Chapter 39 Roundabouts

39.1 Introduction

Roundabouts have a good safety record for vehicular crashes when compared with traffic signals and priority junctions but much depends on the size of the junction, the flow pattern of vehicles and the presence of pedestrians and cyclists, who are particularly vulnerable. However, the risk of accidents increases as the throughput approaches capacity and gap–acceptance times reduce. Roundabouts tend to cause less overall delay to vehicular traffic than signals at low and medium flow levels and are particularly appropriate for large right–turning flows. Roundabouts can give greater priority to flow on minor roads than main roads and this may create queueing on the major road. Signals may consequently be needed on one or more approaches, particularly at peak periods, to deal with uneven demand flows, which can cause congestion or accident problems on individual arms. Introducing signal–control at roundabouts has been found to improve the safety of cyclists, although not necessarily the overall safety of all road–users (Lines, 1995). This is covered in more detail in Chapter 42. Roundabouts are also appropriate at particular locations, where a significant change in road standard occurs, as they have the advantage over other junction types in slowing down all traffic streams and eliminating crossing conflicts but this too can create accident problems when a roundabout is placed at the end of a high–speed dual carriageway.

There are two main types of roundabout, namely, conventional and mini (see Figure 39.1).

A conventional roundabout has a one–way circulatory carriageway around a kerbed island 4m or greater in diameter, usually with flared approaches to allow several vehicles to enter simultaneously. The recommended number of entry–lanes is usually three or four. Roundabouts are not recommended on dual 3–lane roads, because a design to provide sufficient junction capacity would probably require a very large roundabout indeed.

A mini–roundabout has a one–way circulatory carriageway around a flush, or slightly raised, circular marking less than four metres in diameter, with or without flared approaches. Mini–roundabouts can be effective in improving existing urban intersections that suffer overload or accident problems. Their layout should be designed so that drivers are made aware, in good time, that they are approaching a roundabout. They should only be used where all the approaches are subject to a speed–limit of 30 miles/h or less. Technical Directive TD16/93 (DOT, 1993) [Sa] covers the geometric design of roundabouts and various layouts are described in Table 39.l and illustrated in Figures 39.1 and 39.2.

39.2 Principles of Operation

A roundabout junction operates as a one–way circulatory system around a central island, where entry is controlled by 'Give Way' markings and priority must be given to traffic approaching from the right. The operating efficiency of this type of junction depends on the ability of drivers to respond to safe opportunities to join the stream of circulating vehicles already using the junction.

Roundabouts with more than four arms are generally not desirable, because drivers' comprehension of the layout is affected when roundabouts are large and high circulating speeds may be generated.

Although the initial construction costs may be greater for conventional roundabouts than for other types of junction, because of the larger land-area required, vehicle operating costs are likely to be less because they permit a free flow of traffic when demand is light and they are self–regulating.

The ability of roundabouts to cope with U–turn manoeuvres can be particularly useful, where one or more of the approach carriageways is divided by a continuous central reserve or where U–turns or right–turning traffic would otherwise be dangerous or disruptive.

During uncongested off–peak periods, roundabouts will generally result in less delay than similar junctions with signal–control. However, they are not generally compatible with urban traffic control systems, as they cannot respond to positive control commands. They may also be unsatisfactory where there are cyclists or pedestrians in significant numbers and where special provisions may be required, such as grade– or mode–separation, which can be expensive.

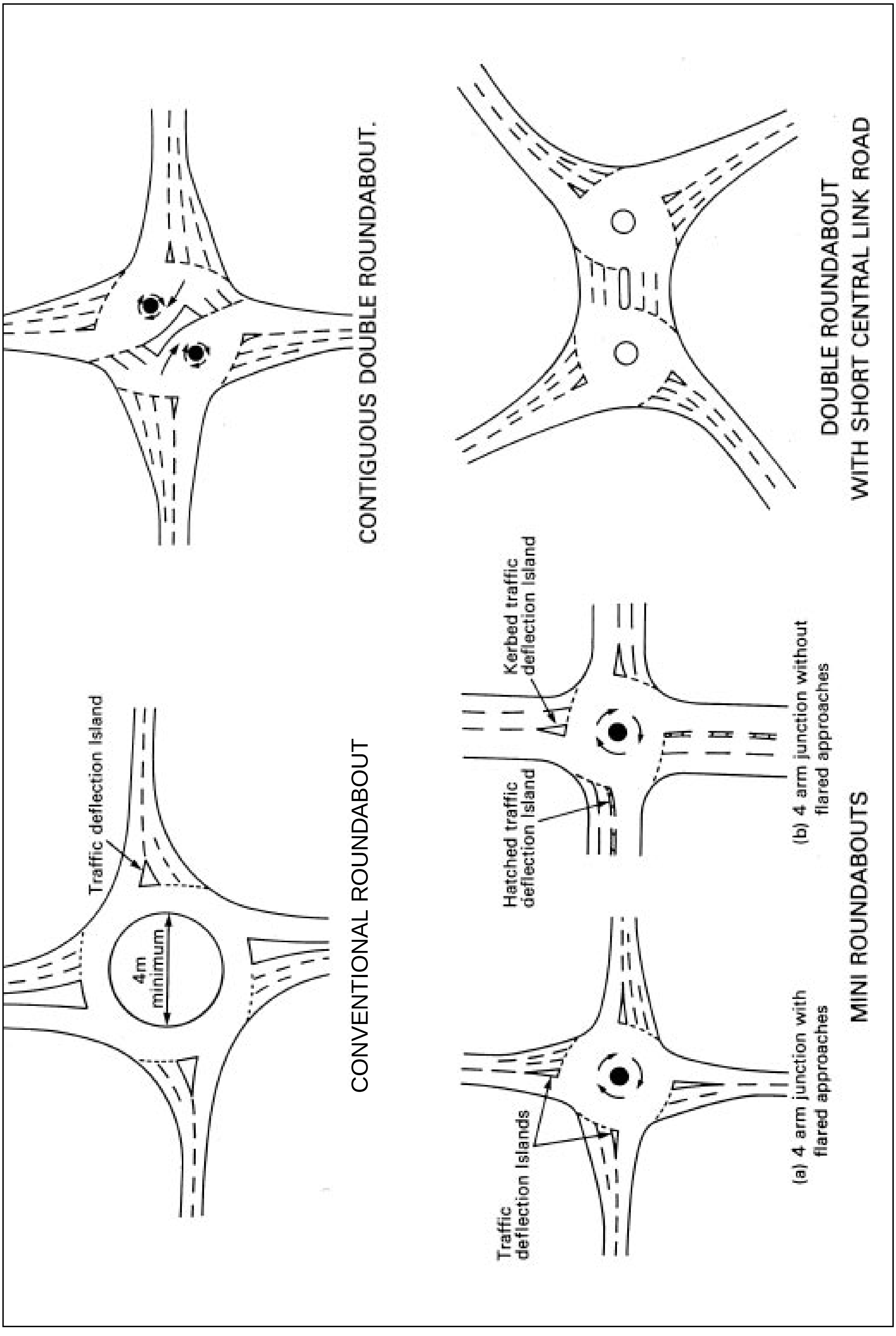


Figure 39.1: Types of rounddbout.

Type	Description	Typical Use/ Location
Conventional	❑ Kerbed central island with diameter greater than or equal to 4m ❑ Flared approaches to allow multiple entry lanes ❑ See Figure 39.1	❑ New developments and construction ❑ Junctions within or at end of dual carriageways ❑ To change direction of a new road at a junction
Mini	❑ Flush or slightly raised central island less than 4m in diameter ❑ Road markings indicate pattern of movement ❑ No street furniture on central island in order to allow long vehicles to overrun ❑ See Figure 39.1	❑ To improve the performance of existing junctions where space is severely constrained ❑ Mainly as conversions from other roundabout and junction types ❑ At sites subject to a 30 miles/h speed-limit
Double	❑ Two conventional or mini roundabouts are placed within the same junction connected by a short link road ❑ See Figure 39.1	❑ For controlling unusual or asymmetric approaches. ❑ At approaches with heavy opposing right–turning movements, staggered approaches and at sites with more than four arms
Grade–separated	❑ At least one traffic movement passes through the junction without interruption, while the remainder are brought to one or more roundabouts at a different level ❑ Compact designs are favoured ❑ For pedestrians and cyclists the roundabout is elevated, to allow easy gradients for pedestrian and cycle network below ❑ See Figure 39.2	❑ On urban motorways and dual carriageways ❑ On high capacity roads and those with high approach speeds of traffic ❑ On new construction where there are high forecast vehicle and pedestrian flows
Ring junctions	❑ A large two-way circulatory system where each approach is provided either with 3-arm roundabouts (normally minis) or with traffic signals ❑ See Figure 39.2	❑ At some special sites to solve particular local problems ❑ For conversion from very large roundabouts which have entry problems ❑ Not recommended for a new facility
Signal–controlled	❑ Traffic entering the roundabout from one or more arms is signal-controlled for all or part of the day ❑ See Figure 39.2	❑ To increase capacity under certain operating conditions
Gyratory systems	❑ Small one-way systems where normal–land use activities can be maintained on the central island	❑ In urban areas, especially town centres ❑ Safe access to the island must be ensured for pedestrians, cyclists and possible maintenance vehicles

Table 39.1: Types of roundabout and their main characteristics.

Photograph 39.1: Segregated cycleway at Cheals Roundabout, Crawley. Courtesy: David Nicholls.

Accident rates and accident severities at roundabouts can be significantly lower than those at signal–controlled junctions of equivalent capacity (see also Chapter 37). The most common problem affecting safety is excessive speed, mainly on entry but also within the roundabout. Cyclists are particularly at risk, especially at conventional roundabouts, where they are over 14 times more likely than a motorised vehicle to be involved in an accident. Decisions as to whether or not roundabouts should be used should, therefore, take account of existing and prospective cycle networks and the amount of cycle–use through the junction. Wherever possible, cyclists should preferably be segregated from other traffic at roundabouts, either vertically or horizontally (see Photograph 39.1).

39.3 Siting of Roundabouts

The decision to provide a roundabout, rather than some other form of intersection, should be based on operational, economic and environmental considerations. Factors to be taken into account at the design stage include the need to reduce speed at certain places for reasons, such as:

- ❑ to effect a significant change in road standard, say from dual to single carriageway or from grade–separated intersection roads to at–grade intersection roads; or
- ❑ to emphasise the transition from a rural to an urban or suburban environment; or
- ❑ to achieve a sharp change in route direction, which could not be achieved by ordinary curves using standard radii.

Roundabouts should preferably be sited on level ground or in sags, rather than at or near the crests of hills, because it is difficult for drivers to appreciate the layout when approaching on an uphill gradient. However, roundabouts on hill tops are not intrinsically dangerous, if correctly signed and with adequate visibility standards provided on the approaches to the give–way line, ie in excess of the stopping distance for the design speed.

39.4 The Geometric Features of Roundabout Design

The terminology used to describe the geometry of roundabout design is given in Figure 39.3. The main geometric design features are as set out below.

Entry–Path Curvature

Vehicle approach speeds should be moderated to appropriate levels, so as to achieve the desired levels of safety and capacity. This can be achieved by deflecting the vehicle entry–path at the junction approach, using suitably positioned traffic islands, small adjustments to kerb lines and by staggering the entry arms, as shown in Figure 39.4. Entry–path curvature should not exceed 100m radius, otherwise higher accident rates are likely to occur. This, however, is dependent upon the amount of circulating traffic across the arm and the balance of turning movements on that approach.

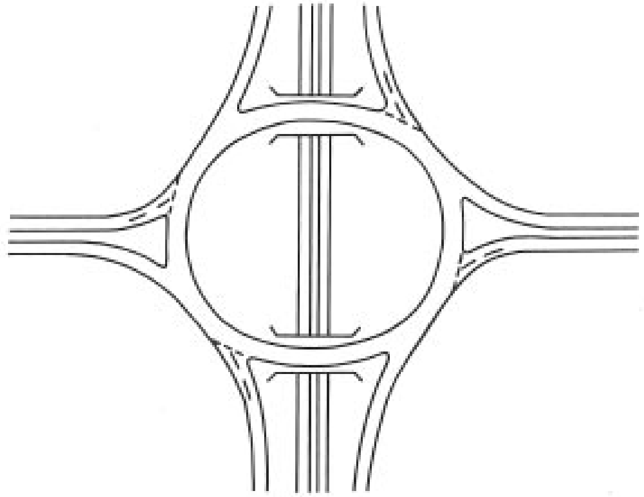
Where mini roundabouts are being created, at existing junctions where a 30 miles/h speed limit applies, an appropriate entry angle can be achieved by small traffic deflection islands or, less effectively, by road markings. It is sometimes best to experiment first with temporary materials to obtain the optimum entry shape.

Entry Widths

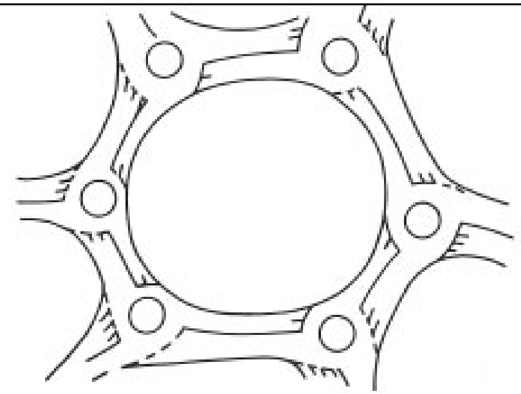
Theoretical capacity is very sensitive to small changes in entry width. It is good practice to add at least one extra lane–width to the entry approach but, as a general rule, not more than two lanes should be added and no entry should be more than four lanes wide. There may be some cases, usually associated with low predicted flows, where increased entry width is not operationally necessary but it is still recommended that at least two entry lanes be provided. This gives added flexibility in the event of breakdown and eases the problem of space for long vehicles turning. Entry widening on the offside by means of sharp reverse curves is not recommended. Segregated left–turning lanes can be beneficial in particular situations (see below).

Flare Length

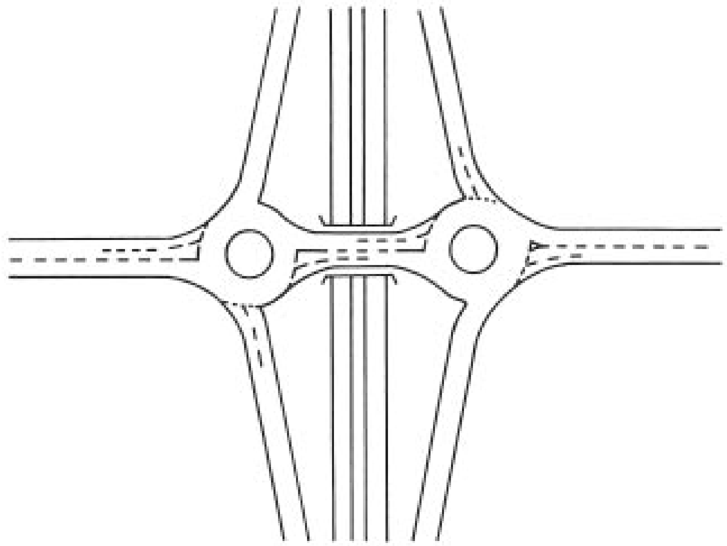
Theoretical capacity is also very sensitive to small changes in the flare length, which should develop gradually, avoiding any sharp angles, in order to be used effectively.



Two Bridge Roundabout at Grade-Separated Interchange.



Ring junction layout with small conventional or mini–roundabout



Grade-Separated Interchange with One Bridge and Two Roundabouts-Dumbell Interchange.

Signal-controlled roundabout

Figure 39.2: Types of roundabouts (grade–separated and signal controlled).

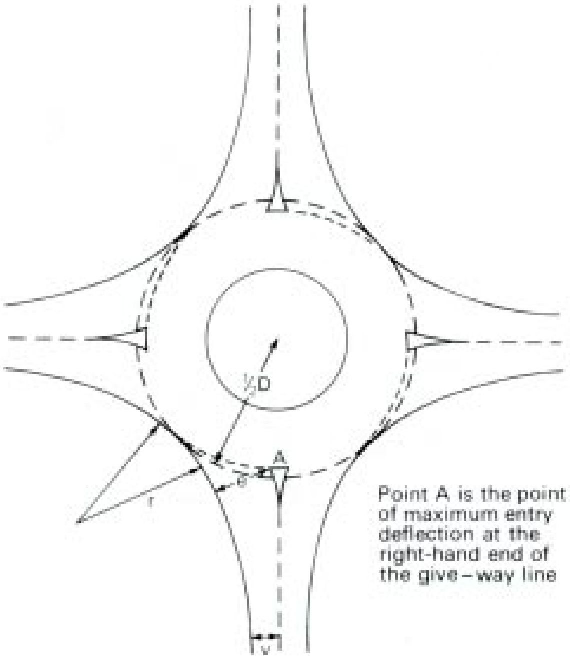


Figure 39.3 (a)

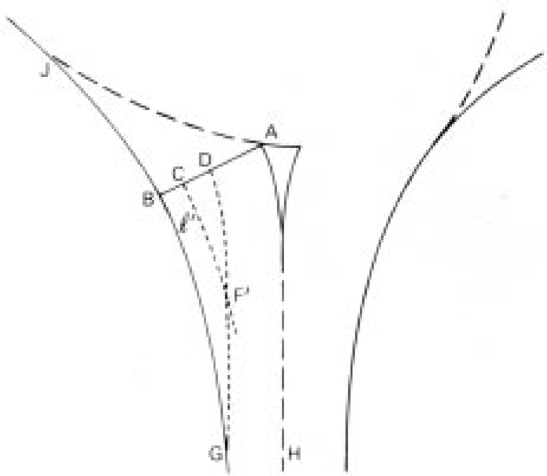


Figure 39.3 (b)

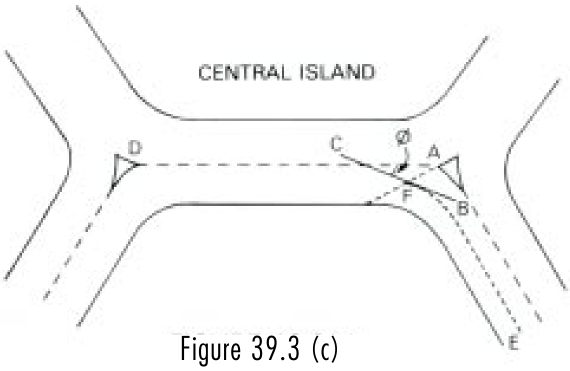


Figure 39.3 (c)

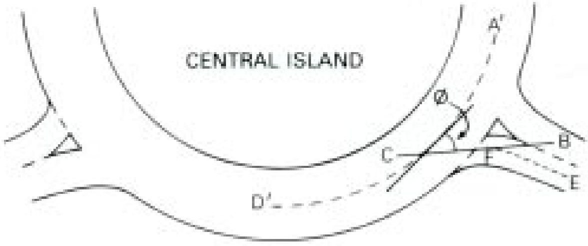


Figure 39.3 (d)

Geometric parameter	Definition	Practical range
Entry width (e)	The width of the entry arm into the junction measured from point A along the normal to the nearside kerb. See Figure 39.3 (a).	4m–15m
Approach half-width (v)	The width of the entry arm upstream of the flare measured form the median line to the nearside kerb along a normal. See Figure 39.3 (c).	2m–7.5m
Average length of flare (l′)	In Figure 39.3 (b) l′ is defined by l=CF where the line CF is parallel to BG and distance is (e–v)/2 from it. Usually CF is curved and its length measured along the curve to get l′.	1m–100m
Sharpness of flare (S)	A measure of the rate at which extra width is developed in the entry flare. It is defined by the relationship S=1.6(e–v)/l′.	0m–2.9
Entry radius (r)	Measured as the minimum radius curvature of the nearside kerbline at entry. See Figure 39.3 (a)	3m–100m
Entry angle (ø)	The angle between the circulating traffic and that entering the junciton. Figures 39.3 (c) and (d) show Ø for well defined conventional roundabouts. For other types see TD 16/95.	10m–60°
Inscribed circle diameter (D)	The diameter of the largest circle that can be inserted within the junction outline.Where the outline is asymmetric, the local value in the region of entry is used. See Figure 39.3 (a).	15m–100m

Figure 39.3: Geometric parameters of roundabout design.

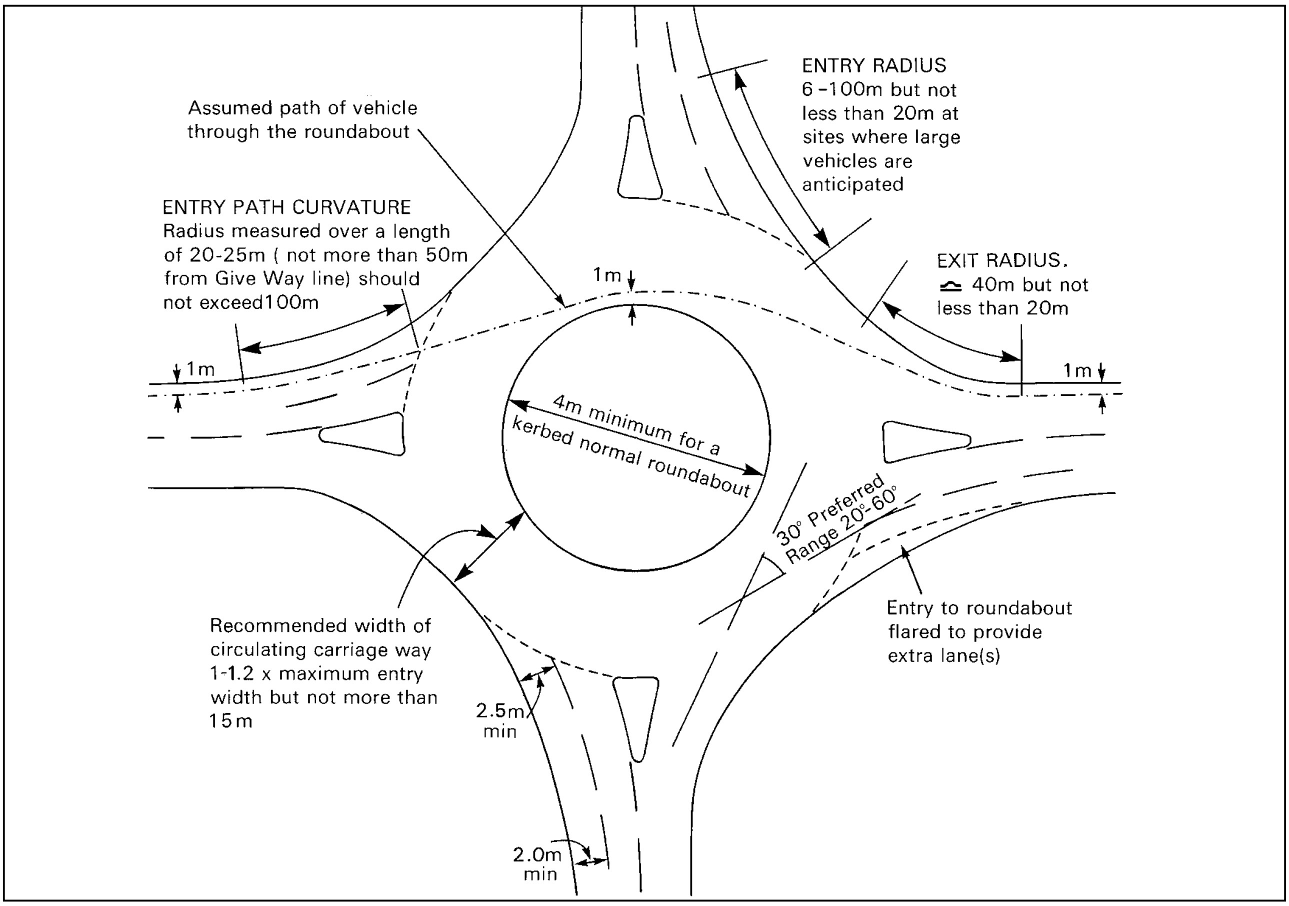


Figure 39.4: Typical layout of a conventional roundabout showing entry details.

Entry Angles and Radii

The entry angle should be considered with effective entry width, to ensure that traffic in the offside lane can enter the circulatory carriageway on a natural path, without conflicting with the central island or traffic entering on its nearside. Entry angles below 20° and above 60° should be avoided, as entry accidents are likely to increase.

The entry radius should always lie between six metres and 100m. A good practical design often lies in the range 20m to 30m. Where a roundabout is designed to cater for long vehicles in particular, the entry radius should not be less than 10m. Increasing the entry radius above 30m provides little (if any) increase in capacity. As values drop below 15m, they produce increasingly severe reductions in capacity and substantially higher operating costs.

Circulatory Carriageway

The circulatory carriageway should not exceed 15m in width and, if possible, should be circular in plan, avoiding deceptively tight bends. The width of the circulatory carriageway should be constant and should lie between 1.0 and 1.2 times the maximum entry width. It is normal practice to avoid short lengths of reverse curve between entry and adjacent exits, by linking these curves or joining them with straights between the entry radius and the exit radius. One method is to increase the exit radius. However, where there is a considerable distance between the entry and the next exit, as at three–arm roundabouts, reverse curvature may result.

Inscribed Circle Diameter (ICD)

The relationship between the central island diameter and the inscribed circle diameter (ICD) is the most important consideration for the passage of large vehicles. The following advice is based on the turning swept–path generated by a 15.5m long articulated vehicle, with a single axle at the rear of the trailer, which is often adopted as the 'Design Vehicle' for roundabouts. The turning width required by this type of vehicle is greater than that for most other vehicles. The requirements for other vehicles, including a single unit rigid vehicle, such as a 12m long bus or an 18m long drawbar trailer combination, are less onerous.

The smallest ICD for a conventional roundabout that will accommodate the design vehicle is 28m. If this cannot be provided, a mini roundabout should be used. Note that it may be difficult, if not impossible, to meet the entry deflection requirement with conventional roundabouts which have ICDs of about 39m or less. The largest ICD for a mini roundabout should be 28m.

Large Islands

The size of the central islands is in itself not critical but will depend on the requirements for entry deflection, the inscribed circle diameter and the width of the circulatory carriageway. At conventional sites, the island is likely to be circular and will be kerbed.

The presence of a roundabout can be made more obvious to approaching traffic by landscaping and planting. The screening of traffic on the opposite side of a roundabout to the point of entry can, without restricting visibility, avoid distraction and confusion caused by traffic movements of no concern to a driver. Planting can also provide a positive background to chevron signs and direction signs on the central island, while visually uniting the various vertical features and reducing any appearance of clutter. However, good maintenance of landscaped roundabout islands is clearly essential and is likely to be expensive. Generally, the planting of roundabout central islands less than 10m in diameter is inappropriate, as the need to provide visibility leaves only a small central planting area available.

Small Islands

The circular marking (1.0m – 4.0m diameter) of a mini roundabout should be as large as possible in relation to the site and should be domed, up to a maximum height of 125mm at the centre. This doming, in conjunction with the presence of some adverse crossfall, will help to make the roundabout more conspicuous to drivers. No bollards, signs, lighting columns or other street furniture should be placed on the dome or on any central island less than 4.0 m in diameter.

Deflection Islands

Where physical deflection is not possible on the approach, road markings, indicating small traffic islands, should be used to induce some vehicle deflection. These islands should be kept free of all furniture, except the 'Keep Left' bollards and other essential signs.

Segregated Left–turning Lanes

Segregated left–turning lanes are a useful method for giving an improved service to vehicles intending to leave a roundabout at the first exit after the entry. Their use should always be considered when more than 50% of the entry flow, or when more than 300 vehicles/ h in the peak hour, are seeking to turn left at the first exit. Vehicles are channelled into the left hand lane by lane arrows, supplemented by advance direction lining signs. These vehicles proceed to the first exit without having to give way to others using the roundabout (see Photograph 39.2). Segregation by road markings is more common than by use of additional islands but is less effective because it is subject to abuse. Care needs to be exercised in how vehicles will merge or give way to other vehicles exiting from elsewhere on the roundabout. Segregated left–turn lanes pose particular dangers for cyclists on the relevant approach, who are not turning left, and also when exiting the roundabout with fast moving traffic in the segregated lane on their nearside. Alternative designs which encourage lower speeds may need to be considered.

Pedestrians and Cyclists

Whenever possible, cyclists and pedestrians should be segregated from other traffic at roundabouts. Where cyclists and pedestrians need to be accommodated, particularly where roundabouts are used in traffic–calming schemes, it may be appropriate to consider modifying some of the geometric standards. In these circumstances, it has been found preferable for single–lane approaches without flares, but with deflections, to be used. Multi–lane approaches to roundabouts can mean that circulating cyclists are hidden from the view of drivers approaching the roundabout. Even if the approach cannot be reduced to a single lane, the use of flares should be avoided. Approaches should be deflected towards the centre of the central island, with relatively small radius kerbs, to maximise the conspicuity of circulating cyclists and to discourage

Photograph 39.2: Segregated left–turn lane at Cheals Roundabout, Crawley. Courtesy: David Nicholls.

high entry speeds. The requirement for 'easy exits' should be reviewed, to ensure that circulating cyclists are not compromised and that drivers are not encouraged to accelerate towards any pedestrian crossing which might be located on the exit arm.

39.5 Visibility Requirements

With the increasing tendency to landscape and plant the larger central islands of roundabouts, it is important that visibility requirements are given close attention in order to ensure safe operation. The design has to consider the ultimate height and shape of plants and the operational and cost implications of maintenance.

The following guidelines, based on TD16/93 (DOT, 1993) [Sa], represent good practice concerning the provision of visibility. When these guidelines are not complied with, additional signing is needed to alert drivers of all vehicles to potential hazards. Attention should be given to the visibility of cyclists, taking account of the paths they are likely to take when using the roundabout

Visibility, with the exception of visibility to the right at entry, should be assessed in accordance with an eye–height of 1.05m and an object–height of 0.26m. Visibility to the right at entry should be based upon a driver's eye–height of 1.05m to an object–height of 1.05m.

Visibility on approaches

The forward visibility at the approach to a roundabout should not be less than desirable minimum stopping sight distance for the design speed of the approach measured to the give–way line. In special cases, a departure from standards, to one step below desirable minimum stopping sight distance, may be adopted to avoid severe environmental damage.

Drivers of all vehicles approaching the give–way line should be able to see the full width of the circulatory carriageway to their right, for a distance appropriate to the size of the roundabout (39m to 70m measured along the centre line of the circulatory carriageway). This visibility should be checked from the centre of the offside lane at a distance 15m back from the give–way line. Checks should be made that poor crossfall design or construction does not restrict visibility.

Drivers of all vehicles approaching the give–way line should be able to see the full width of the circulatory carriageway ahead of them for a distance, measured along the centre line of the circulatory carriageway, appropriate to the size of the roundabout (39m – 70m). The visibility should be checked from the centre of the nearside lane, at a distance of 15 m from the give–way line.

Visibility on the circulating carriageway

Drivers of all vehicles circulating on a roundabout should be able to see the full width of the circulatory carriageway ahead of them for a distance appropriate to the size of the roundabout (39 m – 70 m). This visibility should be checked from a point 2m in from the central island.

Visibility of pedestrian crossings

Drivers of all vehicles approaching a pedestrian crossing across an entry should have a minimum distance of visibility to it of desirable minimum stopping sight distance for the design speed of the link. At the give–way line, drivers of all vehicles should be able to see the full width of a pedestrian crossing across the next exit, if the crossing is within 50m of the roundabout. In urban areas, adjacent roadside development may, however, prevent this visibility splay being established fully.

Obstructions to visibility

Signs, street furniture and planting should not obstruct visibility. Infringements by isolated slim obstructions, such as lamp columns, sign supports or bridge columns can be ignored, provided they are less than 550mm wide.

39.6 Safety Considerations in Design

Roundabouts are generally considered to be the safest form of at–grade junction with accidents costing, on average, 50% less than at other junction types and about 70% less than on links. Notwithstanding their good record, care must be taken in the layout design of roundabouts to secure the safety benefits. There are particular difficulties in providing safe operating

Photograph 39.3: Circulating carriageway made two–way and entry controlled by a mini–roundabout.

conditions for cyclists and pedestrians, where excessive speed, both at entry or on the roundabout, is usually the most common problem. Significant factors contributing to high entry and circulating speeds are:

- ❑ inadequate entry deflection;
- ❑ very acute entry angles, which encourage fast merging manoeuvres with circulating traffic;
- ❑ poor visibility to the give–way lines;
- ❑ poorly designed or positioned warning and advance direction signing; and
- ❑ incorrect siting of 'Reduce Speed Now' signs.

Additional safety aspects to be considered in designing a layout are set out below.

Angle between adjacent arms

The accident potential of an entry appears to decrease as the angle, clockwise between its approach arm and the next approach arm, increases. Ideally, entries should be equally–spaced around the perimeter of a roundabout, with a minimum angle of 60° between adjacent arms.

Gradients

Whilst it is normal to flatten approach gradients to about two per cent or less near to the entry, research at a limited number of sites has shown that this has only a small beneficial effect on accident risk.

Visibility to the right at entry

This has comparatively little influence on accident risk, so little is gained by increasing visibility above the recommended level. However, it is important in the immediate vicinity of the entry arm that any cyclists on the circulatory carriageway are clearly visible. As cyclists often hug the inside kerb, it is important that, in this position, they remain in the normal line of vision of drivers approaching and entering the roundabout.

High circulatory speeds

High speeds normally occur on large roundabouts with excessively long and/or wide one–way circulatory carriageways. They can also be caused at smaller roundabouts by inadequate deflection at entries. The solution to high circulatory speed usually has to be fairly drastic, involving signal–control of the problematical entry arms. In extreme cases, the roundabout may have to be converted to a ring junction, in which the circulatory carriageway is made two–way and the entries/exits are controlled by individual mini roundabouts or traffic signals (see Photograph 39.3).

Street Furniture

Care should be taken over the incorporation of signs

Photograph 39.4: Roundabout with spiral markings. Courtesy: David Nicholls.

and guard rails into the design, since it is important that these features should not obstruct a driver's view on entry to the roundabout.

Two–wheeled vehicles

Although roundabouts have an impressive overall safety record for most types of vehicle, this does not apply to two–wheeled vehicles. Research has shown that, on four–arm roundabouts on Class A roads, injury accidents involving two–wheeled vehicles constitute about half of all those reported. The proportion of accidents involving pedal cyclists is about 15%, although they typically constitute less than two percent of the traffic flow. The accident involvement rates for two–wheeled vehicles, expressed in terms of accidents per road–user movement, are 10–15 times those of cars, with pedal cyclists generally having slightly higher accident rates than motor cyclists.

The provision of pedestrian and cyclist facilities are considered further in Sections 39.8 and 39.9 respectively. Chapters 22 and 23 cover these particular facilities in more detail.

Goods vehicle accidents

The problem of long goods vehicles either overturning or shedding their loads at roundabouts has no obvious solution in relation to layout geometry. Whilst there are only about 60 personal injury accidents a year in this category, there are considerably more damage–only accidents. Load shedding often causes congestion, delay and expense to clear, especially if it occurs at major junctions. Experience suggests that roundabouts where these problems persist usually exhibit one or more of the following design faults:

- ❑ inadequate entry deflection leading to high

entry speeds; or
- ❑ long straight sections of circulatory carriageway leading into deceptively tight bends; or
- ❑ sharp turns into exits; or
- ❑ excessive crossfall changes on the circulatory carriageway.

The computer program ARCADY 3 can be used to estimate accident frequencies for ranges of traffic flows and entry geometry (DOT, 1992).

In general, to reduce accidents, the designer should adopt the following measures:
- ❑ reduce entry widths;
- ❑ reduce circulating width (must be between 1.0 and 1.2 x the maximum entry width);
- ❑ tighten the radius of entry–path curvature (reducing entry width and circulating width can help achieve this);
- ❑ try to space the arms equally around the roundabout, as this maximises the angle between adjacent arms;
- ❑ try to ensure that the roundabout itself is fully visible to approaching drivers on all approaches;
- ❑ try to avoid left hand bends on the approach road within 500m of the roundabout (right hand bends have a better accident record than straight approaches); and
- ❑ where the number of two–wheeled vehicles is large, consider another junction type or provide other suitable routes to accommodate them.

39.7 Traffic Signs, Road Markings and Street Lighting

Consideration of the need for, and layout of, traffic signs and road markings should be an integral part of the design process. Advice on the use and siting of signs is given in the Traffic Signs Manual (HMG, 1994) [Sb].

Road markings are used to channelise traffic and, where required, to indicate a dedicated lane. Lane indication arrows, to reinforce the map–type advance direction signs on entries, can be beneficial where heavy flows occur in a particular direction. Lane dedication should not be used where entries are less than three lanes wide. Where any particular lane is dedicated, the other lanes should also have arrow markings. This arrangement should always be accompanied by advance direction signing which indicates lane dedication. Lane dedication arrows and markings on the circulatory carriageway will not be necessary in many cases. However, their use, including the use of spiral markings, may be beneficial on roundabouts with unusual operational problems (see Photograph 39.4).

Photograph 39.5: Pedestrian guard–rail maintaining visibility. Courtesy: David Nicholls.

Signing and marking measures found useful in reducing accidents at existing roundabouts with poor safety records include:
- ❑ the repositioning or reinforcement of warning signs, the provision of map–type advance direction signs, making give–way lines more conspicuous, moving the central island chevron sign further to the left to emphasise the angle of turn, placing another chevron sign above one in the normal position and placing chevron signs in the central reserve in line with the offside lane approach on dual carriageways;
- ❑ the provision of a ring of black and white paving, laid in a chevron pattern inside the central island perimeter at a gentle slope, to improve the conspicuity of central islands;
- ❑ the provision of yellow bar markings with decreasing spacing on fast, dual carriageway, approaches;
- ❑ the reduction of excessive entry widths by hatching or physical means;
- ❑ the provision of anti–skid road surfacing on entries and on the roundabout itself; and
- ❑ the erection of 'Reduce Speed Now' signs or count–down markers.

The provision of road lighting at roundabouts is an important safety consideration and should be in accordance with the British Standard Code of Practice for Road Lighting (BSI, 1992) but care has to be taken to minimise the environmental impact. When an existing roundabout intersection is being modified, the lighting layout should be checked for suitability with the new road arrangement and any alterations carried out prior to, or at the same time as, the roadworks.

39.8 Pedestrian Facilities (see also Chapter 22)

Separate pedestrian routes, with crossings, should be located away from the flared entries to roundabouts, where the carriageway widths are less and vehicular traffic movements are more straightforward. However, where this is not practical, the following alternatives should be considered:

- ❑ an unmarked crossing place (i.e. dropped kerbs), associated with a central refuge wherever possible; or
- ❑ a Zebra or non–signal–controlled crossing, with or without a central refuge; or
- ❑ a Pelican or other signal–controlled crossing; or
- ❑ a subway or footbridge.

The type of facility selected will depend upon the expected volumes and movement patterns of both pedestrians and vehicular traffic and should be designed in accordance with current recommendations and requirements.

If a Zebra, Pelican, Puffin, or Toucan crossing (see Chapter 22) is provided close to the entry/exit points of a roundabout, there will inevitably be consequences for the operation of the roundabout and also, possibly, for safety. Where a crossing is provided within the intersection itself, care will need to be taken with the design to ensure that approach speeds are not excessive and that there is no confusion as to priority. Puffin and Toucan crossings have the advantage that on–crossing detection can be employed to vary the crossing green–times so that, when only a few pedestrians or cyclists are crossing, delays to vehicular traffic is minimised. Roundabout exit radii should not encourage vehicles to accelerate out of the roundabout and hence approach the crossing at high speeds.

In urban areas, where large numbers of pedestrians are present, short lengths of guard rail should be used to prevent indiscriminate crossing of the carriageway. The design of guard railing should not obstruct drivers' visibility. Types of guard rail are available which are designed to maintain drivers visibility to pedestrians through them and vice versa (see Photograph 39.5).

39.9 Cyclists' Facilities (see also Chapter 23)

Roundabouts are a particular hazard for both pedal and motor cyclists. Research is continuing on how to improve the safety of cyclists at roundabouts. The use of peripheral cycle tracks can offer some protection (see Photograph 39.1) but this will normally require the use of Toucan crossings, in order that cyclists can safely cross all the entry/exit roads. Cycle lanes within the circulatory carriageway can help to make drivers aware of the presence of cyclists, and provide a protected area for them. However, the lanes must be swept regularly otherwise they can get covered with debris and cyclists will not use them. Designers should be aware of the following:

- ❑ conventional roundabouts, with small central islands and flared entries, have accident rates which are about twice as high as those with large central islands and unflared entries. This relationship appears to apply consistently for all types of vehicular road–user;
- ❑ about 70% of pedal cycle accidents at smaller normal roundabouts involve entry/circulating conflicts. For example, a motor vehicle entering a roundabout collides with a circulating pedal–cycle passing the entry; and
- ❑ at roundabouts on dual carriageways, the accident rate for cyclists is two to three times greater than that at dual carriageway traffic signals but, for cars, the opposite is true.

It is recommended that where substantial numbers of cyclists are expected the following options should be considered:

- ❑ a design of roundabout layout with more emphasis on safety than on high capacity; or
- ❑ an alternative form of intersection, such as traffic signals; or
- ❑ a signposted alternative cycle route away from the roundabout; or
- ❑ full grade–separation, incorporating, for example, a combined pedestrian/cyclists' subway system.

Even when cycle–flows are not high, the fact that cyclists are likely to use the roundabout must not be ignored and every effort should be made to protect their safety. Programmes to encourage more cycling are in hand and it is likely that, as a result, more cycling will take place. Sites which presently exhibit little or no cycling activity may well, in the future, experience an increase in this activity. So, it is essential, where future cycling routes can be identified, that account is taken of any likely increase in cycle–flows.

39.10 Capacity and Delay

In evaluating alternative designs, the operational performance of any particular roundabout design needs to be assessed. Several criteria for operational performance have been proposed, including:

❑ maximisation of vehicular throughput;
❑ maximisation of reserve capacity;
❑ optimisation of volume/capacity ratio (V/C); and
❑ minimisation of total delays.

Capacity is estimated using Kimber's empirically based equation (Kimber, 1980), which estimates the maximum throughput for each arm of a junction from the flows and six geometric parameters.

$$\text{Entry Capacity } C = k\,(F - fc\;Qc)$$

where k, F, and fc are geometry–dependent constants and Qc is the circulating flow (pcu/h).

It should be remembered that the throughput estimates have a known standard error of about ±15%, for typical flow values, and significant queues and delays can, therefore, occur before capacity is reached.

Reserve capacity is defined as the difference between the capacity and the demand flows and is often expressed as a percentage of the capacity ie a demand flow of 1,500 veh/h on a capacity of 2,000 veh/h is considered to have a reserve capacity of 500 veh/h or 25%.

For a demand flow of Q, the reserve capacity is calculated, as follows:

$$\text{Reserve capacity (RC)} = (C - Q)\text{ pcu/h.}$$

However, care has to be exercised in using this measure since, as the demand flow rises on all arms, the circulating flow also increases, thereby decreasing throughput.

The ratio of volume to capacity (V/C) serves a similar purpose to the reserve capacity but is expressed differently.

$$\text{V/C ratio} = \text{Volume/Capacity} = Q/C$$

As total in–flows increase, the throughput drops as in the case of reserve capacity. It is common for the Highways Agency [Sc] to recommend that design solutions should have a V/C ratio of 0.85. However, the resulting delays depend on the flows as well as the V/C. Delay, including both traffic and geometric elements, is the best measure of operational performance and is normally measured as average delay per vehicle (see also Chapter 37). Queues are only important when there is a danger of blocking–back to other junctions, thereby causing additional delays.

Queue–length is not a good measure of performance, because approaches with large flows and capacity can have quite long, but fast–moving, queues with a low average delay per vehicle. Conversely, very short queue–lengths can occur at low flows and capacity, but with quite large delays, as the queue is very slow to disperse.

The interactions between junction layout, capacity, flows and delays are complex and most engineers are advised to make use of computer programs, such as ARCADY (DOT, 1992), RODEL (Crown, 1989) or ROBOSIGN (Kay *et al*, 1992), which are designed to carry out these calculations. The programs estimate queues and delays and can represent the way in which these vary through time, as occurs through peak periods. The cumulative delay can be converted to cost, using a suitable value of time for comparison with accident and construction costs.

39.11 Safety Evaluation

In addition to the evaluation of operational performance, the safety performance of layouts needs to be assessed in coming to a design solution. Advice is given in Technical Advice note TD16/93 (DOT, 1993) [Sa]. Much of this is based on experience and good practice. The programs ARCADY, RODEL and ROBOSIGN contain forms of an empirical model, which can be used for evaluating the accident probabilities associated with different layouts (Maycock *et al*, 1984). However there are a number of statistical limitations attached to the use of such models and great care needs to be exercised in interpreting the outputs.

Four main types of vehicular accidents can occur on roundabouts:

❑ entry/circulating accidents, involving collisions between an entering vehicle and a circulating vehicle;
❑ approaching accidents between vehicles on the approach to the junction, mostly rear–end shunts when one vehicle runs into the back of another, but also including accidents where a vehicle is changing lanes;
❑ single–vehicle accidents, involving a vehicle colliding with some part of the junction layout or with street furniture; and
❑ other accidents which include pedestrian accidents and a variety of vehicular accidents which occur relatively infrequently, such as circulating vehicles colliding with each other and with other exiting vehicles.

It should be noted that, in the context of accidents on roundabouts, pedal cycles are included in the term 'vehicle'.

The relationship between the geometry and the total number of accidents (all types) is complex. A geometric parameter that may reduce one accident type may increase the incidence of another.

Design layouts should also be subject to an appropriate safety audit, as described in Chapter 16.

39.12 References

BSI (1992)	BS 5489: 'Code of Practice for Road Lighting', British Standards Institute.
Crown BC (1989)	'RODEL – Interactive Roundabout Design', Staffordshire County Council.
DOT (1992)	TA44/92 (DRMB 5.1.1) 'Capacities, Queues, Delays and Accidents at Road Junctions – Computer Programs ARCADY/3 and PICADY 3', Stationery Office [Sa].
DOT (1993)	TD 16/93 (DMRB 6.2.3) 'Geometric Design of Roundabouts', Stationery Office [Sa].
HMG (1994)	SI 1994 No. 1519 'The Traffic Regulations and General Directions 1994', Stationery Office.
Kay WA, Sang L Irani and Katesmark S (1992)	'Advanced Roundabout Design with ROBOSIGN', PTRC.
Kimber RM (1980)	Report LR942 'The Traffic Capacity of Roundabouts', TRL.
Lines CJ (1995)	'Cycle accidents at signalised roundabouts', Traffic Engineering + Control 36(2).
Maycock G and Hall R (1984)	Report LR1120 'Accidents at 4–Arm Roundabouts', TRL.