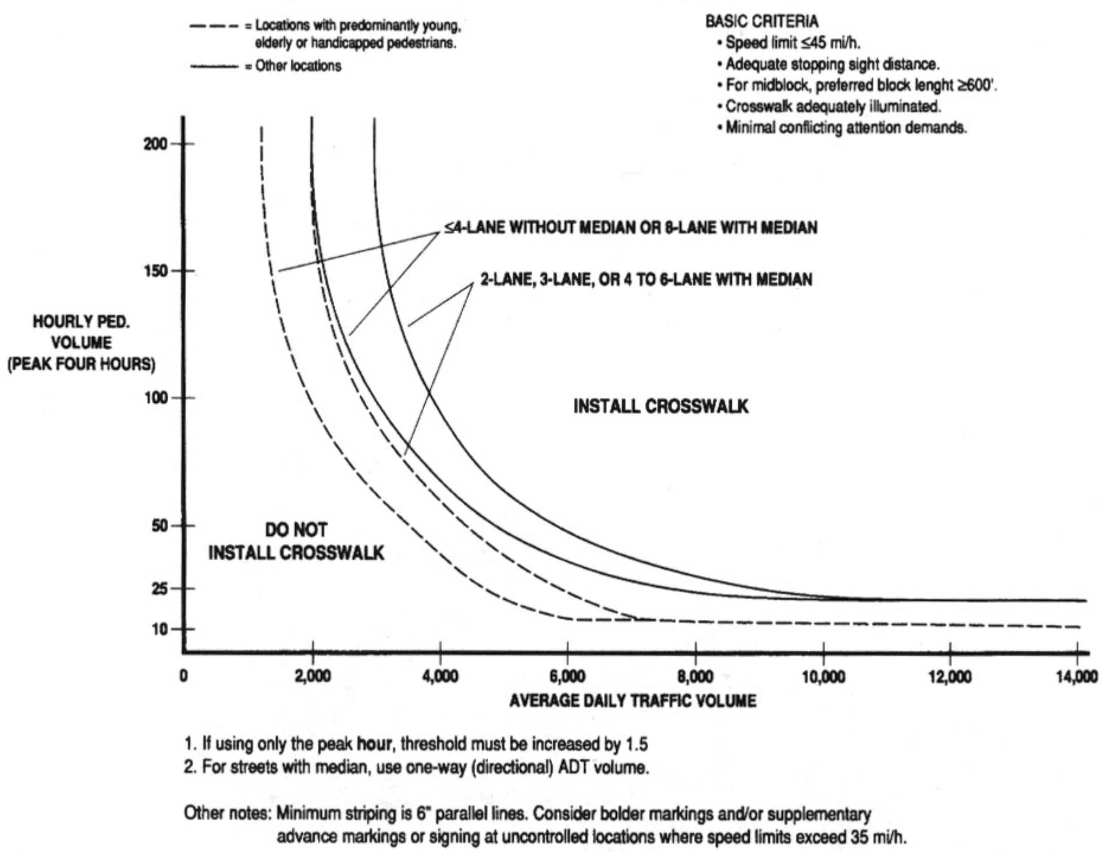
4.2.5. Current practise

The decision about the installation of pedestrian crossings requires a careful judgement. No set of guidelines can cover every condition or guarantee improved safety. Overuse of pedestrian crossings may lead to their decreased effectiveness and high economical costs.

Pedestrian crossings are suitable where they can concentrate multiple pedestrian crossings to a single location or they can delineate the optimal crossing location with the lowest accident risk. Pedestrian crossings may be helpful at location with high children presence or on recommended school routes.

Smith & Knoblauch (1987 cited in ITE 1998) developed criteria relating pedestrian and vehicle volumes for determining when zebra crossing (crosswalk marking) may be beneficial. The chart (*see Figure 4.26*) takes into account road width and presence of children, elderly or disabled persons. Satisfaction of these criteria means that benefits of crosswalk may outweigh economic costs and possible disadvantages.

Figure 4.26: Guidelines for the installation of marked crosswalks at uncontrolled crossings, USA



Source: Smith & Knoblauch 1987

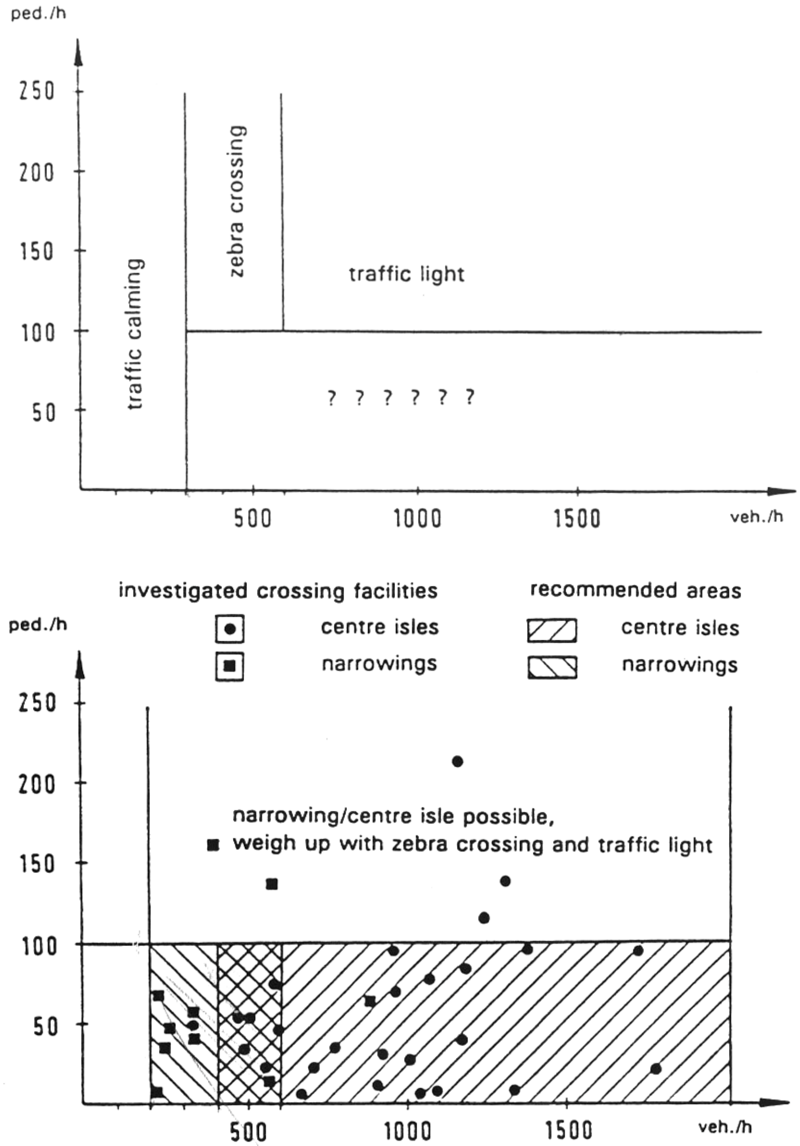
Füsser (1995) differentiates two approaches to solution of the pedestrian safety problem. First one, "hard", represent clear separation between pedestrian facilities and those for cars, while "soft" approach relies on the road user's co-operation in conjunction with an enforcement of low speed limit.

As Füsser farther mentions, "Soft", pedestrian-oriented designs for crossing facilities use the known repertoire of traffic calming and appear to function particularly well on collector roads (including local distributor roads) with a low speed level, especially in "30 km/h-zones".

"Hard", car-oriented designs for crossing facilities do not change the character of a roadway and are mostly limited to the installation of centre isles. They function particularly well on major roads, even in case of a medium-to-high speed level (about 50 km/h), but only if the volume of crossing pedestrians is low and the complexity of the crossing arrangement is straight forward.

Based on these findings, the proposed countermeasures (*see Figure 4.27*) depend on pedestrian and vehicle flow. Central islands are recommended for roads with high vehicle volume, but relatively small pedestrian volume. Traffic calming is useful for roads with high pedestrian volume and low vehicle volume. Use of traffic calming means to include installation of the traffic sign "traffic calming" and high engineering measures ensuring very slow vehicle speeds and equal rights for pedestrians and drivers. This may be substituted by "30 km/h-zone" with a limited use of engineering measures. In case of both high pedestrian and vehicle volume, traffic lights are recommended.

Figure 4.27: Recommended pedestrian crossing measure based on pedestrian and vehicle flow



Source: Füsser 1995

4.2.6. Marked crossings without other measures

Marked road crossings are believed to have a positive safety effect. In fact this statement is not evident and several studies oppose it.

Ekman (1996) found that pedestrians' accident risk is higher for marked crossing than for crossing without any facility. The reason for a higher accident rate is probably due to the false feeling of "safety". Pedestrians crossing the road without any obvious pedestrian protection are more careful. This results in a decrease of the accident rate. Also

Similar result was published in a Norwegian study (Elvik et al 1997 cited in Towliat 2001). Marked crossings without other measures led to an increase in the number of accidents for both pedestrians and vehicles (30 % and 35 % respectively). The increased pedestrian accidents could have been due to a combination of pedestrians' and car drivers' disregard for the pedestrian crossing, and the increased risk within a 50-metre radius of it. The increase of vehicles accidents could be explained by several rear-end collisions. Moreover, there was no difference between a pedestrian crossing at a junction and on a road stretch when it concerned the number of accidents.

According to a ITE (1998) practise guidebook, marked crossings encourage pedestrians to cross within markings compared to crossings without markings, but accident risk including correction for higher pedestrian volume is higher. The explanation could be again pedestrians' "false feeling of safety", because crosswalk markings are not as visible to motorists as for pedestrians.

ITE warns to overuse marking at crossings, since there is no evidence that more crossing marking will provide safer conditions. These markings create extra costs concerned with their installation and maintenance. According to ITE (1998), it is recommended from cost and safety – effective reasons to use a ladder design using a 12-inch (30 cm) stripe with a 24-inch (60 cm) space. Because of high implementation costs, it's recommended to use at least 10-feet (3,1 m) crosswalk width.

Although results from other studies are in favour of marked pedestrian crossing, the conclusion is that safety of marked crossing without any other treatment (see other pedestrian crossing types) is questionable and introduction of such facility can not guarantee safety effect under all circumstances.

4.2.7. Raised crossings and crossings with speed humps

A raised pedestrian crossing is a crossing located on a speed table, very long and broad or a flat-topped speed hump. The speed table can either be parabolic, making it more like a speed hump, or trapezoidal. Typical width of crosswalk is 3 - 4,5 m (PBIC, 2 – internet source). Increased safety effect is reached if different texture or colour is used and/or warning strips at the edges are drawn. The edges of should be always clearly visible. Special pavement may also improve environment aesthetics.

The main effect of raised crossing is the speed reduction at location of crossing and increase yielding to pedestrians crossing at the raised devices. For example, motorists yielding to pedestrian on one street in Cambridge USA, increased from 10 % to 55 % after the installation of raised crosswalk. Another advantage is the better accessibility for wheel-chaired, who do not have to overcame a step elevation.

However this measure should not be used if a sight distance is limited and/or the street is steep. Also this measure should be avoided if the road is an emergency or bus route. Special care should be paid to drainage.

Figure 4.28: Raised pedestrian crossings in Norrköping, Sweden

Figure 4.29: Raised pedestrian crossing as a part of pedestrian street

Source: PBIC, 3 – internet source

Costs of raised crossings varies from 2 000 – 7 000 $, depending on drainage conditions and used materials. The Swedish source states costs 75 – 125 000 Swedish crowns (7 000 – 12 000 $).

The measure with similar character to raised crossings is a speed hump. Speed humps have similar advantages and disadvantages as raised crossings, but it is cheaper. The disadvantage is that vehicle's speed in opposite directions may be asymmetrical since speed hump is located at only one side of crossing and if speed humps are located from both sides, they require more space. Moreover, raised crossings stress the importance crossings as a homogenous part of pedestrian environment and wheel-chaired have less difficulties to overcome the road at raised crossing.

Figure 4.30: Pedestrian crossing with speed hump in Stockholm, Sweden

4.2.8. Pedestrian crossings with road narrowing

Road narrowing is a curb extension that narrows a street by widening the pavements, planting strips or traffic signs. Road narrowing can be created by bringing both curbs in, or they can be done by more dramatical widening of one side.

The purpose of narrowing is to reduce a two-lane street to one lane at the treatment point, which in turn requires drivers to yield to each other. Drivers' uncertainty brings higher attentiveness to all other road users. The width of narrowing may also be an effective tool to restrict heavy vehicles access if unwanted. This treatment is appropriate for low volume streets, typically under AADT 5000.

Figure 4.31: Pedestrian crossing with road narrowing in Norrköping, Sweden

The advantage of the treatment is that emergency vehicles can pass relatively unimpeded.

The cost of the measure depends on local conditions and technical solution and may varies from $ 5000 – 20 000 (PBIC,4 – internet source). If only traffic sign narrows the road, the cost can be about $ 2000.

4.2.9. Pedestrian refuge islands

Pedestrian refuge islands, also known as crossing islands, centre islands or median slow points–are raised islands placed in the centre of the street at intersections or mid-block to help protecting crossing pedestrians from motor vehicles.

Islands divide carriageway into two parts, which may be crossed independently. Pedestrians deal with traffic only from one direction. Moreover, island provides resting area for disabled or wheel-chaired. Islands help to control traffic by limiting the uncertainty of vehicle trajectory. In turn it provides better information about the driver intention to other road users. If designed as such approach, it can be designed to force a greater or less slowing of cars, depending on how dramatic the curvature is. Moreover, the island calls for the greater attention of the existence of pedestrian crossing and there are opportunities for additional signage in the middle of the road.

Conditions under which the refuge islands are the most beneficial:

- *Wide, two-way streets and intersections with high traffic volume, high travel speed, and large pedestrian volume*

- *Wide streets where the elderly, people with disabilities, and children pedestrians cross regularly*

Figure 4.32: Pedestrian refuge island in Portland

Source: Fehr & Peers Associates, 2

The benefit of islands is a high decrease of pedestrian crashes and causalities, for example in the USA by 57 –82 % (PBIC, 5 – internet source). However, there are several conditions, where it is not appropriate to use a traffic island. In narrow streets, which do not provide sufficient area, use of pedestrian islands is not recommended. Narrowing of a lane can also lead to insufficient place for cyclists. Next problem is that islands may obstruct turning manoeuvres of large vehicles.

The pedestrian island has to have a certain minimal width, ensuring visibility for drivers and rest and waiting place for pedestrians (including wheel-chaired). The width should be sufficient to carry waiting cyclist on the island. Curb edges should be modified for needs that wheel-chaired have and steps should be avoided. All literature sources stress the need of proper illumination and proper visibility unhindered by plants, traffic signs, poles, advertisements or parking cars.

Costs of pedestrian refuge islands range from \$6,000 - \$9,000. The cost for installing a raised concrete pedestrian refuge island (with landscaping) is about \$10,000 to \$30,000. The cost is less for an asphalt island or one without landscaping (PBIC, 5 – internet source).

Special type of islands, used along the road, is called raised medians. Streets with raised medians, in both central and suburban areas have lower pedestrian crash rates compared to undivided streets (ITE 1998). They are beneficial for pedestrians, because they can serve as a place of refuge for pedestrians who cross a street at mid-block or at intersections. They provide space for street trees and other landscaping which, in turn, can help reducing speeds by changing the character of a street, but they should not be used if there is not enough of space necessary for wider pavements, bicycle lanes, landscaping buffer strips, or on-street parking. The cost for adding a raised median is approximately \$50,000 to \$100,000 per 100 m, depending on the design, site conditions, and whether the median can be added as a part of a utility improvement or other street construction project (PBIC, 6 – internet source).

Figure 4.33: Central median in Seattle, the USA

Source: PBIC, 6 – internet source

4.2.10. Combined countermeasure

One type of combined crossing facility was examined by Towliat (2001) in urban areas of Sweden. The design of crossing is based on self-explanatory design and attractiveness of measure. The aim was to reduce vehicle speed to about 30 km/h and also improve driver give-way behaviour.

The most important traffic-safety elements were speed cushions and narrowing of the carriageway at pedestrian/bicycle crossings. The carriageway is narrowed to about 3,2 to 3,5 m to enable the speed cushion to be effective. The speed cushion was placed about 5 m in front of the crossing. Crossings were equipped by lampposts in order to increase visibility and attractiveness of the location.

Figure 4.34: Experimental site in Örebro, Sweden

Source: Towliat 2001

The results show that speed (on the 85-percentile level) decreased from 49-60 km/h to 26-34 km/h. The give-way behaviour was also significantly improved. Only 20 % drivers gave way to pedestrian before introduction, but one year after introduction it was 67 %.

The estimation of the risk of expected injury accidents by means of converting the number of serious conflicts into the number of expected personal injuries accidents produced the following results:

- *car-car accidents decreased by 60 % from 0,15 to 0,06 accidents/year,*
- *car-pedestrian accidents decreased by 41 % from 0,12 to 0,07 and*
- *car-bicycle accidents decreased by 31 % from 0,42 to 0,29 accidents/year*

This measure brought also noise reduction effect, but the emissions increased due to slowing down and acceleration along experimental stretch.
Car and bus drivers had a more positive attitude to measures at individual crossings, while pedestrians and cyclists were more approving of systematic and consistent measures. Bus passengers had a positive attitude to both types of measures. Pedestrian and cyclists felt safer. Car and bus drivers were irritated and dissatisfied with measures that appeared on a large scale. The drivers' acceptance of the measures strongly increased over time.

Bus drivers thought that speed cushions were the best type of speed reducer for buses in urban traffic compared to such types as sinusoid-shaped humps, plateau (elevated-intersection) and a normal hump placed across the whole carriageway. Bus drivers' acceptance depended strongly on design details and was better if they were able to pass the cushions with small difficulty.

4.2.11. Variable warning signs

Automatic warning and detection systems are based on the principle of improved and relevant information to motorists about the presence of pedestrians at interaction points. Two infra-red or microwave detectors are modified to detect automatically pedestrian wishing to cross the road. When the pedestrians are detected, the signs light up their warning message consisting of warning triangle and/or warning text.

Figure 4.35: The variable sign principle

Source: PBIC, 7 – internet source

Variable signs improve drivers' speed and give-way behaviour. This measure is well-accepted by drivers and also unprotected users think it is easier and more convenient to cross the road with the countermeasure.

Extra costs are necessary for variable sign, power source, poles and detectors. The cost of pair of detectors is approximately 600 $ and 2000 $ for infra-red and microwave detector respectively.

Figure 4.36: Variable warning sign, Sweden

Source: Towliat 2001

4.2.12. Signalled pedestrian crossings

This type of crossing is often used when pedestrian crossing is located at a road junction or at a midblock.

At some junctions, pedestrians (and sometimes also cyclists) are detected by a push-button. This means that the pedestrian signal will only be activated when a pedestrian pushes the button. One of the advantages for motorists is that their waiting time is minimised. On the other hand, this is a disadvantage for pedestrians because a button must be pushed before they obtain a green signal. If pedestrians are unfamiliar with this type of crossing, the button may go unnoticed and, thus, unpushed, thereby resulting in an additional delay.

A new type of pedestrian crossing designed to improve safety and to reduce pedestrian delays was tested in Britain, France and the Netherlands. Pedestrians in vicinity of crossings are detected either by pressure sensors in mats or by infra-red or micro-wave detectors. Sensors detect whether pedestrian is waiting to cross and once the signals have stopped the traffic, infra-red detectors then observe as pedestrian crosses the road, ensuring that motorists remain halted until the pedestrian reached the other side. Traffic will not be stopped if pedestrians press the button but cross before the lights change, or if they decide not to cross at all.

Signalled pedestrian crossing may offer safer crossing for vision impaired people. An audible signal makes it easier for the blind and people with impaired vision to locate the crossing area at a signalised junction and different sounds indicate green and red signal (Brüde et al, 1998).

4.2.13. Grade separated pedestrian crossings

From the safety point of view, this type is an optimal solution. However, this solution is costly and space taking and often it is impossible to fit this crossing into central parts of towns or cities. These crossings may be used as a part of a complex architectonic solution e.g. when planning new residential zones, new shopping malls or public transport stations.

This type of crossing, if it is not a part of complex architectonic design, may cause inconveniences for pedestrians who have to overcome a difference in elevation or detour. Criminality may be a problem in some cases.

4.3. Traffic calming

The main purpose of traffic calming techniques is physically and visually to impede speeding and the use of local roads by non-residents avoiding congested routes. Traffic calming should also ensure a more equitable use of the streets and residential areas as public places. Originally, traffic calming was used for neighbourhood traffic control in residential areas, but some techniques of traffic calming may also be used on major roads. Traffic calming is a powerful tool, but careful planning is necessary since the costs of traffic calming measures are high and if improperly planned, negative effects may overbalance positive ones.

The major objectives of traffic calming are:

- *to improve road safety by reducing the number of accidents for all types of users, particularly pedestrian and cyclists, through slower speed,*
- *to enhance the quality of life by controlling the volume of through traffic,*
- *to reduce automobile use by facilitating transit access,*
- *to encourage pedestrian and bicycle use, and*
- *to reclaim the street as a multi-use public place*

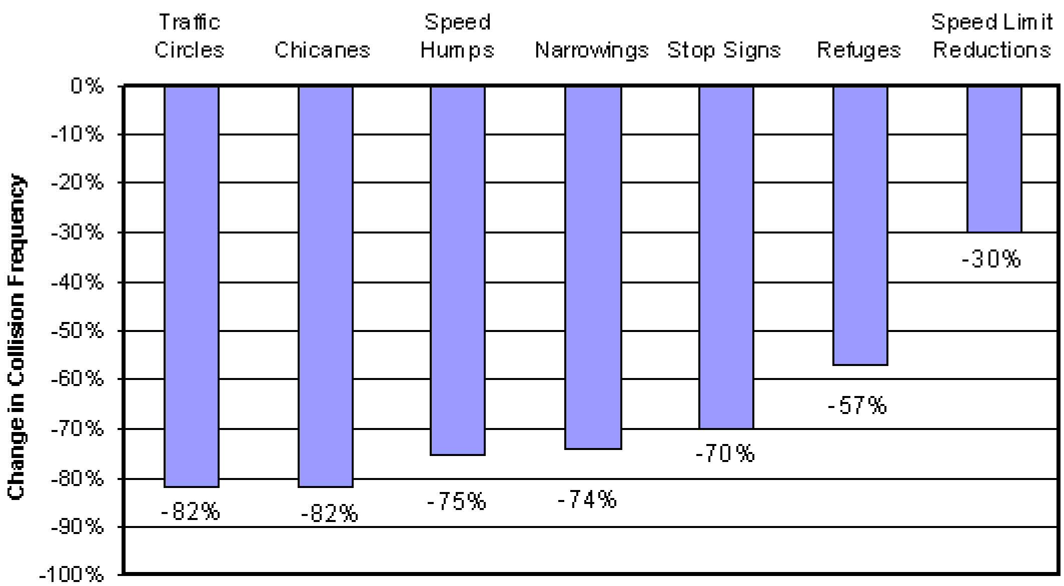
Source: Sarkar, Nederveen & Pols, 1997

Traffic calming generally provides the greatest benefits to pedestrians, bicyclists and local residents, while imposing the greatest costs on motorists who drive often and are used to drive fast. Traffic calming tends to increase horizontal equity by reducing the external costs imposed by motor vehicles and improving the balance between different uses of public streets. Traffic calming tends to increase vertical equity because it benefits people who are physically, economically and socially disadvantaged, while imposing the greatest drawbacks on relatively wealthy, higher mileage drivers (Litman, 1999).

4.3.1. General effects of traffic calming

A Study by Zein et al (1997) summarised international experience with traffic calming. They stated that in 85 case studies from Europe, Australia, and North America the decrease in collision frequency ranged from 8 % to 100 %. The same researchers also analysed micro-level safety benefits of traffic calming measures. The change in accident frequency is shown on the *Figure 4.37*. The reduction of severity was difficult to evaluate due to different methods of measuring severity in source studies. The results of a meta-analysis of 33 studies evaluated by Elvik (2000) indicate that area-wide urban traffic calming schemes on the average reduce the number of injury accidents by about 15 % with the largest reduction in the number of accidents at residential streets (25 %) and the relatively smallest reduction (10 %) on main roads.

Figure 4.37: Safety Benefits of Traffic Calming Devices



Source: Geddes et al 1996

According to a study (Department of Transport, U.K., 1997 cited at Zein et al, 1997) there can be a reduction of between 60 and 70 % in casualty collisions through the use of traffic calming measures. This study also indicates that the most traffic schemes pay themselves in less than 2 years, and many within 1 year.

Besides safety impacts, traffic calming brings some environmental impacts. Hall (1992) summarised previous studies concerning environment implications of traffic calming. The reductions in vehicle speed may also lead to reductions in noise, although excessive use of low gears and frequent acceleration and acceleration may increase noise levels. However, where speeds have been reduced from 50 km/h to 30 km/h, typical reductions in noise levels of between 4-5 dBA have been measured. Also use of rumble strips cause problems because of increased noise level. It has been shown that granite sets result in noise levels between 3-5 dBA.

However there are also some negative effects of traffic calming. Traffic calming typically decreases capacity and increases vehicle delays. It may cause delays of emergency vehicles, which in turn can cause health and property damage. For example, a study (Bunte, 2000) from Austin, Texas, USA shows that Austin would lose an additional 37 lives per year with patients of sudden cardiac arrest if the Fire and EMS Departments experienced a 30 second delay in response times due to traffic calming. The analyses also concluded that at best, only one pedestrian life could be saved each year from traffic calming as pedestrian fatalities rarely occurred within residential neighbourhoods. Another study states (Hall 1992) that each road hump encountered additive six seconds to the journey time of a fire engine.

4.3.2. Traffic calming techniques

Traffic calming schemes generally incorporate a wide range of measures designed to complement each other in both safety and environmental terms. Schemes are designed to be self-enforcing i.e. the layout of traffic calming itself forces drivers to reduce speed. Traffic calming techniques may be divided into 4 groups;

Group 1

The first group of traffic techniques links to traffic management. It includes measures such as **street closures, one-way streets, diagonal and semi-diverters, forced turn channelisation** and **Cul de Sac**. The purpose of these measures is to cause a detour for through traffic and therefore to make areas less attractive for this kind of traffic.

Full street closures are barriers placed across a street to close completely the street to through-traffic, usually leaving only pavements opened. But the full street closure is generally inappropriate, if the street is too narrow to allow cars to back off at the closure point. There is also a number of measures available to create road closures for general traffic while allowing access for buses and/or cyclists. Half closures are barriers that block travel in one direction for a short distance on otherwise two-way streets.

Figure 4.38: Full closure at Palo Alto (California, USA) and half closure at Eugene (Ontario, USA)

Source: Fehr & Peers Associates, 3,4 – internet source

Group 2

The second group includes techniques to reduce speed on links at residential areas. It consists of vertical (e.g. **road humps, cushions, raised pavement and rumble strips**) and horizontal (e.g. **chicanes, road narrowing, central islands**) deflections and other supporting measures (**warning signs, changed surface materials, planting trees and use of street furniture**) emphasising other traffic calming measures.

Vertical shifts in the carriageway are the most effective and reliable of the speed reduction measures, but also other countermeasures help to significantly increase impact of vertical shifts. Vertical shifts may cause problems with drainage.

Perhaps the most common traffic calming technique is a road hump and a cushion (*see Figure 4.39).* The traditional humps are vertical transverse deflections along the whole width of a carriageway, typically rounded or flat topped. These humps are, however, unsuitable if buses or heavy vehicles use the road, because humps influence buses and heavy vehicles more drastically than passenger cars and particularly bus passengers suffer discomfort when the bus drives over the speed humps. Speed cushions were developed as an alternative solution to road humps in order to improve the comfort of passengers and drivers in buses and heavy vehicles. Speed cushions are the special type of road hump which do not cover the full extent of the carriageway width. It enables heavy vehicles and buses to pass relatively unaffected while passenger cars have to reduce the speed significantly.

Figure 4.39: Round-top speed hump and speed cushions

Source: Webster 1998, Department of Environment, Transport and the Regions, UK 1997

The problems with traditional speed humps led to the development of "H" and "S" humps. These modified humps aim to reduce the discomfort to occupants of buses and heavy vehicles similarly to speed cushions. The basic idea is that the longitudinal profile of the hump is different for different widths between wheels and the ramps are shallower for buses and heavy vehicles. The design and dimensions of these humps were chosen so that the car and bus across the humps were comparable.

The “H” humps (*see Figure 4.40*) are more suitable than speed cushions, because with a speed cushion, the inner rear wheels of twin rear wheeled vehicles may cross over the edges of the cushion and cause some discomfort.

Figure 4.40: “H” hump at a raised zebra crossing at Glenorthes, United Kingdom

Source: Webster & Layfield, 1998

The “S” hump (*see Figure 4.41*) was developed in order to solve anticipated problems with the drainage, construction and operational difficulties relating to the angular design of the “H” hump. The “S” hump is similar in principle to the “H” hump, but angular design is replaced with a sinusoidal curve (in plan view) on the front and back edges of the speed table.

Figure 4.41: "S" Hump at a raised zebra crossing at Glenorthes, United Kingdom

Source: Webster & Layfield, 1998

Horizontal shifts in the carriageway are less effective than vertical ones in achieving reductions in speed, however their impact is significantly increased when used in combination with a vertical shift. Horizontal shifts are known as chicanes (*see Figure 4.42*).

Figure 4.42: Example of a chicane and a narrowing

Source: Webster 1998

The speed reducing impact of chicanes is reduced if the measure allows the passage of heavy vehicles as the wider carriageway allows passenger car drivers to drive faster. This may be improved if stone sets or some other uneven surface is used for the side strip allowing the passage of heavy vehicles, but discouraging fast driving of passenger cars.

Chicanes significantly reduce parking spaces and should therefore be avoided if parking spaces are insufficient.

Another example of the change in horizontal alignment is a road narrowing. It may be considered as another supportive measure to vertical deflections. The purpose of narrowing is to reduce a two-lane street to one lane at the treatment point, which in turn requires drivers to yield to each other. Drivers' uncertainty brings higher attentiveness to all other road users. The road narrowing may be combined with the chicane in order to increase effectiveness of the measure.

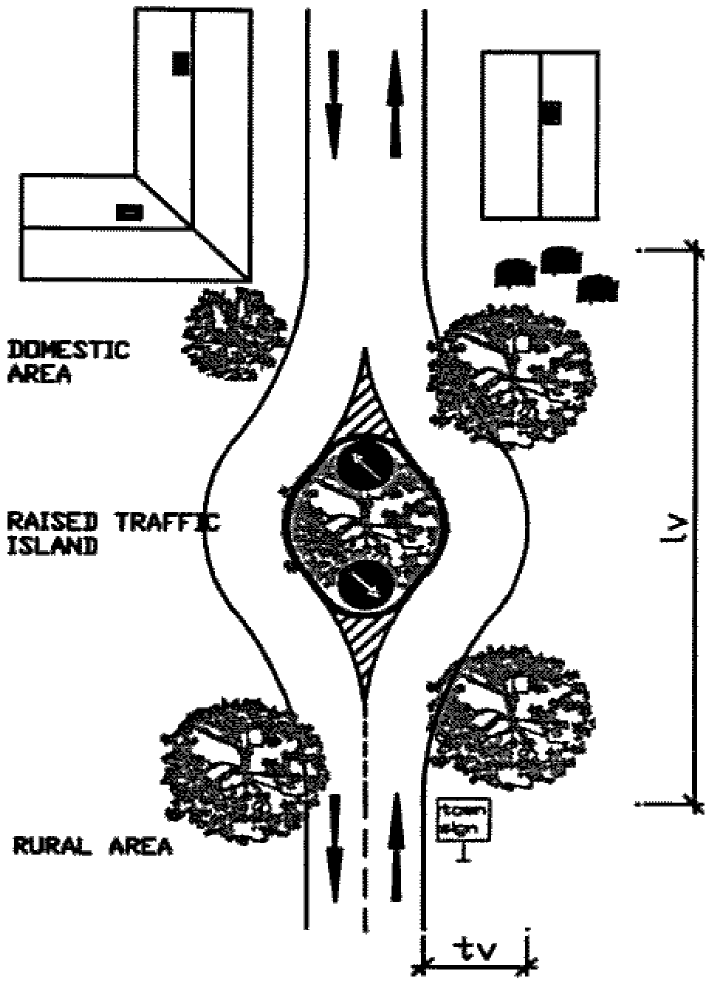
Group 3

The third group consists of measures to increase safety at junctions. It includes **vertical deflections** (e.g. similar to the vertical deflections in the second group or raised junctions), **changes in alignment**, which force vehicles to deviate from a straight ahead path, **curb extensions** and **curve radius reductions** or **use of islands**, which create a refuge for pedestrians and narrow the carriageway. It is also possible to use a special junction design such as a mini-roundabout, which is also called traffic circle. The safety measures at junctions are discussed in the Chapter 4.1 Junctions.

Group 4

The fourth group links to **gateways**. Gateways are used at the entrances to traffic calmed areas in order to warn drivers that they are entering the area with speed restrictions and conditions very different from the surrounding network. Gateways may employ measures such as plateaus, flat topped road humps, different surface materials, road narrowings, traffic islands or “ghost” islands or 30 km/h or 20 mph signs.

Figure 4.43: Sketch of a braking-island's shape



Source: Berger & Linauer, 1999

Gateways may also be used on the entrances at city boundaries, where approaching traffic from the rural road often takes a long time and distance to reduce the speed to an urban compatible speed. In Austria, the concept of raised "braking-islands" was successfully used. The common idea of the so called "braking-islands" is to deflect vehicle path and force drivers to reduce velocity when leaving the rural area and reaching the city limits or to keep velocity when down until reaching the open area. There are several types in use, but the best solution is to extend both lanes to prevent the urban street from acceleration manoeuvres of drivers leaving the village and to avoid misuse of entering drivers by passing the island on the wrong side with high velocity.

Gateways to cities and villages should be sited away from features that already constrain speed, such as bends and summits. It appears that gateways are more suitable for wider roads than for narrower roads where there is less opportunity to provide horizontal deflection by, for example, narrowing and central islands.

Detailed design should be considered from all angles for the sight distance, in particular if measures are close to a junction (Martens & Kaptein, 1999).

4.3.3. Living streets

In some countries, the concept of living streets (e.g. Dutch *woonerf* or German *vekehrsberuhigung*) was accepted. The living streets are narrow streets with various speed-controlling features designed for pedestrian walking speed (11 km/h). This concept allows all modes (car, bike, and pedestrian) in the same place, with the pedestrian having the right-of-way (FHWA, 1994).

Figure 4.44: An example of "living street" (woonerf). Motorists, cyclists and pedestrians share the space on this woonerf or "living street" in Asheville, North Carolina, USA.

Source: PBIC, 8 – internet source

5. CONCLUCIONS

The structure of conclusions reflects the structure of thesis and thus conclusions are drawn on the three levels.

Institutional and legal frame

Although **road design standards** should reflect state-of-the-art of scientific research, it seems that the study results generally do not provide sufficient and systematic information about relationship between various factors and safety. This leads to the fact that committees responsible for compiling road design standards rely heavily on their own judgements instead of relying on research results.

Standards, to be able to serve these aims, have a certain degree of coercion. This may lead the designer to diminishing possibilities to find right balance between various criteria. Road design standards should provide more space for road designer to choose best solution, but they should assist and inform about safety effect of each design decision. The example is a Dutch classification of standards, where the standards may have various firmness – from the firmest *regulations* through *guidelines, recommendations* and *suggestions* to the most voluntary *possibilities*.

National safety programs should assume human to be "errant", which is in a contrast to what was assumed in past. The way is to provide traffic environment, correcting road users mistakes and reducing consequences of accidents. The idea of sharing responsibilities for traffic safety among politicians, planners, road administrators, municipalities, vehicle manufacturers, transportation companies and everyone else who uses streets and roads, as suggested in Swedish Vision Zero, seems promising.

Planning

If **the planning** is limited only on the countermeasure to remove just the problem that is the focus of attention, complications almost always arise. Instead of looking for the answer to the question: "How can we solve this acute problem?" the focus of the work should be checked during all phases of the planning process by asking the question: "How do we – taking into account all demands – want this street to function and work". Plans are then stimulated towards goal-oriented method of working, where no apparently acute demands are allowed to dominate before all demands have been tested and weighed up against each other.

A number of studies have showed **black spot programs** to be highly cost-effective. Elvik in his meta-analysis of black spot treatment evaluation studies however mentions that studies did not consider all factors such as (i) changes in traffic, (ii) general trends in the number of accidents, (iii) regression to the mean and (iv) accident migration. He discovered that "the more confounding factors studies controlled for, the smaller were effects attributed to black spot treatment". While large reductions in the number of accidents, generally 50-90 % were found in studies not controlling for any confounding factors, studies simultaneously controlling for general trends, regression to the mean and accident migration did not find any statistically reliable effect of black spot treatment on the number of accident.

An alternative or a supplement to the black spot programs is **the Conflict Technique** developed by Lund University in Sweden, based on a direct observation of conflicts defined as events when road users have to take an evasive action to avoid an imminent accident. The results are gained in relatively short time.

Public opinion and attitude toward safety measures should not been neglected for several reasons; (i) public disagreement may lead to safety countermeasure being altered or removed consequently after introduction; (ii) angry driver irritated with safety measures can behave aggressively, may try to over-speed in order to reduce time-loss; (iii) decision-making about safety countermeasures is often in responsibilities of regularly voted local authorities and discontent citizens can influence elected politicians to change the decision about safety measure; and (iv) discontent and bad understanding of safety measures can also lead to vandalism. Possible way to influence public attitude is to publish articles, interviews, accident maps and statistics in mass media or on leaflets and brochures distributed to households, organise public meetings and consultations, introduce programs of co-operation between local authority and citizens or influence children by school education.

Selected safety countermeasures

The comparison of accident rates for various types of **intersections** show very low accident rates for roundabouts and quite low rates for signal controlled and grade-separated junctions. The accident rate is high on the contrary for priority junctions, especially for X-junction with strong turning traffic or high vehicle speed.

A junction should be preferably established in a concave vertical curve (sags) for both roads. This should be applied at least for the secondary road. A junction is best constructed on a straight section, and under no circumstances on a sharp horizontal curve. A junction and its surroundings should be designed to be visually clearly distinct from a free road section.

The aim of introduction of **pedestrian crossing facilities** is to provide to pedestrians and/or cyclists with safe and comfortable crossing the road. Well-designed pedestrian crossings increase driver's awareness of pedestrians and cyclists. Pedestrian crossings design should follow three basic principles: (i) low speed (30 km/h), (ii) no obvious priority and (iii) relevant information to motorists about the presence of pedestrians.

An individual remark is that marked crossings without other measures led in some countries to an increase in the number of accidents for both pedestrians and vehicles. The reason is probably “false feeling of safety”.

Traffic calming generally provides the greatest benefits to pedestrians, bicyclists and local residents, while imposing the greatest costs on motorists who drive often and are used to drive fast. Traffic calming tends to increase horizontal equity by reducing the external costs imposed by motor vehicles and improving the balance between different uses of public streets. Traffic calming tends to increase vertical equity because it benefits people who are physically, economically and socially disadvantaged, while imposing the greatest drawbacks on relatively wealthy, higher mileage drivers.

The benefits of traffic calming in terms of safety or typically satisfactory, but there may be some adverse effects such as increase in emissions of exhaust gases, inconveniences for public transport passengers or delay of emergency vehicle service.

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