3. ROAD SAFETY MANAGEMENT

3.1 Purpose of Road Functional Classification

Functional classification is the process by which roads and streets are grouped into classes or systems, according to the character of traffic service they are intended to provide. There are three road functional classifications: arterial, collector and local roads. All roads and streets are grouped into one of these classes, depending on the character of the traffic (local or long distance) and the degree of land access that they allow (Table 3.1).

TABLE 3.1 FUNCTIONAL CLASSIFICATION SYSTEM
(FHWA, 1997)

FUNCTIONAL SYSTEM	SERVICE LEVEL PROVIDED
Arterial	Provides the highest level of service at the greatest speed for the longest uninterrupted distance, with some degree of access control.
Collector	Provides a less highly developed level of service at a lower speed for shorter distances by collecting traffic from local roads and connecting them with arterials.
Local	Consists of all roads not defined as arterials or collectors; primarily provides Access to land with little or no through movement.

Typically, travellers will use a combination of arterial, collector and local roads for their trips. Each type of road has a specific purpose or function. There is a basic relationship between functionally classified road systems in serving traffic mobility and land access. Arterials provide a higher level of mobility and a greater degree of access control, while local facilities provide a high level of access to adjacent properties but a low level of mobility. Collector roads provide a balance between mobility and land access (Figure 3.1).

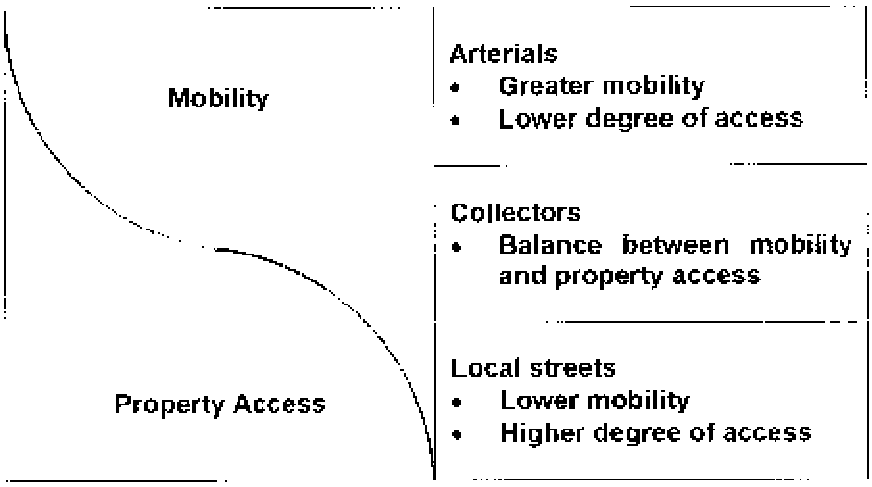


Figure 3.1 Relationship between Mobility and Accessibility

The first step in the design process is to define the function of the facility. The level of service required to fulfil this function for the anticipated volume and composition of traffic provides a rational and cost-effective basis for the selection of design speed and geometric criteria within the range of values available to the designer (for the specified functional classification). The use of functional classification as a design type should appropriately integrate the road planning and design process (AASHTO,1994).

Once the functional classification of a particular roadway has been established, so has the permissible range of design speed. With the permissible range of design speed defined, the principal limiting design parameters associated with horizontal and vertical alignment are also defined. Similarly, a determination of functional classification establishes the basic roadway cross section in terms of lane/shoulder width, type and width of median area, and other major design features (Figure 3.2).

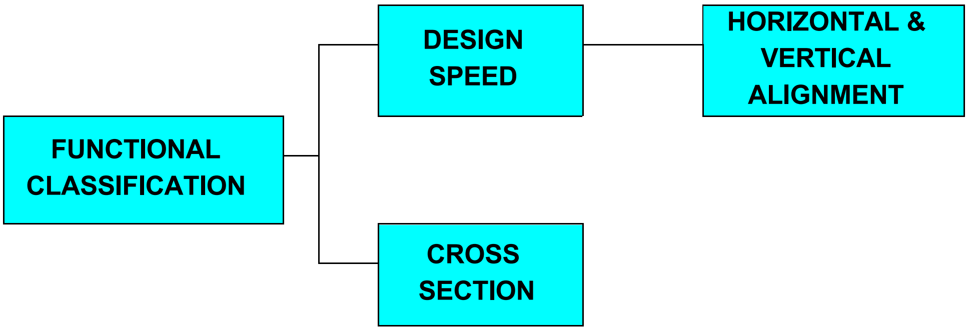


Figure 3.2 **Relationship between Functional Classification and Geometric Design**

The importance of the functional classification process as it relates to highway design lies in the fact that functional classification decisions are made well before an individual project is selected to proceed to the detail design phase. Such decisions are made by national, provincial and local authorities as part of their long term planning functions. Reassessments of functional classifications occur relatively infrequently; a functional classification of a particular road section may therefore represent a decision made 10 years ago.

Even after the decision on the classification of a road section has been made, there is still a degree of flexibility in the major controlling factor of design speed, as shown in Table 3.3. As a result of the range of geometric design options using different design speeds, arterials and collectors can vary in appearance (FHWA, 1997).

The highway system of the United States consists of slightly more than 6,3 million km of road (FHWA, 1995). Of this total, 5,0 million km are located in rural areas, and the remaining 1,3 million km are urban roads. Each of these rural and urban roads has been given a functional classification as shown in Table 3.2.

TABLE 3.2 FUNCTIONAL CLASSIFICATION OF US HIGHWAYS
(FHWA, 1995)

FUNCTIONAL SYSTEM	PERCENT OF TOTAL KM	% OF TOTAL TRAVEL
Interstate	1,2	22,8
Freeway/ Expressway	0,2	6,2
Other Principal Arterial	3,8	24,3
Minor Arterial	5,7	18,4
Major collector	11,1	7,8
Minor collector	7,2	2,1
Collector	2,2	5,3
Local	68,6	13,1
TOTAL	100	100

In terms of jurisdictional responsibility, about 5% of the total is administered by the Federal Government, approximately 16% is under State control, and the remaining 79% is under control of county and local governments.

The South African road network consists of approximately 525 000 km of road, of which 20 000 km are national routes (including 2 000 km toll roads), 340 000 km are provincial roads and 165 000 km are urban roads. South Africa's roads carry between 80 and 90 percent of all passenger and freight movements in the country (Department of Transport, 1996).

In South Africa, the functional classification occurs along similar lines, a typical example of which is shown in Table 3.3 below.

TABLE 3.3 FUNCTIONAL CLASSIFICATION OF RSA ROADS
(Stanway Edwards Ngomane Associates, 1998)

CLASS	TRAFFIC MOVEMENT	ACCESS	VEHICLE TYPE	DESIGN SPEED	RESERVE WIDTH
A Freeway	Uninterrupted Traffic flow > 20 000 vpd	No property access Exit/ entrance at Interchanges spaced at 3,0-5,0km	All Including Express bus	80-120	60-100
B Arterial	Uninterrupted Flow except at intersections 10 000-30 000 vpd	Access at Intersections Spaced at 350-600m	All Including Bus	50-90	45-62
C Collector	Interrupted flow 5 000-20 000 vpd	Access at Intersections spaced 80m	All Including bus	40-60	25-40
D Local	Interrupted flow 1 800-12 000 vpd	Primarily access	Primarily passenger car	30-70	16-25
E Local Residential	Interrupted flow < 2 000 vpd	Primarily access	Primarily passenger car	20-40	10-25
F Local Commer-cial/ Industrial	Interrupted flow	Primarily access	Single unit, semi-trailer	40-60	16-25

One of the issues concerning the relationship between roadway functional classification and design guidelines is that the classification process is not an exact science. The predominant traffic service associated with a particular route cannot be definitely determined without exhaustive surveys of traffic origin-destination patterns on each link of the road network. Engineering judgment based on experience must play a role in making design decisions (FHWA, 1997).

3.2 Access Management

Refer to Volume 1: Principles and Policies for detail of access management.

3.2.1 Effect of Land Use on Safety

Land use is an important determinant of the function of an area's roads. As land use changes because of development, especially at the urban fringe, road functions also change. It is not uncommon for roads that once served as rural local access routes to farmland, and now serve suburban residential townships and commercial land uses, to be reclassified as urban collectors or arterials, depending on the intensity of development and the type of traffic generated by the development. Design standards or guidelines must change to meet actual or impending change in traffic character and road function.

Engineers and planners can play a particularly important role in creating the road network and road environment that present and future road users have to use. They can have a fundamental influence on driver behaviour, by adjusting the design of the road to accommodate human characteristics and to be more forgiving if errors are made.

Land use affects safety since it determines the following:
- Vehicle type generated by the land use
- Trip generation
- Extent of pedestrian and non-vehicular traffic generated
- Safety of passing traffic.

Zoning can be used to control traffic flow, movements and types of traffic serving a particular land use. Sensitive areas, such as schools, educational facilities and institutions for the aged and persons with disabilities, have a high potential for pedestrian-vehicular conflict.

In industrial areas, provision should be made for larger turning circles and accesses. Pedestrian footpaths between residential areas and public transport facilities are required to minimise pedestrian-vehicular conflicts. If possible, industrial development should be located at the urban fringes to prevent heavy vehicle movement through residential areas (TRL, 1991).

In residential areas, pedestrians and vehicles interact in an environment where the road classification should support mainly an access function. The safety of residents is endangered when:
- Residential land use is not separated from other land uses, such as commercial and industrial

- Streets in the network are unlike that of a local street, making it difficult for drivers to judge the function of the road by its appearance
- Inappropriate design supports high mobility and speeds
- Direct accesses to dwellings from distributor roads are permitted instead of from access roads.

Refer to Volume 1: Principles and Policies for detail on access management.

3.3 Effect of Speed on Safety

Speed is one of the most important factors to the traveller in selecting alternative routes or transportation modes. The value of a transportation facility in carrying people or goods is judged by its convenience and economy, which are directly related to its speed. The speed of vehicles depends, in addition to the capabilities of the drivers and their vehicles, upon four general conditions:

- The physical characteristics of the road and its roadsides
- The weather
- The presence of other vehicles and
- The speed limitations (either legal or because of control devices).

The objective in design of any engineered facility to be used by the public is to satisfy the demands for service in the safest and most economical manner (AASHTO, 1994).

The implications of speed are the following:

- Severity of accidents increases with higher speed.
- Performance of safety belts and air bags are compromised at high speed.
- Accidents are more difficult to avoid at high speed; the main reason being longer distance travelled during reaction time, longer distance required to stop and greater difficulty of controlling a vehicle at high speed.
- Increased accident risk owing to greater strain on tyres and brakes at high speed. The age of the vehicle fleet and the poor condition of many vehicles increases the risk, especially when overloaded.
- Greater difficulty for drivers and pedestrians to estimate distances when entering or crossing a road.
- Human factors, especially visual acuity and peripheral vision, contribute to the increased risk of accidents (Van As and Joubert, 1998).

Accident severity increases with speed

The safety effects of speed are illustrated by a Swedish model, developed by Andersson and Nilsson (1995) as reported by Kallberg (1998).

The model shows the relationship between before and after speeds, the numbers of accidents and the number of people injured. This is based on changes to speed limits in rural areas.

TABLE 3.4 EFFECT OF CHANGES IN RURAL SPEED LIMITS ON ACCIDENTS AND INJURIES

(Anderson and Nilsson, 1995)

NUMBER OF INJURY ACCIDENTS n	NUMBER OF PERSONS INJURED m
$n_{IA} = [v_A/v_B]^2\ n_{IB}$	$m_{IA} = [v_A/v_B]^2\ n_{IB} + [v_A/v_B]^4\ (m_{IB} - n_{IB})$
$n_{SA} = [v_A/v_B]^3\ n_{SB}$	$m_{SA} = [v_A/v_B]^3\ n_{SB} + [v_A/v_B]^6\ (m_{SB} - n_{SB})$
v_B = mean speed before v_A = mean speed after n_B = number of accidents before n_A = number of accidents after	m_B = number of people injured before m_A = number of people injured after I/S/F = refers to injured/serious/fatal severity category

In South Africa, approximately 20% of all accidents are attributed to speed (CSS, 1997).

3.3.1 Setting Speed Limits

Speed limits are applied in most countries to control speeds. In South Africa, speed limits are regulated by the Road Traffic Act, 1989. General speed limits of 60, 100 and 120 km/h apply on public roads in urban areas, rural areas and freeways, respectively. The procedure for setting speed limits is contained in Ribbens (1986).

It is a well-known traffic engineering principle that motorists drive at speeds at which they feel comfortable. For example, the legislated 55 mph speed limit on Interstate Highways in the United States was largely ignored by the motoring public, because the speed was considered too slow for the type of roadway provided. Arbitrarily setting lower speed limits in order to reduce traffic speeds is ineffective, unless the speed is consistent with the speeds driven by the public (Fitzpatrick, 1997).

North American countries base speed limits on 85 percentile speeds. On South African roads, 85 percentile speeds tend to be generally higher than the posted speed limits. It appears that South African drivers ignore speed limits and drive at speeds they prefer (Van As and Joubert, 1998). This appears to be a world-wide phenomenon.

There is reason to believe that high variations in speed lead to an increase in accidents. Speed variance can be reduced if speeds are decreased, but apparently this cannot be achieved by lowering speed limits. [p4-8] However, the use of advisory speed limits have proved to be effective in reducing accidents (SEA,1996).

The effect of speed difference between vehicles can be addressed by design, by providing turning lanes at intersections, climbing lanes, and preventing stopping and parking of vehicles on roadways (Van As and Joubert, 1998).

On low-volume roads (ADT<2 000 vpd), posted speed limits were found not to be significant factors affecting accident rates (Zegeer et al, 1994).

A speed limit represents a compromise between mobility and safety. This is a trade-off, which must be accepted by those who favour lower limits and those who favour higher limits. However, a speed limit is not necessarily the best method of speed control, and alternative methods may be more effective.

Drivers will ignore speed limits that appear to be absurd

Speed limits must be consistent. Speed limit differences on roads of the same design and environmental conditions appear absurd to drivers, and this is probably the reason why drivers disregard limits. Consistency of speed limits, however, does not imply that speed limits cannot be adapted to conditions at particular locations.

It is important that the majority of drivers should perceive a speed limit as realistic and reasonable. Unrealistic speed limits that fail to gain the respect of the majority of drivers will most likely be ignored, and also undermine respect for speed limits in general. The purpose of speed limits is to accommodate the majority of drivers, but to bring legal sanction against those, who drive markedly faster than is reasonable on that road (Van As and Joubert, 1998).

Speed limits on all public roads should be set by a traffic engineer, based on spot speed studies and the 85 percentile operating speed. If the speed limit of an existing roadway is to be raised, the engineer should examine the roadside features to determine if modifications are necessary to ensure roadside safety.

The 85 percentile speed is considered to be the appropriate posted speed limit, even for those sections of the roadway that have an inferred design speed less than the 85 percentile speed. Posting a roadway’s speed limit based on its 85 percentile speed is considered to be sound and typical engineering practice. This practice remains valid even if the inferred design speed is less than the resulting posted speed limit. In such situations, the posted speed limit would not be considered excessive or unsafe.

Arbitrarily setting lower speed limits at point locations owing to a less than desirable stopping sight distance is neither effective nor sound engineering practice.

If a road section has (or is expected to have) a posted speed in excess of the road’s inferred design speed, and a safety concern exists at the location, then appropriate warning or information signs should be installed to warn or inform drivers of the condition. Slightly less than desirable stopping sight distances do not present an unsafe operating condition, owing to the conservative assumptions made in establishing desirable stopping distances. It is important to remember that any sign is a roadside object, and that it should be installed only if the need for it is clearly demonstrated.

New or reconstructed roads/sections should be designed to accommodate operating speeds consistent with the road's highest anticipated posted speed limit, based on the road's initial or ultimate function (Fitzpatrick et al, 1995).

The findings of research by Van As and Joubert (1998) regarding setting of speed limits are the following:

- South African speed limits tend to be high when compared to speed limits in other countries, but not the highest
- The current situation with speeding in South Africa and in most countries is unsatisfactory. There is general support for low speed limits, but speed limits are nevertheless ignored. Traditional methods of law enforcement to curb speeds appear to have failed. An urgent need exists for new and innovative approaches to curb speeds; engineering measures appear to be the answer
- The main problems with establishing a speed limit are that it applies to a spectrum of conditions and represents a compromise between mobility and safety, which must be accepted by those in favour of lower limits as well as those in favour of higher speed limits.

Their conclusions and recommendations are the following:

- General Speed Limit
- The General speed limit should be retained, but road authorities are encouraged to use speed calming measures. The current 100 km/h general speed limit should be retained (also for gravel roads), but only as a default limit in the absence of a posted speed limit. The 80 km/h limit for heavy vehicles should be retained, and a general speed limit of 100 km/h should apply to coaches, buses and minibuses, and posted on the rear of these vehicles. An enforcement tolerance of 10% (subject to a minimum of 5 km/h) is proposed for both minimum and maximum speed limits, to be prescribed in the National Road Traffic Act.
- Speed Limits for Special Conditions
- General speed limits for wet conditions are not recommended
- Speed limits for night conditions are also not recommended
- Minimum speed limits on multi-lane roads should preferable only be considered on the faster lanes.
- Guidelines for Setting Speed Limits
- Factors affecting speed limits are land use, road type and intersection control. Speed limits have been developed for a range of typical land uses, road types and intersection control, based on existing limits and overseas practice
- The 85 percentile speed is used as a norm for setting speed limits in many countries. However, one cannot rely on drivers' judgement of safe speeds.
- Document to be included in the South African Road Traffic Signs Manual (Department of Transport, 1993)
  This document has been developed based on the recommendations of Van As and Joubert, 1998 (Appendix B), and replaces the previous RV/19 guideline on setting speed limits (Ribbens, 1986). It will be incorporated into the Department of Transport, 1993.

- Changes to the National Road Traffic Act and Regulations
  These recommendations have recently been approved in principle, and are intended to be included in the National Road Traffic Act, 1996 and the Regulations (Republic of South Africa, 1996). These include the establishment of Speed Limit Review Boards, appointed by the South African National Roads Agency and Provincial Governments, to ensure that guidelines are applied properly, consider appeals, to certify speed limits (including limits at roadworks) and to accredit persons qualified to set speed limits.
- Guidelines for Establishing Speed Limits at Roadworks
  It is possible that few adhere to speed limits at roadworks, because roadworks speed limits have not been properly managed and controlled. It is proposed that these speed limits should be certified, and that uncertified limits be made a punishable offence. Speed limits have been recommended, based on certain factors, especially the proximity of the works to the travelled way.

Safety Principles of Speed Zones

Speed zones should:

- Ensure that road users are warned of approaching changes in the speed environment ahead
- Inform road users of the maximum speed limit applicable to the approaching road section
- Guide road users by indicating legal travel speed
- Control vehicles by appropriate enforcement and traffic management.

Speed Variance

An important traffic characteristic that affects safety is speed variance. A major influence on speed variance is the difference between the design speed and the posted speed limit. It has been shown that speed variance will be minimised if the posted speed limit is correlated with the design speed.

<u>This emphasises the link between posted speed limit and design speed, and supports the recommendation that speed limits should be set by a traffic engineer, based on spot speed studies (Fitzpatrick, 1997). Current road traffic legislation authorises traffic officers to set speed limits on all public roads</u>.

It has also been found that drivers tend to drive at increasing speeds as the roadway geometry improves, regardless of the posted speed limit. Accident rates do not necessarily increase with an increase in average speed, but <u>do</u> increase on all classes of roads with an increase in speed variance (Garber and Gadiraju, 1992).

3.3.2 Effect of Speed Control

Speed control is a controversial issue, since criteria for establishing speed limits are not accepted as readily as other traffic control measures, such as no-passing zones or traffic signals. The primary responsibility of traffic engineers is to identify safe speeds to reduce the probability of accidents to a minimum.

Design speed may appear to be a natural factor for setting of speed limits. The problem with design speed is that it can appear unreasonable to drivers (Knowles, 1997). This is mainly because (design) speed affects the design of only a few elements, although it is used for the full length of the road. Long straight road sections have a much higher design speed than, for example, horizontal curves. It is probable that design speed should not be directly applied when setting speed limits, but indirectly by considering the basic elements contributing to the design standard of the road.

The road network consists of a range of functional classes, varying from accessibility to mobility as their primary function. Roads with a high degree of accessibility have more conflict points and speeds are more dispersed. Such roads have greater potential for accidents, and therefore require lower speed limits. Roads with primarily a mobility function, such as freeways, are designed according to higher standards, allowing vehicles to travel at higher speeds. Road classification should therefore be used as a main factor in setting speed limits (Van As and Joubert, 1998).

Road width is an important factor in road accidents and should be taken into account when setting speed limits. Narrow roads are less safe, as a result of the hazard of a vehicle leaving the road. In New South Wales, speed limits of 110 km/h are only applied on two-lane roads with 3,1 m lanes and 0,8 m shoulders. In South Africa, Ribbens (1986) provided for reduced speed limits on roads narrower than 6,0 m, and recommends that the speed limit be reduced to 50 km/h in urban areas and 80 km/h in rural areas (Van As and Joubert, 1998).

Medians are normally associated with safer roads, such as freeways and multi-lane divided roads. The main safety benefit of rural divided roads is the provision of more than one lane per direction, which eliminates problems associated with overtaking on two-lane roads. Medians also separate opposing traffic streams. In urban areas, median barriers help to reduce cross-traffic conflicts. Median barriers are roadside hazards in their own right, which should also be taken into account when setting speed limits. Higher speed limits can be allowed in urban areas when a median is provided. Ribbens (1986) does not provide for medians as a factor in the setting of speed limits. However, Australian guidelines allow for higher speed limits on rural divided roads (Austroads, 1996; RTA, 1995; Vic Roads, 1996).

Road alignment in the shape of sharp curves, blind rises and steep gradients can be hazardous at high speed, and speed limits should be reduced if such elements generally occur. Isolated problems, however, are best handled by posting advisory speeds.

The presence of roadside hazards affects the number and severity of accidents. When engineering measures are not plausible, speed limits should be lowered. For isolated hazards, warning signs with advisory speed limits are preferable. The guidelines by Ribbens, 1986 provide for a reduction in speed limits when unprotected fixed objects occur close to the roadway. The clear distance and number of roadside objects are taken into account. Advisory speed limits should be posted at isolated hazards, such as narrow bridges, narrow overhead structures or a single tree near the roadway.

Intersections are particularly hazardous, as reflected in the accident rates. Lower speed limits at intersections are warranted. The guidelines allow a reduction on the basis of the spacing of intersections and pedestrian crossings. The Department of Transport (1993) recommends that traffic signals not be installed at an intersection where the speed limit is greater than 80 or 90 km/h.

The influence of factors, such as road width, roadside hazards and road surface condition should be taken into account by means of the 85 percentile speed (Van As and Joubert, 1998).

3.3.3 Setting Advisory Speeds

Advisory speed signs are used to indicate safe speeds for specific conditions on a road. They reduce the need to vary speed limits along a road section, which may confuse drivers.

An advisory speed is posted (in 10 km/h intervals) if it differs by more than 20 km/h from the speed limit or the 85 percentile speed immediately upstream of the sign. An advisory sign is not required if vehicles are unlikely to travel at speeds greater than the appropriate speed.

Isolated problems are best handled by posting advisory speeds. If advisory speeds are required continuously along a road, the speed limit should be reduced (Van As and Joubert, 1998).

3.3.4 Setting Speed Limits at Roadworks

Speed limits at road works are required not only to safeguard construction workers, but also the motorist, because of the greater hazard resulting from the increased level of activity at roadworks. Roadworks are particularly dangerous on high-speed roads, because of the speed adaptation problem (Van As and Joubert, 1998).

Excessive vehicle speed is a major contributor to accidents at roadwork sites. The purpose of speed limits is therefore to reduce the number and severity of accidents to minimum levels consistent with the provision of smooth and efficient traffic flow. It is essential that speed limits are realistic and that the public can learn to respect and rely on them. In planning the traffic management and work phases, the use of unrealistically low speed limits, over excessive distances, should be avoided. Procedures for setting speed limits at roadworks are given in Chapter 13 of Department of Transport (1997).

The basic safety principles governing the design speed of permanent roadways should also govern the design speed of roadworks.

3.4 References

AASHTO, 1994. *A Policy on Geometric Design of Highways and Streets*, Washington, DC, USA

Andersson, G; and Nilsson, G, 1995. *Speed Limits, Speed and Safety,* Speed Management and Enforcement US Panel, Gothenburg, Sweden

Austroads, 1996. *Urban Speed Management in Australia*, Sydney, Australia

Central Statistical Services, 1997. *Road Traffic Collisions, 1996*, Pretoria, South Africa

Cirillo, JA, 1992. *Safety Effectiveness of Highway Design Features. Volume I, Access Control*, FHWA, Washington, DC, USA

Department of Transport, 1993. *South African Road Traffic Signs Manual*, Vo*lume 1,* Pretoria, South Africa

Department of Transport, 1996. *A Future for Roads in South Africa*, Pretoria, South Africa

Department of Transport, 1997. *South African Road Traffic Signs Manual, Roadworks Signing, Chapter 13*, Pretoria, South Africa

Federal Highway Administration, 1982. *Synthesis of Safety Research Related to Traffic Control and Roadway Elements, Report FHWA-TS-82-233*, FHWA, Washington, DC, USA

Federal Highway Administration, 1995. *Our Nations Highways, Selected Facts and Figures FHWA*, Washington, DC, USA

Federal Highway Administration, 1997. *Flexibility in Highway Design*, Washington, DC, USA

Fitzpatrick, K; Blaschke, JD; Shamburger, CB; Krammes, RA; and Fambro, DB, 1995. *Compatibility of Design Speed, Operating Speed and Posted Speed, Research Report 1465-2F*, Texas Transportation Institute, College Station, Texas, USA

Garber, NJ; and Gadiraju, R, 1989. *Factors Affecting Speed Variance and its Influence on Accidents*, *Transportation Research Record 1213*, TRB, National Research Council, Washington, DC, USA

Garber, NJ; and Gadiraju, R, 1992. *Impact of Differential Speed Limits on the Speed of Traffic and the Rate of Accidents*, *Transportation Research Record 1375*, TRB, Washington, DC, USA

Glennon, JC; and Azzeh, JA, 1976. *Access Control on Arterial Highways, ASCE Transportation Engineering Journal 76(1)*, USA

Homburger, WS, 1989. *Residential Street Design and Traffic Control,* ITE, Washington, DC, USA

Institute of Traffic Engineers, 1961. *An Informational Report on Speed Zoning*, Traffic Engineering, Washington, DC, USA

Institute of Transportation Engineers, 1992. *Traffic Engineering Handbook*, ITE, Washington, DC, USA

Johnson, HD, 1980. *Cross-over Accidents on All-purpose Dual Carriageways, Supplementary Report 617*, TRL, Crowthorne, UK

Kallberg, V, 1998. *The Two Effects of Speed on Accidents: Number and Severity, 77th Annual Meeting of Transportation Research Board*, Washington, DC, USA

Knowles, V; Persaud, B; Parker, M; and Wilde, G, 1997. Safety, *Speed and Speed Management: A Canadian Review*, IBI Group, Toronto, Canada

Koepke, FJ; and Levinson, HS, 1992. *Access Management Guidelines for Activity Centres*, *NCHRP Report 348*, TRB, National Research Council, Washington, DC, USA

NAASRA, 1988. *Guide to Traffic Engineering Practice: Part 4, Road Crashes*, Sydney, Australia

Ogden, KW, 1996. *Safer Roads: A Guide to Road Safety Engineering*, Avebury Technical, Sydney, Australia

Republic of South Africa, 1989. *Road Traffic Act, 1989 (Act No 29 of 1989)*, Pretoria, South Africa

Ribbens, H, 1986. *Guidelines for the Setting of Speed Limits, RV/19*, NITRR, Pretoria, South Africa

Roads and Transportation Association of Canada, 1986. *Manual of Geometric Design Standards for Canadian Roads*, Ottawa, Canada

Roads and Traffic Authority, 1995. *Speed Zoning (Draft), Traffic Engineering Manual*, RTA Traffic Technology Branch, New South Wales and Traffic Authority, Australia

Rosenbaum, M, 1987. *Traffic Control for Reversible Flow Two-Way Left Turn Lanes, Public Roads, Vol 50, No 1*, FHWA, Washington, DC, USA

Simpson, D; and Brown, M, 1988. *A Review of Recent Department of Transport Accident-based Studies, Journal of the Institution of Highways and Transportation 35(2)*

Stanway Edwards Associates, 1996. *Balgowan Traffic Safety Management Project, SARB Progress Report No 10: Phase 3*, Pretoria, South Africa

Stanway Edwards Ngomane Associates, 1998. *Pretoria Road Hierarchy Functional Classification System,* Pretoria, South Africa

Transport Research Laboratory, 1991. *Towards Safer Roads in Developing Countries: A Guide for Planners and Engineers*, TRL, Crowthorne, UK

Van As, SC; and Joubert, HJ, 1998. *Setting of Speed Limits in South Africa*, *Report RR 96/006*, Department of Transport, Pretoria, South Africa

Vic Roads, 1996. *Speed Zoning Guidelines, Traffic Engineering Manual*, Victoria, Australia

Walker, CD and Lines, CJ, 1991. *Accident Reductions from Trunk Road Improvements, Research Report CR 321*, Transport Research Laboratory, Crowthorne, UK

Zegeer, CV; and Council, FM, 1992. *Safety Effectiveness of Highway Design Features. Volume III, Cross Sections*, FHWA, Washington, DC, USA

Zegeer, CV; Stewart, R; Council, F; and Neuman, T; 1994. *Roadway widths for Low Traffic Volume Roads, NCHRP Report 362*, TRB, Washington, DC, USA

4. INTERSECTIONS

4.1 Effect of Design on Intersection Safety

The safety, efficiency, speed, operational cost and capacity of the road network depend on the design of its intersections. Intersections represent the most critical elements of the road system in terms of safety. As points of spatial conflict, intersections by their very nature produce opportunities for collisions involving motor vehicles and pedestrians. The importance of intersections is illustrated by the fact that 42% of all accidents in urban areas occur at or near intersections (CSS, 1997).

Particularly in urban areas, the capacity of signalised intersections can effectively define the capacity of the road system. With the need to safely accommodate cyclists and pedestrians with varying degrees of mobility, and the need to handle left and right turns, the challenge becomes even more complex (FHWA, 1997).

The main objective of intersection design is to reduce the severity of potential conflicts between motor cars, buses, trucks, bicycles, pedestrians and facilities, while facilitating the convenience, ease and comfort of people traversing the intersections. The design should be fitted closely to the natural paths and operating characteristics of the users (AASHTO, 1994).

Intersection design can vary widely in terms of size, shape, number of travel lanes and number of turning lanes. Basically, there are three types of at-grade intersections, determined by the number of intersecting legs, topography, traffic patterns and the desired type of operation. Each roadway radiating from an intersection is called a leg. Most intersections have 4 legs, which is generally accepted as the maximum recommended number for safety and capacity reasons. The three basic intersection types are:

- T-intersection (3 approach legs)
- Four-leg intersection
- Multi-leg intersection (5 or more approach legs).

Intersections are critical locations in the road network from both a safety and efficiency (capacity) viewpoint. Intersections have a range of control strategies, ranging from being uncontrolled, having priority control, or using traffic circles or traffic signals. Safety is one of the most important considerations in the selection of control strategy.

By their very nature, intersections are risky, since different road users (vehicles, pedestrians, cyclists) are required to use the same space, and collisions are only avoided if they are separated in time. The main factors affecting safety at intersections are shown in Table 4.1.

TABLE 4.1 MAIN FACTORS AFFECTING SAFETY AT INTERSECTIONS (TRB, 1987)

- Number of legs
- angle of intersection
- sight distance
- alignment auxiliary lanes
- channelisation
- friction
- turning radii
- lighting
- lane and shoulder widths
- driveways
- right of way and
- approach speed.

These factors are discussed in greater detail below (Neuman, 1985; TRB, 1987)

4.1.1 Number of Legs

Accidents increase as the number of legs increases

The hazard of at-grade intersections increases as the number of legs increases. Thus, three-legged T-intersections are less hazardous than four-legged, cross-type intersections, which in turn are less hazardous than five-legged intersections. The increasing hazard results from a number of factors, including a large increase in the number of potential conflict points, an increase in the number of options underlying driver choice, difficulty in proper signing and road marking, including delineation of appropriate travel paths, and impaired surface drainage resulting from increased surfaced area within the intersection.

4.1.2 Angle of Intersection

The preferred angle between intersecting legs at an intersection is 90º. At angles deviating significantly from this standard, drivers of crossing vehicles are unable to detect the presence or judge the speed of approaching vehicles, and the time and area of conflict is increased. It also becomes increasingly difficult to make turning movements, partly because of larger vehicle off-tracking.

Accidents increase as the number of lanes increases

4.1.3 Number of Through Lanes

The intersection accident rate, expressed in accidents per million entering vehicles, is typically higher when the approach roads have a larger number of lanes. However, the number of lanes is usually determined by capacity rather than by safety considerations.

4.1.4 Sight Distance

Improved sight distance enhances intersection safety

At intersections, sight distance refers to the driver's view entering the intersection. If this view is enlarged by the removal of obstructions in the line of sight, the driver is better able to judge the hazard of entering the intersection, and as a result, safety is enhanced. Although intersection sight distance is viewed as beneficial in all circumstances, it is considered less significant under traffic signal control, where decisions are based primarily on signal indication, and perception of threat from crossing traffic is usually a secondary consideration. Improvements to intersection sight distance primarily impact angle collisions.

4.1.5 Alignment

From a safety standpoint, intersecting roadways should be flat and straight. Curvature in either the horizontal or vertical plane that impairs sight distance will increase intersection hazard. A small gradient does not appear to be harmful, and may even be beneficial in improving surface drainage. More substantial grades become a liability as stopping sight distance on a downward approach increases, and conflict is intensified by reduced acceleration following a stop on an upward approach. Horizontal curvature on approaches to at-grade intersections is mostly harmful. Not only is it more difficult for drivers to discern the proper paths of travel, but their visual focus is along lines tangential to these paths. Horizontal curves add further complexity to an already difficult driving environment.

4.1.6 Auxiliary Lanes

Auxiliary lanes reduce speed variance and disruption to through traffic by accommodating special needs of turning vehicles; deceleration, acceleration and waiting. Although auxiliary lanes are beneficial in virtually every situation, the extent of their impact is dependent on the volume of turning movements, volume of possibly conflicting movements, and approach speed. The primary impact of auxiliary lanes is on collisions between vehicles on the same approach, particularly the rear-end type. They are typically more effective in reducing hazards when accommodating right-turning vehicles than left-turning ones, and a separate right-turn phase at signalised intersections is often necessary for full benefits to be realised. One disadvantage of auxiliary lanes is increased pedestrian crossing time as a result of the added roadway width.

On primary roads, additional turning lanes are essential, irrespective of traffic volumes.

4.1.7 Channelisation

The advantages of channelisation with respect to safety have been firmly established (Neuman, 1985). Channelisation can be used to delineate proper paths of travel, separate points of conflict, control angle of conflict, and provide pedestrian refuge. The establishment of right-turn lanes, a fundamental element in many channelisation improvements, provides significant reductions in accident rates, especially at unsignalised intersections.

Channelisation is required for the provision of protected left-turn lanes, is often necessary to eliminate excessive painted areas otherwise associated with turning roadways, and is usually considered when the intersection is large. Although kerbed islands provide more positive control than paved ones, hazards associated with striking raised islands suggest that mountable kerbs or painted, flush islands are preferred when approach speeds are high and fixed illumination is not provided.

4.1.8 Tyre-pavement friction

Of all road and street locations, intersections place the greatest demands on the tyre-pavement interface. The most critical conditions exist when a large number of vehicles must stop, the approach speed is great, and stopping must be achieved quickly. The type of surfacing material, its prior wear or polishing by traffic, and the slope of the surface are important pavement attributes that affect tyre-pavement friction. Grooving can be used to partly compensate for deficient pavement surfaces. Tyre-pavement friction affects primarily multi-vehicle accidents that occur when the pavement is wet or icy.

4.1.9 Turning Radii

Safety is degraded when vehicles must either encroach on adjacent lanes or slow excessively in order to execute turning movements. From a geometric standpoint, right turns are more critical than left turns, and the degree of hazard is related to both vehicle size and traffic volumes.

4.1.10 Road Lighting

At night road lighting provides advance warning of the presence of at-grade intersections and allows the approaching driver to view objects outside the field of view of headlight illumination. Although the eye’s delay in adjusting to the changing level of background illumination, diffusion of light on dirty or damp windscreen surfaces, and the roadside hazards of lighting standards are undesirable influences, on balance the overall effect of overhead lighting is beneficial. In specific situations, such as intense pedestrian activity, installation of road lighting can provide substantial gains.

This can also be enhanced by phasing road lighting in and out, thereby allowing drivers to adjust to changing conditions. Refer to Slater (1997) for details of road lighting.

4.1.11 Lane and Shoulder Widths

Incremental changes in lane and shoulder widths have little effect on the accident pattern at intersections. The types of accidents affected by lane and shoulder conditions on open roadways, namely opposite-direction (OD) and run-off-road (ROR) accidents, are not significant at intersections. At the same time, the presence of a shoulder may well be beneficial, not only because of the space it provides for collision avoidance manoeuvres, but also because of sight distance, obstacle-offset, and radius-of-turn implications.

4.1.12 Driveways

Driveways in the vicinity of intersections place additional demands on the driver both in terms of the level of information that must be processed and the complexity of required decision-making. The hazard of nearby driveways, expressed primarily in their effect on multi-vehicle accidents, is less for entrances designed for easy and rapid use and for those located farther from the intersection. Safety is further enhanced if the site served by the driveway can properly accommodate parking and off-roadway circulation needs.

Accidents increase as approach speeds increase

4.1.13 Assignment of Priority

Common rules-of-the-road assign the right of intersection use to the vehicle that enters first, or, in the event of two vehicles approaching simultaneously, the vehicle on the right. When sight distance is restricted, or as volumes increase, safety demands more positive control of traffic. Yield and stop signs and traffic signals represent progressively more definitive means for priority assignment. The optimal technique from a safety standpoint depends heavily on site-specific characteristics, and can best be determined by using warrants presented in the Department of Transport (1993a). Signalisation, especially, is not necessarily a safety panacea.

Compared with other forms of control, signalisation is often accompanied by fewer angle collisions but more rear-end collisions. The net effect of signalisation depends on site-specific characteristics: usually intersections having complex geometry and large traffic volumes respond best to traffic signal control. The first intersections encountered on approaches to urban areas and isolated rural intersections are difficult to safely signalise, because they are not expected by drivers.

4.1.14 Approach Speed

The hazard of at-grade intersections increases as approach speed increases. Time available for driver decision-making and response is less, braking requires longer distances, and, in the event of a collision, the kinetic energy dissipated is much greater. Furthermore, high approach speeds may indicate that approaching drivers do not expect the intersection and, hence, are ill-prepared to deal with the decisions it may demand. To the extent they are capable of lowering approach speeds, traffic control devices, such as advisory speed signs, flashing lights, and rumble strips improve safety at intersections.

Higher speeds intensify the problem of dilemma zones at signalised intersections. These are zones in which motorists approaching a traffic signal that turns yellow find they are too close to stop before reaching the intersection and too far to get through the intersection before the light turns red. Special remedies proposed for this problem are all-red intervals, longer amber indications, and systems that detect the presence of a vehicle in its dilemma zone and extend the green phase.

One-way streets have less conflicts

4.1.15 On-Street Parking

Intersections with adjacent on-street parking are more hazardous than intersections with no parking. Vehicles parked at the roadside restrict sideward visibility necessary for safe operation at intersections, and parking manoeuvres disrupt through-traffic movements. The degree of hazard is intensified at locations of concentrated pedestrian activity.

4.1.16 One-Way Operation

At least in the environment in which it is feasible, one-way operation is considerably safer than two-way operation. The advantage stems mainly from a reduction in the number of conflict points, but extends to other factors, such as improved signal timing, reduced headlight glare, and so forth.

4.1.17 Miscellaneous Traffic Control Measures

Before and after studies demonstrate that significant benefits can sometimes be achieved at hazardous intersections by minor changes in traffic control, including:

- Improved delineation
- No-passing signs and markings
- Flashing lights
- Advance warning of hazards
- Advance directional signing
- Prohibition of right turns
- Enlarged signs and signal lenses
- Additional signal faces
- Removal of roadside distractions and

- Adjustment of signal timing.

The degree of improvement achieved by such means is obviously dependent on the extent to which a specific deficiency can be ameliorated.

Guidelines for good intersection design generally incorporate these considerations. The basic principles of good intersection design are reviewed below. The main design principles for intersections are shown in Table 4.2.

TABLE 4.2 MAIN DESIGN PRINCIPLES FOR INTERSECTIONS (TRB, 1987)

- Minimise the number of conflict points and therefore the opportunities for accidents
- Give preference to major movements by means of alignment, delineation and traffic control
- Separate conflicts in space or time
- Control the angle of conflict; crossing streams of traffic should intersect at a right angle (or close to it), while merging streams should intersect at small angles to ensure low relative speed
- Define and minimise conflict areas
- Define vehicle paths
- Ensure adequate sight distances
- Control approach speeds using alignment, lane width, traffic control and speed limits
- Provide clear indications of road reserve requirements
- Minimise roadside hazards
- Provide for all vehicular and non-vehicular traffic likely to use the intersection, including special provisions for heavy vehicles, public transport vehicles, pedestrians and other vulnerable road users
- Simplify the driving task and
- Minimise road user delay.

Many intersection designs incorporate several of these principles. For example, traffic circles usually include all of the above principles to some degree. Intersections controlled by traffic signals also combine many of these principles, but some, such as adequate sight distance, minimum conflict angles and minimum number of conflict points, are less important as a result of the possibility of time-separation of conflicting movements.

The greatest challenge in intersection design is balancing the need to achieve safety objectives for the majority of user groups, and competing traffic and environmental objectives, such as capacity, delay, noise and aesthetics.

Mid-Block Locations

The main design principles for driveways and pedestrian crossings at mid-block locations are shown in Table 4.3.

TABLE 4.3 MAIN DESIGN PRINCIPLES AT MID-BLOCK LOCATIONS (TRB, 1987)

- Ensure appropriate and consistent standards of horizontal and vertical alignment
- Develop roadway cross sections to suit road function and traffic volumes
- Delineate roadway and vehicle paths
- Ensure appropriate standards of access control from adjacent land use and
- Ensure that the roadside environment is clear or forgiving (Ogden, 1996)

The intersection should allow vehicles and other road users to progress straight ahead or to turn into another roadway with minimum delay and maximum safety. The layout and operation of the intersection should therefore be obvious and unambiguous, with good visibility of traffic control devices and of other road users. Different intersection types will be appropriate under different conditions, but generally as traffic flows and the ratio of minor to major road flow increases, more control is necessary, for both safety and capacity reasons.

4.2 Intersection Control

In increasing degree of standard and control, intersections are:

- uncontrolled, relying on a priority rule to indicate the right of way
- priority road designated by YIELD or STOP signs
- traffic circle
- signal controlled, with turning traffic filtering through oncoming traffic
- signal controlled, with control of some or all turning movements or
- grade separations.

The particular needs of all road user groups should be considered to improve the quality of the design. Table 4.4 shows typical accident rates in Australia for different intersection configurations, different forms of control and different functional classifications. It indicates that certain intersection configurations tend to be safer than others. However, intersections must also satisfy other efficiency and environmental requirements, especially capacity on arterial roads. By combining safety, environmental and capacity considerations, guidelines can be developed to determine which intersection type is appropriate for particular conditions.

TABLE 4.4 TYPICAL INTERSECTION ACCIDENT RATES
(Barton, 1989)

INTERSECTION TYPE	**AVERAGE CASUALTY ACCIDENT RATE (MVM)**
Cross Intersections	
• urban signalised	1,7
• urban unsignalised	2,4
• high speed signalised	2,5
• rural unsignalised	5,2
T-intersections	
• urban signalised	1,4
• urban unsignalised	1,5
• high speed signalised	2,1
• rural unsignalised	3,3
Multi-leg Intersections	
• urban signalised	3,2
Traffic Circles	1,6
Staggered T-intersections	2,9
Road Hierarchy (Urban)	
• primary arterial/primary arterial	2,4
• primary arterial/secondary arterial	1,8
• primary arterial/collector street	1,4
• primary arterial/ local street	0,8

Table 4.5 shows a typical outcome, indicating the appropriate intersection type with regard to the role of the intersecting roads in a functional hierarchy of roads.

TABLE 4.5 INTERSECTION CONTROL IN ROAD HIERARCHY

(NAASRA, 1988)

CONTROL	PRIMARY ARTERIAL	SECONDARY ARTERIAL	COLLECT OR ROAD	LOCAL STREET
Traffic Signals				
primary arterial	A	A	O	X
secondary arterial		A	O	X
collector road			X	X
local street				X
Traffic Circles				
primary arterial	O	O	X	X
secondary arterial		O	O	X
collector road			A	O
local street				A
STOP or YIELD Signs				
primary arterial	X	X	A	A
secondary arterial		X	A	A
collector road			A	A
local street				A

A = Most likely to be appropriate treatment
O = May be appropriate treatment
X = Usually appropriate treatment.

4.2.1 Which Type of Control?

The decision to install a STOP or YIELD sign is primarily based on sight distance criteria. In South Africa, STOP signs are erected at most intersections. Where the minor road has adequate sight distance, a YIELD sign may be erected. At traffic circles, YIELD signs are usually erected, permitting entering vehicles to merge with traffic within the circle. When large traffic volumes cannot be adequately accommodated by means of YIELD signs, traffic signals may be installed to control traffic demand and regulate traffic movements.

Large traffic circles allow vehicles to queue between intersections around the circle, and traffic signals ensure that the queues do not extend across the other intersections. The use of co-ordinated traffic signals permits several traffic movements to occur simultaneously, thereby enhancing capacity and safety. The use of signals also ensure that pedestrians, cyclists and persons with disabilities can be accommodated in safety (Ogden, 1996).

4.2.2 Traffic Circles

The use of traffic circles may be applicable (Austroads, 1993, TRL, 1991):

- at intersections where traffic volumes lead to unacceptable delays to traffic on the minor road with STOP or YIELD control, or where traffic signals lead to increased delay for all approaches
- at intersections with high right-turning volumes
- at intersections with more than four approaches, where priority control is not appropriate and signals are less efficient, owing to the large number of phases

- at intersections between collector streets, or between a collector and a local street, where a disproportionately high number of accidents occur
- on local streets as part of traffic calming to control speeds
- at rural cross intersections, where there is an accident problem involving vehicles on adjacent approaches or turning vehicles
- at intersections where the main traffic flow turns at right angles (for example, a main road passing through a rural town)
- where major roads intersect at Y- or T-intersections, which usually involve a high proportion of turning traffic.

The use of traffic circles may be less appropriate:

- where a satisfactory design cannot be provided owing to space or topography
- where traffic flows are unbalanced, with high volumes on one or more approaches that dominate the traffic circle
- where the major road intersects a minor road, and a traffic circle leads to unacceptable delay to minor road traffic
- where there is considerable pedestrian activity, and high speeds or heavy flows make it difficult for pedestrians to cross (unless special facilities are provided)
- at an isolated intersection in a network of synchronised traffic signals; a linked signalised intersection may be preferable in this case
- where peak period reversible lanes are used
- where traffic flows leaving the intersection are interrupted by a traffic control device that leads to queues blocking the intersection.

Well-designed traffic circles have a good safety record. This results from the control they exercise over approach speeds, the smaller number and spatial separation of conflict points, the simplicity of decision-making required of the driver, and the positive response required of the driver to pass through a circle (unlike other intersections that go unnoticed).

These features can be enhanced by the provision of traffic islands on the approaches, which provide additional advance warning to the driver, and give good visual cues of the location of intersecting traffic flows, as well as providing refuge to pedestrians to allow them to cross the road in stages.

However, safety problems can occur if (TRL, 1991):

- the merging angle is too sharp
- the circle has an unusual shape
- signing is inadequate or confusing
- there are steep approach gradients
- there is adverse crossfall on the circular roadway
- there are non-motorised vehicles present and
- the deflection on approach is insufficient to slow vehicles to a safe speed.

4.2.3 Pedestrian and Cyclist Safety

From a safety viewpoint, traffic circles present a problem to cyclists and, to a lesser extent, pedestrians. Some studies have found that bicycle accident rates at traffic circles were up to 15 times greater than that of cars, and 2-3 times greater than bicycle accident rates at signalised intersections (Allot and Lomax, 1991). The problem is caused primarily by a cyclist travelling around the circle and being struck by an entering vehicle failing to give way (Jordan, 1985; Layfield and Maycock, 1986; Crampton, Hass-Cleu and Thrush, 1990). The choice of a traffic circle should therefore take account of the proportion of cyclists and non-motorised road users expected to use the intersection (Austroads, 1993).

Measures to improve cyclist safety at traffic circles (Austroads, 1993; Harrison, Hall and Harland, 1989; Institution of Highways and Transportation, 1987; and Burden, 1993) include:

- avoiding squeeze points on the approach
- ensuring adequate deflection and speed control (speed < 50 km/h)
- avoiding large circles, to discourage high speed circulating traffic
- ensuring sight lines are not obstructed
- considering provision of paths and ramps to allow cyclists and pedestrians to bypass the circle by moving from island to island and
- providing adequate lighting.

Pedestrians are as safe as at other intersections, provided they are considered in the design (Austroads, 1993). This is the result of factors, such as traffic islands, permitting pedestrians to cross in stages, and the slower speed of vehicles. Depending on the intensity of pedestrian activity, it may be necessary to provide a signalised pedestrian crossing some distance from the circle. Inter-visibility of pedestrians and motorists is important to maximise pedestrian safety. Visibility can be enhanced by prohibiting parking on the approaches, providing a higher level of street lighting and ensuring that signs and vegetation do not obstruct the visibility of pedestrians, especially children.

Except where pedestrians and cyclists occur in significant numbers, traffic circles can be highly safety cost-effective to replace STOP and YIELD controlled intersections. For example:

- A 78% reduction in casualty accidents was found when traffic circles were installed at low volume sites (Teale, 1984)
- The installation of traffic circles led to an 81% reduction in casualty accidents (Corben, Ambrose and Foong, 1990)
- Walker and Pittam, 1989 revealed that the accident rate at mini-circles was comparable to that at rural T-intersections and better than that at signalised intersections
- The County Surveyor's Society (1987) showed that the installation of small or mini-circles at existing STOP and YIELD controlled intersections can reduce accidents by 30 to 40%, and at existing signalised intersections can reduce fatal and serious accidents by 60 to 80%
- Department of Transport (1986) indicates that traffic circles have the potential to bring about a 50 to 60% reduction in injury accidents, compared to 40% for signalised intersections

- Hedman (1990) suggested that the installation of traffic circles had little effect on accident frequency, but resulted in a 50% reduction in severity.

In Australia, the installation of traffic circles indicated a benefit:cost ratio of 7,5 for accident savings alone over a life cycle of 10 years (Corben, Ambrose and Foong, 1990). Another study (Bureau of Transport and Communications Economics, 1993) showed a benefit:cost ratio of between 3,1 and 6,0 for traffic circle construction at accident sites.

Guidelines for designing traffic circles have been prepared by the Department of Transport (1993b) and Austroads (1993). Local guidelines for mini-circles have also been prepared by Department of Transport (1997).

4.2.4 Rural Intersections

Most rural intersections are likely to be STOP or YIELD controlled. Various measures can be employed to improve safety at rural intersections. One particularly noteworthy treatment is the conversion of a cross intersection into a pair of staggered T-intersections, which is often effective in reducing accident frequency and severity. Hedman (1990) reported in Sweden that paired T-intersections are 1,5 to 2,0 times safer than cross intersections. This is comparable with studies by Kuciemba and Cirillo (1992). Of course, very skew intersections can benefit from being staggered, provided a right-left sequence is followed.

Corben (1989) suggested that candidate sites for replacement should not form part of:

- a co-ordinated signal route
- a tram (light rail) route
- routes with active priority provided for buses
- an intersection of an arterial and a non-arterial road, nor should they be
- part of a designated on-road bicycle route nor
- requiring special timing, directional control or monitoring to achieve specific traffic management objectives.

4.2.5 Signalised Traffic Circles

Heavily trafficked traffic circles are often signalised at some or all approaches to enhance safety and capacity. According to the County Surveyor's Society (1993), there is little influence on total accidents, but there is a decrease in accidents involving bicyclists and motorcycles and an increase in rear-end accidents, and possibly an increase in pedestrian accidents.

4.2.6 Traffic Signals

Traffic signals are widely used to control intersections in urban areas, and occasionally in rural areas, where they meet capacity and safety objectives. By separating the use of road space in time across major traffic flows, signals have the potential to significantly reduce conflicts. They also have the scope to provide for pedestrians and cyclists. In their simplest form, they operate according to a fixed time sequence, but are often vehicle actuated (responding to traffic demands), and are increasingly linked and synchronised to provide network control.

Under the right conditions, the installation of traffic signals will reduce the number and severity of accidents. If signals are installed in terms of a safety warrant, significant benefits can be expected. Hakkert and Malalel (1978) reported a reduction of 48% in casualty accidents after installation, while Corben, Ambrose and Foong (1990) found a reduction of 53% for new intersection signals. Datta and Dutta (1990) showed a 15,5% reduction in total accidents.

Although traffic signals have the potential to reduce the incidence of accidents, they also change the pattern of accidents at an intersection. Studies by Nguyen et al (1987), Willett (1979) and Datta and Dutta (1990) show large reductions in right angle accidents, but equally large increases in accidents involving vehicles turning from the opposite direction.

Warrants for the installation of traffic signals are given in the Department of Transport, (1993a).

4.3 How Much Sight Distance is Needed?

Recent intensive research concerning intersection sight distance (ISD) (Harwood et al 1996) has recommended far-reaching changes to AASHTO (1994) in this regard. Should AASHTO accept the recommendations of Harwood et al (1996), and those of Fambro et al (forthcoming NCHRP Report: *Determination of Stopping Sight Distances*), these amended standards could be reflected in the new edition of AASHTO (1994), expected to be published in the year 2000. The recommendations are listed in Tables 4.6 to 4.13.

TABLE 4.6 GENERAL RECOMMENDATIONS FOR ISD
(Harwood et al, 1996)

- More consistent conceptual basis for ISD models to set revised ISD values
- ISD at uncontrolled and YIELD controlled intersections to provide sufficient sight distance for vehicle to stop before reaching the intersection
- ISD to be based on gap acceptance theory
- Each approach or departure ISD to be reviewed to identify effect of terrain or roadside objects that obstruct ISD.

TABLE 4.7 ISD FOR INTERSECTIONS WITH NO CONTROL

(Harwood et al, 1996)

- Approach ISD at intersections with no control (right-of-way rule) to be based on variation of stopping sight distance (SSD) model.
- Reaction time to be 2,5 sec and deceleration rate to be 3,4 m/s^2
- Revised ISD values to be according to Table below:

DESIGN SPEED (km/h)	REVISED ISD (m)	REVISED ISD (m) (Fambro)
20	20	20
30	25	25
40	30	35
50	40	45
60	50	55
70	65	65
80	80	75
90	95	90
100	120	105
110	140	120
120	165	135

TABLE 4.8 ISD FOR INTERSECTIONS WITH STOP CONTROL

(Harwood et al, 1996)

- ISD along major road for left and right turns to be based on critical gaps of 7,5 sec for passenger vehicles, 9,5 sec for single unit trucks, 11,5 sec for combination trucks based on design speed. Add 0,5 sec for passenger vehicles and 0,7 sec for trucks per lane for major road with more than two lanes
- ISD along minor road to be 4,4 m (preferably 5,4 m) from major road edge
- Sight distance to cross is less than to turn left or right. Critical gaps are 6,5 sec for passenger vehicles, 8,5 sec for single unit trucks, 10,5 sec for combination trucks based on design speed. Add 0,5 sec for passenger vehicles and 0,7 sec for trucks per lane for major road with more than two lanes.

DESIGN SPEED (km/h)	ISD (CROSSING) (m)	ISD (TURNING) (m)
30	55	65
40	70	85
50	90	105
60	110	125
70	125	150
80	145	170
90	165	190
100	180	210
110	200	230
120	220	250

TABLE 4.9 ISD FOR INTERSECTIONS WITH YIELD CONTROL

(Harwood et al, 1996)

- ISD along major road for left and right turns to be based on critical gaps of 7,5 sec for passenger vehicles, 9,5 sec for single unit trucks, 11,5 sec for combination trucks based on design speed. Add 0,5 sec for passenger vehicles and 0,7 sec for trucks per lane for major road with more than two lanes
- At four-leg YIELD controlled intersections, two sight triangles to be considered; one for ISD to cross and one for ISD to turn left or right.

  At T-intersections only left and right turns to be considered
- For crossing, ISD values to be according to Table below:
- For left and right turns, ISD values to be 25 m along minor road; along major road based on critical gaps for STOP controlled intersection, shown in Table below

DESIGN SPEED (km/h)	ISD (CROSSING) (m)	ISD (TURNING) (m)
30	30	65
40	40	85
50	50	105
60	65	125
70	85	150
80	110	170
90	140	190
100	165	210
110	190	230
120	230	250

TABLE 4.10 ISD FOR INTERSECTIONS WITH TRAFFIC SIGNAL CONTROL

(Harwood et al, 1996)

- ISD to be based on stopped vehicles being inter-visible
- ISD for traffic signal operating on flashing mode during low-volume periods to be same as for STOP control for crossing and turning
- ISD for left turn on red to be same as for STOP control.

TABLE 4.11 ISD FOR RIGHT TURNS FROM MAJOR ROAD

(Harwood et al, 1996)

- ISD at unprotected right turns from major road to be based on critical gaps of 5,5 sec for passenger vehicles, 6,5 sec for single unit trucks, 7,5 sec for combination trucks, as shown in Table below. Add 0,5 sec for passenger vehicles and 0,7 sec for trucks per additional lane for right turns crossing more than one lane
- Use parallel and offset right turn lanes on divided roads to minimise sight distance restrictions resulting from opposing right turning vehicles

DESIGN SPEED (km/h)	SIGHT DISTANCE (m)
30	45
40	60
50	75
60	90
70	105
80	120
90	135
100	155
110	165
120	185

TABLE 4.12 ISD MEASUREMENT RULES

(Harwood et al, 1996)

- Driver eye height to be 1,08 m and object height 1,08 m (RSA uses 1,05 m and 1,30 m)
- Also to be used in design of vertical curves to accommodate ISD

4.4 Channelisation for Safety

Intersection design is based on the following objectives:

- The design and traffic control scheme should optimise the operational quality of traffic flow through the intersection
- The intersection should be designed to minimise accidents and their adverse effects.

Operational quality refers to level of service, delay, comfort and ease of navigation. Safety relates both to accident frequency and severity. Good design results in an intersection that is easily traversed by unfamiliar drivers, produces minimal delay for all users, and is as safe as is practicable.

Intersections have unique features, and are intended to operate in such a way that vehicles travelling in opposite or conflicting directions must share the same space. The available choice of travel paths is much greater than on other road sections.

To achieve safe, efficient operations, the conflicts inherent in intersections must be managed. The objective of good intersection design and traffic control is to achieve the following:

- The number of points of conflict should be reduced to the minimum required for efficient operation
- The complexity of conflict areas should be reduced whenever possible
- The frequency of actual conflicts should be limited and
- The severity of conflicts that occur should be limited.

Complex intersections are difficult to operate efficiently, create confusion, and should be avoided. Each point of conflict is a potential source of delay or even has the potential for an accident. Given that conflicts are inherent in intersections, it is desirable to mitigate their adverse effects, by reducing the risk of conflicts and reducing the consequences of those that occur.

Years of experience and studies have revealed the following:

- Many intersection problems are caused by concentrating activities in a small area, forcing drivers to make multiple decisions and errors. Their actions affect other drivers and make matters worse.
- Intersections usually require changes in vehicle speeds to operate safely. Most drivers entering an intersection must decelerate or brake in response to traffic control measures to make turns or avoid conflicts. These speed changes also give rise to driver error and conflict, as other drivers are required to see and respond to them.
- Inattentive, unfamiliar or inexperienced drivers can have a negative effect on operations. Sudden lane changes or braking and high approach speeds give rise to safety problems. The chances of a driver making an improper move are aggravated by the wide choice of available routes to follow.

These typical problems are at the core of the application of the functional objectives of channelisation.

4.4.1 Principles of Channelisation

These principles are based on an understanding of the operational nature of intersections, and from the fundamental principles of intersection design:

- Undesirable or wrong-way movements should be discouraged or prohibited by means of channelisation
- Desirable paths for vehicles should be clearly defined by all elements of the intersection
- Desirable and safe vehicle speeds should be encouraged by the intersection design
- Design of the intersection should separate points of conflict if possible
- Traffic streams should cross at near right angles and merge at flat angles
- Intersection design should facilitate the movement of high priority traffic flows
- Intersection design should facilitate its traffic control scheme
- Intersection design should accommodate slow or stopped vehicles clear of through traffic lanes and
- Safe refuge from vehicles for pedestrians, persons with disabilities and others should be provided where needed.

The tools available to designers and traffic engineers are summarised in Table 4.14. They comprise six physical features of the intersection, as well as traffic control devices. The latter are integral to any intersection, and fulfil some of the basic channelisation functions.

TABLE 4.14 DESIGN ELEMENTS FOR CHANNELISATION

(Neuman, 1985)

TABLE 4.14 DESIGN ELEMENTS FOR CHANNELISATION (Neuman, 1985)
• Traffic lanes • Traffic islands • Median dividers • Corner radii • Approach geometry (including horizontal and vertical geometry) • Tapers and transitions • Traffic control devices

Table 4.15 shows which basic design elements are applicable in addressing the principles of channelisation.

TABLE 4.15 ELEMENTS FOR APPLYING CHANNELISATION PRINCIPLES

(Neuman, 1985)

DESIGN ELEMENT	TRAFFIC LANE	TRAFFIC ISLAND	MEDIAN DIVIDER	CORNER RADIUS	APPROACH GEOMETRY	ROAD-WAY TAPER / TRANSI-TION	TRAFFIC CON-TROL DEVICES
PROHIBIT MOVEMENTS		X	X	X	X		X
DEFINE VEHICLE PATHS		X	X	X	X	X	
PROMOTE SAFE SPEEDS				X	X	X	
SEPARATE CONFLICTS		X	X		X		X
CROSS / MERGE ANGLES		X	X		X	X	
PRIORITY MOVEMENTS	X			X	X		X
TRAFFIC CONTROL	X	X	X				X
SLOWING VEHICLES	X					X	
PEDESTRIAN REFUGE		X	X	X			X

4.4.2 Guidelines for Channelisation

One or more of the principles of channelisation apply at each intersection. Good, cost-effective intersection design focuses on the principles and objectives of a particular site. The functional classification, location, traffic patterns and environment dictate what is acceptable in terms of safety and delay. This has an effect on which principles to apply, and how the design elements are combined to give the desired result.

Table 4.16 shows the operational and safety considerations for intersections in different areas.

TABLE 4.16 OPERATIONAL/SAFETY CONCERNS AT INTERSECTIONS

(Neuman, 1985)

	RURAL INTERSECTIONS	**SUBURBAN INTERSECTIONS**	**URBAN INTERSECTIONS**
OPERATIONAL CONCERNS	Maintain high speeds on through movements	Maintain flexibility to accommodate traffic growth	Intersection capacity
	Navigation for unfamiliar drivers	Access control along main routes	Accommodate parking, deliveries
	Provide for comfortable turning movements	Capacity of major signalised intersections	Maintain signal progression schemes and network concerns
SAFETY CONCERNS	Mitigate rear-end conflicts caused by turning vehicles	Angle and rear-end conflicts at congested intersections	Pedestrian conflicts
	Provide adequate geometry and sight distance for safe gap acceptance	Localised pedestrian-related problems (schools, shopping)	Angle and rear-end conflicts at congested intersections
	Avoid surprise situations (hidden inter-sections, unusual channelisation)	Driveway access conflicts	

Guidelines for channelisation are presented in Neuman (1985).

4.5 Intersections on Divided Roads

Most accidents on divided roads occur at intersections. Median width plays a key role in the safety of intersections on divided roads, and therefore has a major effect on the safety of divided roads.

At rural, unsignalised intersections, the frequency of accidents decreases as the median width increases. At suburban, signalised and unsignalised intersections, accident frequency increases as the median width increases. Unsafe situations arise when there is competition for limited space in the median roadway, and when driver confusion results in erratic driving.

At urban/suburban intersections, wide medians result in longer travel time for right turning vehicles. Not only does this involve longer clearance intervals and add to delays, but also affects safety at these intersections.

The effect of median width on accidents at these intersections is shown in Figures 4.1, 4.2 and 4.3 (Harwood et al, 1995).

Accidents increase as median width increases

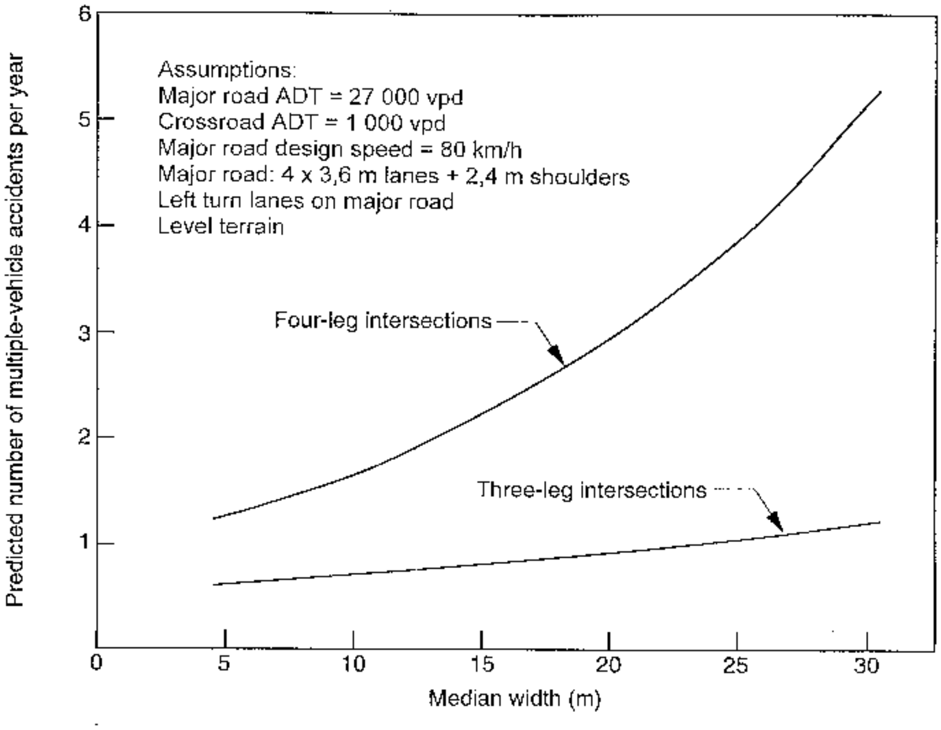
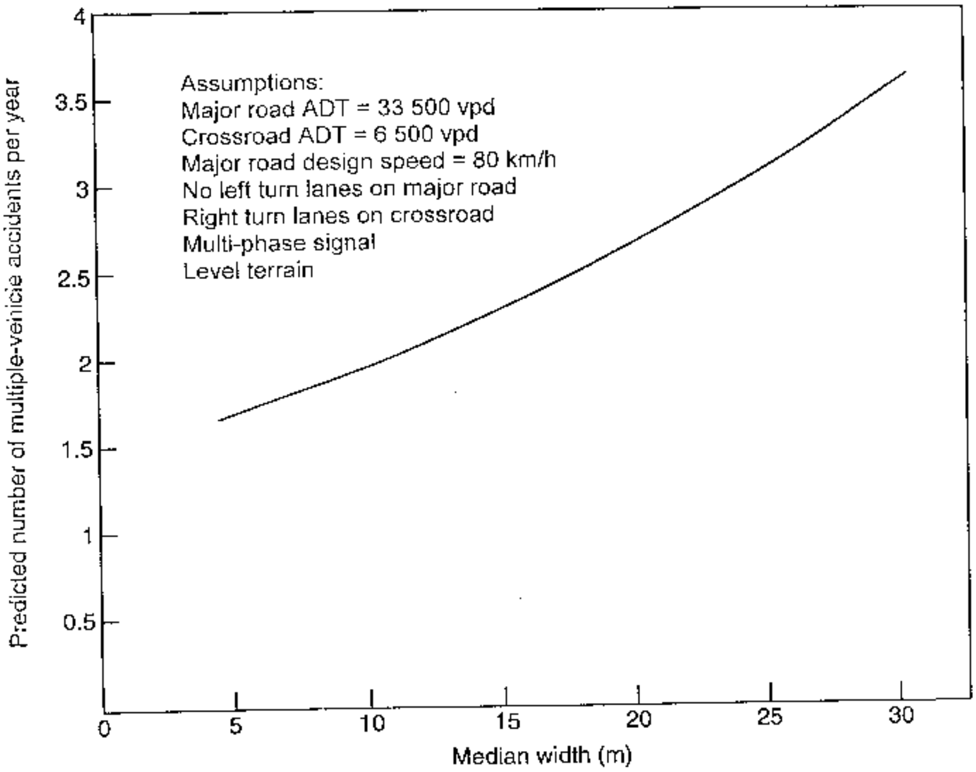


Figure 4.1 Effect of Median Width on Accidents at Urban/Suburban Unsignalised



Accidents increase as median width increases

Figure 4.2 Effect on Median Width on Accidents at Urban/Suburban Signalised Intersections

Accidents decrease as median width increases

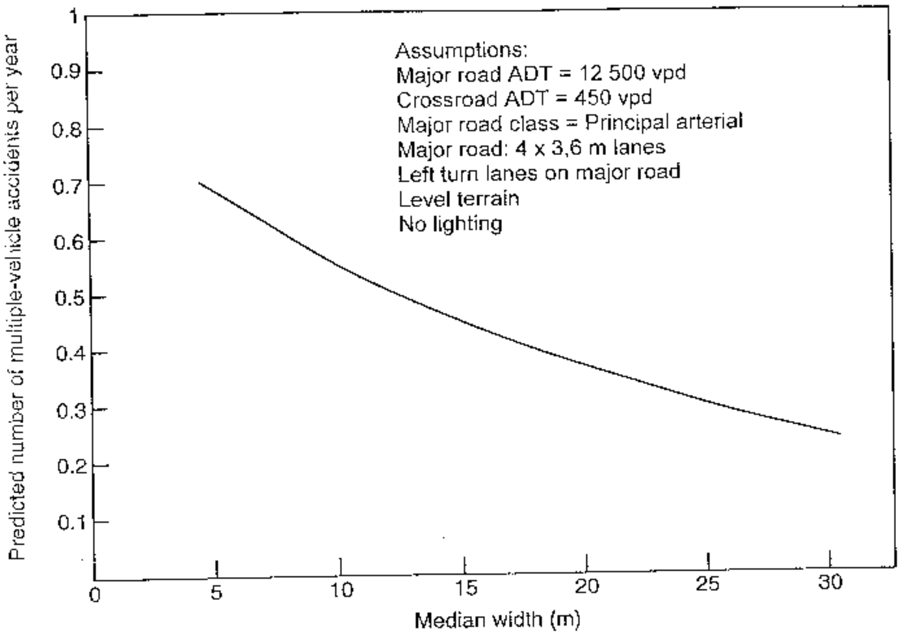


Figure 4.3 **Effect of Median Width on Accidents at Rural Unsignalised Intersections**

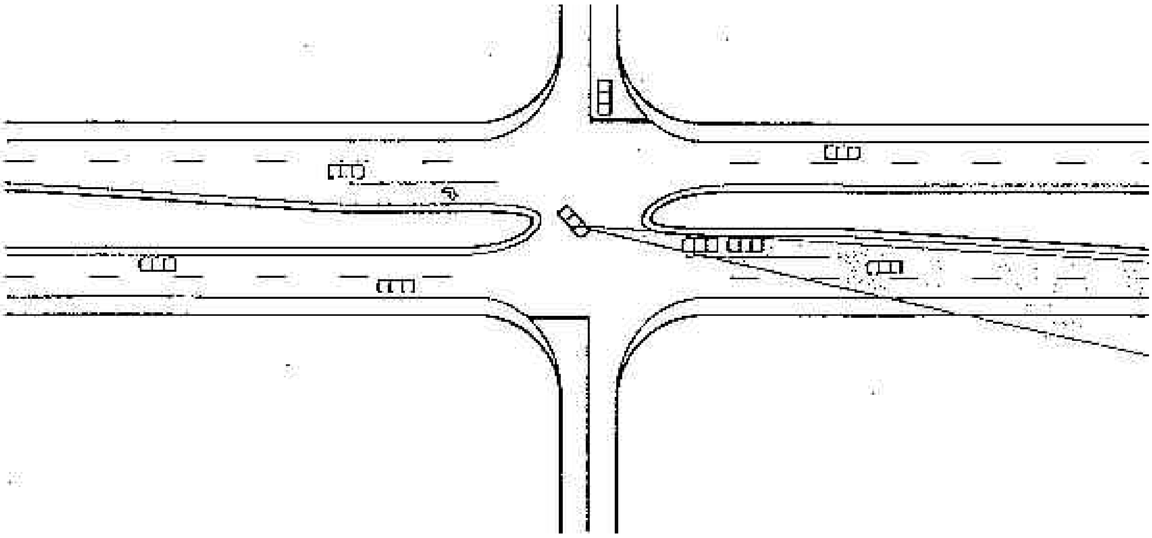
4.5.1 Recommendations

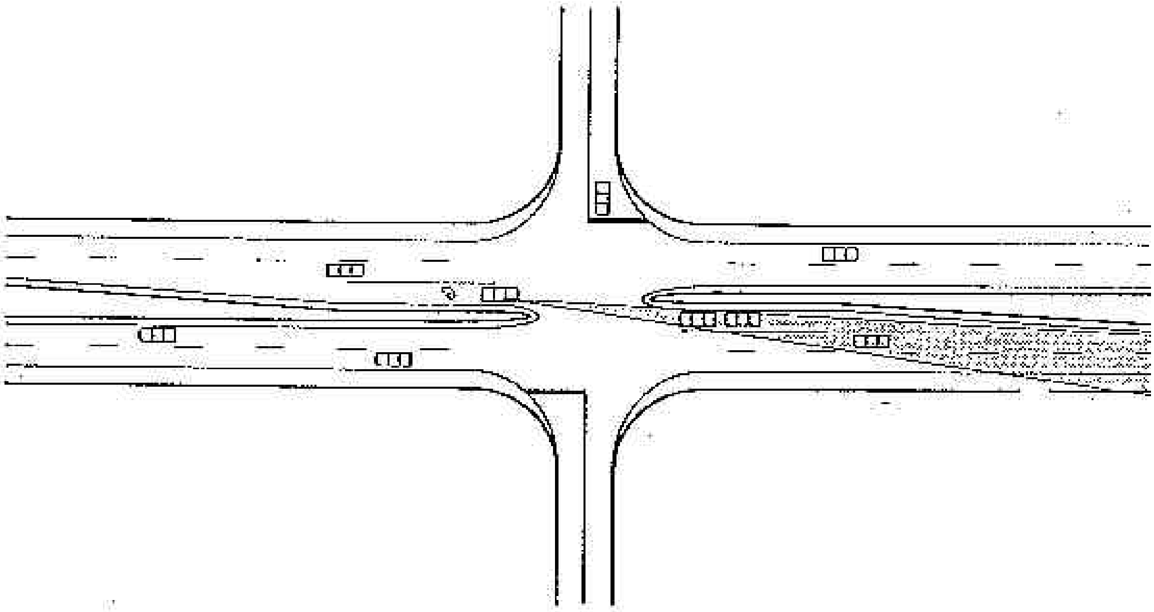
The following is recommended:

- At rural, unsignalised intersections, medians should be as wide as practical, to accommodate turning and crossing movements by the design vehicle, as well as right-turn movements. However, if these intersections are likely to require signalisation in the foreseeable future, narrower medians should be considered (see below). Where possible, median opening length should be limited to the crossroad width plus shoulders.
- At suburban, unsignalised intersections, medians should not be wider than necessary to provide for right turns. Wider medians are associated with increased accident frequency. At specific intersections, where a significant proportion of buses or trucks are in evidence, the median width should accommodate such vehicles stopped in the median.
- At signalised intersections, medians should not be wider than necessary to provide for right turns. Wider medians are associated with increased accident frequency and delays.
- At rural, unsignalised intersections, with median widths in excess of 30 m, a double white centreline to separate opposing traffic in the median opening is recommended.

- At unsignalised intersections with median widths of approximately 18m or less, dashed road markings extending the median edgeline across the intersection will assist drivers to define the boundaries of the median opening.
- Careful design and signage is required at wide median intersections to discourage wrong-way right turns from the crossroad onto the near-side carriageway. If possible, the farside carriageway should be visible to the driver entering the intersection. It is desirable that such intersections be illuminated at night. (Harwood et al, 1995)

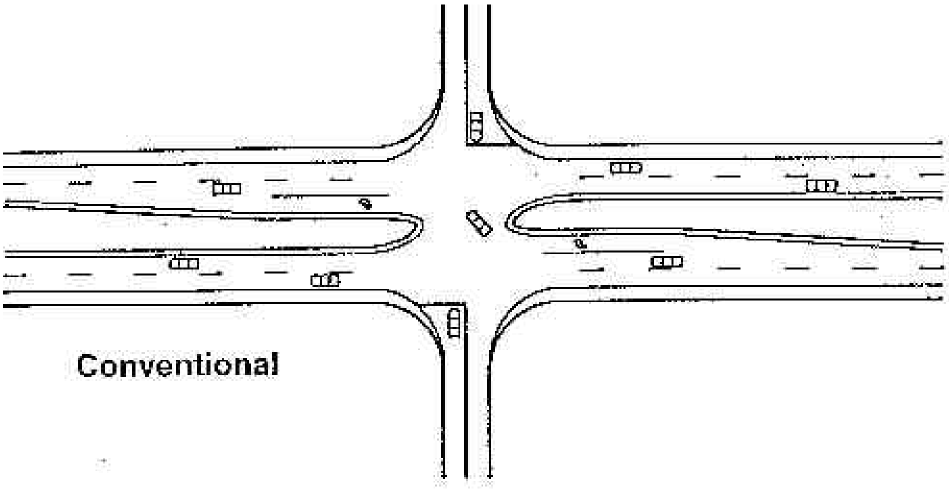
Median width is often determined by the turning treatment required at intersections. Figure 4.4 shows the effect of sight obstuctions caused by turning vehicles.



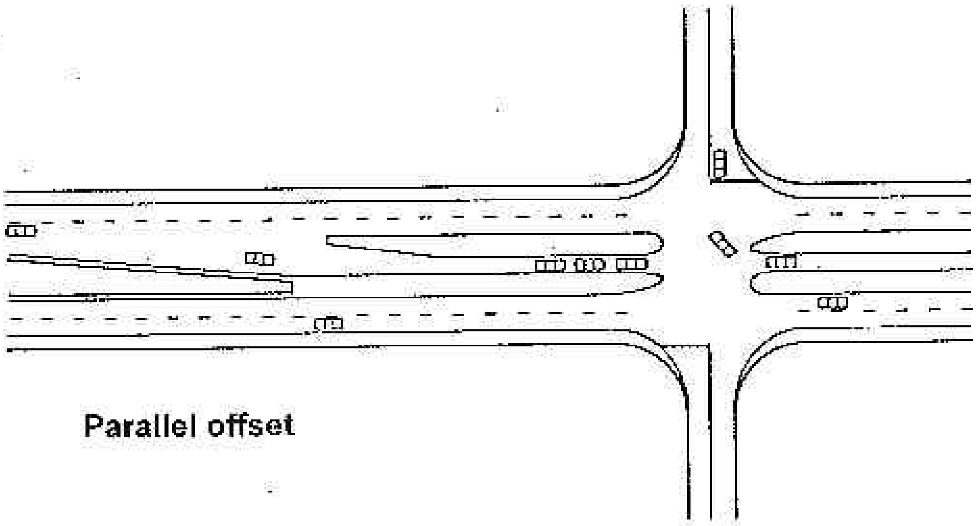


Examples of different treatments include:
- No right turn
- Single right turn
- Parallel offset
- Tapered offset and
- Double right turn.

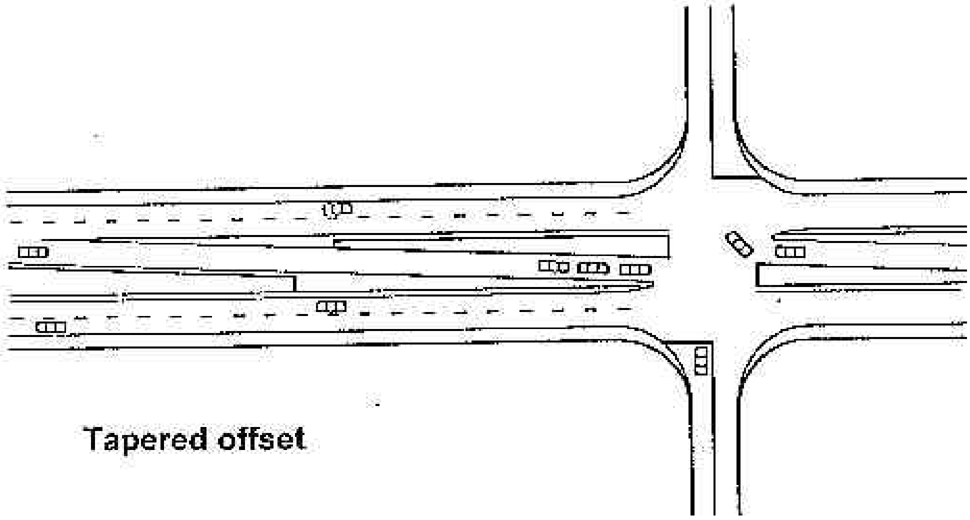
Figure 4.5 shows some of the turning treatments at median intersections.



Conventional



Parallel offset



Tapered offset

Figure 4.5 Turning Treatments at Median Intersections

Table 4.17 illustrates which of these treatments are feasible, marginal, or not feasible within the given median width. Marginal cases refer to substandard widths for turning lanes and/or median dividers. For example, a median width of 3,6 m will allow a single turning lane 3,0m wide and a divider 600 mm wide, too narrow to erect a road sign on the divider or to safely accommodate a pedestrian or cyclist refuge (2,0m wide).

TABLE 4.17 TURNING TREATMENT IN MEDIAN
(Neuman, 1985)

MEDIAN WIDTH (m)	NO RIGHT TURN	SINGLE RIGHT TURN	PARALLEL OFFSET RIGHT TURN	TAPERED OFFSET RIGHT TURN	DOUBLE RIGHT TURN
>12,0					
12,0					
11,4					
10,8			Feasible		
10,2					
9,6					
9,0					
8,4					░
7,8					░
7,2			░	░	░
6,6			░	░	▓
6,0			░ Marginal	░	▓
5,4			░	░	▓
4,8		░	░	▓	▓
4,2		░	▓	▓	▓
3,6		▓	▓	▓	▓
3,0		▓	▓ Not Feasible	▓	▓
2,4		▓	▓	▓	▓
1,2		▓	▓	▓	▓

4.5.2 Guidelines for Median Widths at Intersections

The key factors to be considered in selecting median width at intersections are shown in Table 4.18.

TABLE 4.18 KEY FACTORS IN SELECTING MEDIAN WIDTH AT INTERSECTION
(Neuman, 1985)

- Rural/suburban/urban area
- Crossroad through and turning volumes and vehicle mix
- Volume and vehicle mix for turns from divided roads
- Design vehicle for crossing and turning movements
- Traffic control:
  - ❖ Signalised intersection
  - ❖ Unsignalised intersection likely to require signals in the future
  - ❖ Unsignalised intersection unlikely to require signals in the foreseeable future
- Crossroad width and cross section
- Right-turn treatment
- Need for U-turns on divided roads.

The advantages of increasing median width are shown in Table 4.19.

TABLE 4.19 ADVANTAGES OF INCREASING MEDIAN WIDTH

(Neuman, 1985)

- Interference from opposing traffic minimised
- Perception of greater freedom
- Increased recovery area for errant vehicles
- More open space and park-like appearance
- Reduced headlight glare from opposing vehicles
- Flatter median slopes possible
- Less need for median barrier
- Extra width for additional lanes in future
- Extra width for median right-turn and U-turn storage lanes
- Extra width for median acceleration lanes
- Offset right-turn lanes to minimise sight restrictions by opposing right-turning vehicles possible
- U-turns for larger vehicles possible.

The disadvantages of decreasing median width are shown in Table 4.20.

TABLE 4.20 DISADVANTAGES OF NARROW MEDIANS

(Neuman, 1985)

- Crossing and turning movements may require simultaneous gaps in traffic in both travel directions if median is too narrow to store a vehicle
- Vehicles too long to store in the median may encroach on through lanes
- Stacking or side-by-side storage of vehicles may result in encroachments or confusion as to right-of-way
- U-turns by large vehicles difficult
- Right-turning vehicles on divided roads forced to wait in fast lane if right-turn lane is not provided
- Provision of single or double right-turn lanes may not be possible
- Increased costs to widen median when right-turn lanes prove to be necessary
- Narrow medians require median barriers, which are difficult to terminate at intersections
- Limited provision for pedestrian or cyclist refuge. (see elsewhere)

The disadvantages of wide medians are shown in Table 4.21.

TABLE 4.21 DISADVANTAGES OF WIDE MEDIANS

(Neuman, 1985)

- Driver confusion in large unchannelised area
- Driver failure to heed traffic control devices or stop
- Driver failure to see far-side carriageway and making wrong-way movements
- Crossing or turning vehicles may overflow available storage area
- Sight distance of right-turning vehicles possibly restricted by opposing right-turning vehicles
- A wide crossroad median results in a very large and confusing intersection
- Wider medians require longer clearance times and less efficient signal cycles
- Long clearance times may result in crossroad vehicles being trapped in the median
- Wide medians make signal-head location difficult to ensure visibility
- Very wide medians may require each carriageway to be signalised separately, thus less efficiently
- Signal phases and clearance times may be inappropriate for pedestrians and cyclists.

4.6 Pedestrians at Intersections

Geometric design manuals, such as AASHTO (1994) do not provide comprehensive coverage of design criteria for pedestrian facilities. This is especially applicable in the case of the design of intersections, where pedestrian conflicts are greatest. Pietrucha and Opiela (1993) state that AASHTO (1994) is mainly vehicle-oriented, and does not present a fully integrated approach to highway design. The functional classification of roads is related purely to vehicular traffic, and does not incorporate considerations for non-motorised modes. More attention should be given to the design of intersections, traffic islands and medians that address pedestrian safety.

The similarities and differences in the design considerations for roads and pedestrians are noted in Table 4.22:

TABLE 4.22 ELEMENTS OF ROAD AND PEDESTRIAN FACILITIES
(Neuman, 1985)

DESIGN ELEMENT	**ROAD**	**PEDESTRIAN FACILITY**
Reserve Width	• Capacity dictates number of lanes • Standard widths by functional class • Minimise land acquisition costs • Future improvement options	• Required space (Fruin) • Amenity space desirable • Pathway alignment influenced • Pathway separation influenced
Lane Configuration	• Cross Section • No of Lanes • Medians • Reserve width limits • Capacity dictates number of lanes	• Kerbs impediment to pedestrians • Barriers may enhance pedestrian safety
Horizontal Alignment	• Terrain usually dictates • Adequate sight lines	• Minimise grade differentials • Locate crossing to maximise visibility
Channelisation	• Minimise conflicting movements • Enhance capacity • Minimise delay • Enhance signal effectiveness	• Islands provide refuge for pedestrians • Pedestrians must deal with faster traffic • Queuing space affected
Drainage	• Minimise surface water	• Minimise ponding • Avoid drainage structure in pedestrian paths
Vertical Alignment	• Provide safe stopping distances • Provide adequate • drainage • Provide smooth transitions between grades	• Pedestrian exposure may be more critical • Locate crossing with • adequate sight lines
Turning Radii	• Increased radii means higher speeds • Facilitates turning of larger vehicles	• Increases pedestrian walking distances • Affects queuing space • Complicates pathway connection
Ancillary Facilities (Bus Stops, Parking)	• Minimise operational impacts • Minimise traffic impediments	• Boarding/alighting passengers at safest point • Ensure all passengers are visible around parked vehicles
Structures	• Provide adequate number of lanes	• Provide adequate separation from traffic • Provide physical separation where needed

Pedestrian facilities are discussed in Section 6.9.

4.7 Practical Guidelines

4.7.1 Priority and Layout

Intersection layout and control should be simple and obvious to drivers

The layout and control arrangement at an intersection should be simple and obvious to approaching motorists. Straight priority is usually expected, and deviations from this rule may require additional visual reinforcement. Even where the priority is straight, some existing visual cues, such as fence lines or lines of trees on the minor legs may suggest the continuation of a road so strongly that the control signs and markings are not noticed by some motorists.

Traffic circles are a form of intersection control with their own set of priority rules. It is essential that traffic circles look like traffic circles and that other types of intersection island treatments do not. The approach radius should be tighter than the exit radius. Also, motorists tend to drive in lines as straight as possible, with the result that outer kerb lines will not be trafficked and collect debris. Within intersections with simple priority, it is still possible to confuse motorists with complex island arrangements and hazard markers (delineators).

4.7.2 Visibility

Provide adequate visibility distances for merging traffic: do not confuse visibility distances with warrants for stop signs. Avoid creating obstructions by street furniture or landscaping. Provide adequate visibility to control features: for example, on crests and curves road markings and other devices may be hidden, yet need to be visible for decision-making. Use road signs and markings to guide drivers safely into the correct position for their following manoeuvres.

Avoid Y-junctions and intersections with acute angles, as these restrict forward and side visibility. Many older drivers have restricted neck movement. Similarly, avoid intersections on the inside of curves, as building, fences and landscaping invariably encroach into sight lines, even when they are intentionally kept clear at the design and construction stage. Do not attempt to reduce speeds by relying on limited forward and side vision.

4.7.3 Other Issues at Intersections

On left hand curves in particular, start a splitter island sufficiently far back that the island nose is on the right of the approach path and line of view, to prevent wrong way movements into the oncoming traffic path.

Provide safe pedestrian and cyclist crossing points. Consider central refuges: they allow people to cross traffic from one direction at a time, which is a much easier task than judging gaps in traffic approaching from both directions at once, and is safer than waiting on a centre-line.

Use appropriate turning radii. Large radii allow excessive speeds and cause hazards for pedestrians. On the other hand, radii that are tighter than the turning path of a design vehicle at low speed will result in these vehicles swinging out wide or hitting kerbs.

4.8 Effect of Design on Interchange Safety

An interchange is a system of interconnecting roadways that provides for movements between two or more grade-separated roadways. Interchange alignment, specifically ramp geometry, at a particular site is determined by many factors, such as number of intersecting legs, traffic volumes, topography and environment, and their consistency with the roadway system they serve.

4.8.1 Horizontal Alignment

Studies have shown that, except for loop ramps in rural areas, all ramps and outer connections showed an increase in accident rates as curve radii decrease, and that outer connections in urban areas show increasing accident rates as ADT increases. Straight outer connections have lower accident rates than curved connections in rural and urban areas for all ADT levels, except for ADT less than 500 vpd (Yates, 1970), as shown in Table 4.23.

TABLE 4.23 EFFECT OF RAMP CURVATURE AND ADT ON ACCIDENT RATES

(Twomey et al, 1993)

ADT	URBAN		RURAL	
	STRAIGHT (R>1750 m)	CURVED (R<1750 m)	STRAIGHT (R>1750 m)	CURVED (R<1750 m)
<500	0,74	0,64	0,00	0,67
500-1000	0,34	0,72	0,13	0,49
1001-1500	0,64	0,84	0,00	0,61
1501-2000	0,15	0,93	0.00	0,20
>2000	0,49	0,82	0,00	0,72
All	0,44	0,81	0,05	0,56

Rural loops with small radii have higher accident rates than rural loops with large radii, and vice versa for urban loops (Lundy, 1967), as shown in Table 4.24.

TABLE 4.24 EFFECT OF LOOP RADII ON ACCIDENT RATES

(Twomey et al, 1993)

ADT	URBAN		RURAL	
	LARGE RADII (R>150 m)	SMALL RADII (R<50 m)	LARGE RADII (R>150 m)	SMALL RADII (R<50 m)
<500	0,00	0,84	1,0	0,26
500-100	0,00	0,96	0,81	0,37
1001-1500	1,32	0,69	0,00	0,00
1501-2000	0,00	0,72	0,00	0,00
>2000	0,14	1,00	0,00	0,00
All	0,20	0,94	0,63	0,25

Off-ramps have the highest accident rate, resulting from high speeds of vehicles entering ramp curves and ramp terminal capacity deficiencies, as shown in Table 4.25.

TABLE 4.25 EFFECT OF RAMP TYPE ON ACCIDENT RATES

(Twomey et al, 1993)

RAMP	NUMBER OF RAMPS	NUMBER OF ACCIDENTS	MILLION VEHICLES	ACCIDENT RATE/MVM
On-ramps				
• Straight	180	282	524,5	0,54
• Curved	150	229	335,2	0,68
Off-ramps				
• Straight	188	420	536,0	0,78
• Curved	142	258	310,1	0,81
Total On/Off				
• Straight	368	702	1060,5	0,66
• Curved	292	487	645,3	0,75

Research has shown that interchange ramps should be designed with flat horizontal curves (except in rural areas), and minimum radius curves for a given design speed and superelevation should be avoided. Sharp curves at the ends of ramps and sudden changes from straight alignment to sharp curves should be avoided as well.

4.8.2 Vertical Alignment

Ramp grades are usually constrained by the position of the intersecting road, which crosses over or under the freeway. Trumpet and cloverleaf ramps, loops without C-D roads, and right hand ramps have consistently higher accident rates than others, irrespective of up- or downgrade. Overall, on-ramps have the same combined accident rate for up- and downgrades. Upgrade off-ramps, however, have lower combined accident rates than downgrade off-ramps. If possible, crossing roads should rather be over the freeway than under.

4.8.3 Interchange Type

The accident rates by interchange type for the intersecting road over the freeway (overpass) are shown in the Table 4.26.

TABLE 4.26 EFFECT OF INTERCHANGE TYPE ON ACCIDENT RATES (OVERPASS)

(Twomey et al, 1993)

RAMP TYPE	ON-RAMP			
	Number of Ramps	Number Accidents	Million Vehicles	Accident Rate
Diamond	53	44	124,9	0,35
Trumpet	9	22	28,7	0,77
Cloverleaf w/o C-D	48	83	111,2	0,75
Cloverleaf with C-D	15	37	73,3	0,50
Cloverleaf Loop w/o C-D	46	64	84,2	0,76
Cloverleaf Loop with C-D	9	14	36,3	0,39
Right Hand	5	14	18,9	0,74
Direct Connection	14	55	101,2	0,54
TOTAL	264	418	708,6	0,59
	OFF-RAMP			
Diamond	45	67	99,4	0,67
Trumpet	7	21	24,6	0,85
Cloverleaf w/o C-D	59	135	155,8	0,87
Cloverleaf with C-D	16	56	82,0	0,68
Cloverleaf Loop w/o C-D	34	59	70,7	0,83
Cloverleaf Loop with C-D	10	19	36,5	0,52
Right Hand	11	81	46,4	1,74
Direct Connection	11	53	61,5	0,86
TOTAL	268	629	710,3	0,89

The accident rates by ramp type for the intersecting road under the freeway (underpass) are shown in the Table 4.27.

TABLE 4.27 EFFECT OF INTERCHANGE TYPE ON ACCIDENT RATES (UNDERPASS)

(Twomey et al, 1993)

RAMP TYPE	ON-RAMP			
	No of Ramps	No of Accident	Million Vehicles	Accident Rate
Diamond	32	44	95,4	0,46
Trumpet	2	5	3,5	1,43
Cloverleaf w/o C-D	27	72	105,4	0,68
Cloverleaf with C-D	5	2	14,3	0,14
Cloverleaf Loop w/o C-D	17	44	53,7	0,82
Cloverleaf Loop with C-D	5	3	8,0	0,38
Right Hand	2	11	8,0	1,38
Direct Connection	2	10	28,6	0,35
TOTAL	92	191	316,9	0,60
	OFF-RAMP			
Diamond	44	73	109,8	0,66
Trumpet	0	--	--	--
Cloverleaf w/o C-D	19	86	76,0	1,13
Cloverleaf with C-D	5	3	13,0	0,23
Cloverleaf Loop w/o C-D	19	47	50,0	0,94
Cloverleaf Loop with C-D	5	1	13,2	0,08
Right Hand	4	124	47,0	2,64
Direct Connection	2	30	29,9	1,00
TOTAL	98	364	338,9	1,07

Ramps provide the connection between crossing roads. The relationship between accident rates and freeway ramp types is shown in Table 4.28 below. Right hand ramps and scissors ramps have much higher rates than others, and should not be used. Diamond ramps have the lowest rates, but these rates do not account for intersecting road and ramp intersection accidents.

TABLE 4.28 EFFECT OF RAMP TYPE ON ACCIDENT RATES

(Twomey et al, 1993)

RAMP TYPE	ON-RAMP	OFF-RAMP	ON & OFF
Diamond	0,40	0,67	0,53
Cloverleaf Ramp with C-D Road	0,45	0,62	0,61
Direct Connections	0,50	0,91	0,67
Cloverleaf Loop with C-D Road	0,38	0,40	0,69
Buttonhook Ramps	0,64	0,96	0,80
Loops with C-D Roads	0,78	0,88	0,83
Cloverleaf Ramps w/o C-D Roads	0,72	0,95	0,84
Trumpet ramps	0,84	0,85	0,85
Scissors Ramps	0,88	1,48	1,28
Right Hand Ramps	0,93	2,19	1,91
AVERAGE	0,59	0,95	0,79

Research on geometric design of ramps on which a high rate of truck accidents occurred concluded the following:

- Truck loss-of-control accidents on ramps are mostly rollover and jackknife accidents
- Jackknife accidents occur mostly at sites with inadequate friction during wet weather
- Truck rollover accidents occur on ramps where trucks exceed the ramp design speed
- Safe design to accommodate trucks should include checking for rollover and skidding potential
- AASHTO policy of ramp downgrades, as high as 8% may be inappropriate in cases where a sharp curve is located at the bottom of the gradient (Ervin et al, 1985).

Collector-distributor roads should be considered in high-volume interchange designs, especially in the case of loops and cloverleaf ramps.

4.8.4 Interchange Areas

Accident rates at various parts of the freeway and interchange are shown for rural and urban areas in Table 4.29.

TABLE 4.29 EFFECT OF INTERCHANGE DESIGN ELEMENTS ON ACCIDENT RATES

(Cirillo, 1967)

INTERCHANGE AREA (RURAL)	VEHICLE MILES (X 100 MILLION)	NUMBER OF ACCIDENTS	ACCIDENT RATE (PER MVM)
Deceleration Lane	2,51	348	137
Off-Ramp	0,57	199	346
Between Speed Change Lanes	6,52	554	85
On-Ramp	0,59	95	161
Acceleration Lane	3,68	280	76
Acceleration/Deceleration Lane	0,49	87	116
TOTAL	14,36	1563	109
INTERCHANGE AREA (URBAN)	**VEHICLE MILES (X 100 MILLION)**	**NUMBER OF ACCIDENTS**	**ACCIDENT RATE (PER MVM)**
Deceleration Lane	5,83	1089	186
Off-Ramp	1,48	546	370
Between Speed Change Lanes	11,87	1982	167
On-Ramp	1,61	1159	719
Acceleration Lane	8,40	1461	174
Acceleration/Deceleration Lane	2,45	555	227
TOTAL	31,64	6792	214

Urban interchanges have much higher rates than rural interchanges, which may be attributed to inadequate acceleration lanes on many urban Interstate Highways. The safety of exit and entrance terminals is enhanced with geometric designs that provide 250m or longer acceleration lanes (or ramp tapers) or auxiliary lanes. Deceleration lanes (or ramp tapers) of 270 m or longer reduce traffic friction on the freeway lanes and account for reduced accident rates.

The potential for accidents has been related to the volume of ramp traffic and the relationship between the ramp and freeway traffic volumes (Highway Users Federation, 1970). A general conclusion is that it may be safer to allow merges or diverges to or from the freeway at several minor flow ramps than at single high-volume on- and off-ramps.

4.8.5 Interchange Systems

Investigations into the effect of interchange spacing on interchange capacity by Cirillo, 1967 were inconclusive, but it was found that accident rates increased when speeds vary from the average speed of the freeway section.

As shown in Table 4.30 below, accident rates in urban areas increase as interchange spacing decreases. In rural areas, the change in rates is not as marked.

TABLE 4.30 EFFECT OF INTERCHANGE SPACING ON ACCIDENTS

(Cirillo, 1967)

	OFF-RAMP SIDE (URBAN)		**ON-RAMP SIDE (URBAN)**	
DISTANCE TO OFF-RAMP NOSE	NUMBER OF ACCIDENTS	ACCIDENT ` RATE/MVM	NUMBER OF ACCIDENTS	ACCIDENT RATE/MVM
<320 m	722	131	426	122
320-640 m	1209	127	1156	125
800-1500 m	786	110	1655	105
1600-3000 m	280	75	278	84
3200-6300 m	166	63	151	59
6400-12000 m	19	69	200	75
>13000 m	--	--	--	--
	OFF-RAMP SIDE (RURAL)		**ON-RAMP SIDE (RURAL)**	
<320 m	160	76	117	80
320-640 m	459	75	482	82
800-1500 m	559	69	560	72
1600-3000 m	479	69	435	64
3200-6300 m	222	68	169	51
6400-12000 m	46	62	52	40
>13000 m	--	--	--	--

4.8.6 Interchange Improvements

When an interchange reaches the end of its design life, safety improvements may be required to enable it to meet current and future traffic demands. These may include extending diamond interchange acceleration and deceleration lanes/tapers, adding ramp lanes, and optimising existing or installing new traffic signals. Improvements to partial or full cloverleaf interchanges may include the addition of collector-distributor roads, extending weaving areas and extending acceleration and deceleration lanes/tapers (Twoney et al, 1993).

4.9 References

AASHTO, 1994. *A Policy on Geometric Design of Highways and Streets,* Washington, DC, USA

Allot and Lomax Consulting Engineers, 1991. *Cyclists and Roundabouts: A Review of the Literature*, Cyclists Touring Club, London, UK

Austroads, 1993. *Guide to Traffic Engineering Practice, Part 6: Roundabouts*, Sydney, Australia

Barton, EV, 1989. *Performance and Design of Intersections* in *Traffic Engineering Practice*, Monash University, Melbourne, Australia

Burden, D, 1993. *Bicycling Element* in *The Traffic Safety Toolbox: A Primer in Traffic Safety*, Institute of Traffic Engineers, Washington, DC, USA

Bureau of Transport and Communications Economics, 1993. *Cost-Effectiveness of Black Spot Treatments: A Pilot Study, BTCE Paper 9*, Department of Transport and Communications, Canberra, Australia

Central Statistical Services, 1997. *Road Traffic Collisions, 1996*, Pretoria, South Africa

Cirillo, JA, 1967. *Interstate System Accident Research Study II, Part I in HRR 188*, National Research Council, Washington, DC, USA, *Part II in Public Roads*, Washington, DC, August 1968

Corben, BF, 1989. *Crashes at Traffic Signals: Guidelines for a Traffic Engineering Safety Program of Replacing Selected Intersection Signals with Roundabouts*, Monash University Accident Research Centre, Melbourne, Australia

Corben, BF; Ambrose, C and Foong, CW, 1990. *Evaluation of Accident Black Spot Treatments, Report No 11*, Monash University Accident Research Centre, Melbourne, Australia

County Surveyor's Society, 1987. *Small and Mini-Roundabouts*, CSS, Chelmsford, UK

County Surveyor's Society, 1993. *Accidents at Signalised Roundabouts*, CSS, Ipswich, UK

Crampton, G; Hass-Kleu, C and Thrush, J, 1990. *Bicycle Safety in German and English Towns, Proceedings PTRC Summer Annual Meeting, Seminar G*, Planning and Computation, London, UK

Datta, TK and Dutta, U, 1990. *Traffic Signal Installation and Accident Experience*, *Traffic Engineering Journal 60(9)*, ITE, Washington, DC, USA

Department of Transport, 1986. *Accident Investigation Manual*, DOT, London, UK

Department of Transport, 1993a. *South African Road Traffic Signs Manual, Volume 1,* Pretoria, South Africa

Department of Transport, 1993b. *The Geometric Design of Roundabouts, Departmental Standard TD 16/93*, DOT, London, UK

Department of Transport, 1993. *South African Road Traffic Signs Manual, Volume 2,* Pretoria, South Africa

Emslie, I, 1997. *Design Guidelines for Mini-Roundabouts, Report CR – 97/039,* Department of Transport, Pretoria, South Africa

Ervin, R; Barnes, M; Mac Adam, C; and Scott, R, 1985. *Impact of Special Geometric Features on Truck Operations at Interchanges*, Transportation Research Institute, University of Michigan, Ann Arbor, USA

Federal Highway Administration, 1997. *Flexibility in Highway Design*, FHWA, Washington, DC, USA

Hakkert AS; and Malalel, D, 1987. *The Effect of Traffic Signals on Road Acccidents with Special Reference to the Introduction of a Blinking Green Phase*, Traffic Engineering and Control 19(6)

Harrison, JH; Hall, RD and Harland, DG, 1989. *Literature Review of Accident Analysis Methodologies and Cycle Facilities, Contractor Report CR 163*, Transport and Road Research Laboratory, Crowthorne, UK

Harwood, DW, 1986. *Multi-lane Design Alternatives for Improving Suburban Highways, NCHRP Report 282*, TRB, National Research Council, Washington, DC, USA

Harwood, DW; Pietrucha, MT; Wooldridge, MD; and Brydia, RE, 1995*, Median Intersection Design, NCHRP Report 375*, TRB, National Research Council, Washington, DC, USA

Harwood, DW; Mason, JM; Brydia, RE; Pietrucha, MT and Gittings, GL, 1996. *Intersection Sight Distance, NCHRP Report 383,* TRB, National Research Council, Washington, DC, USA

Hedman, KO, 1990*. Road Design and Safety, VTI Report 351A*, Swedish Road and Traffic Institute, Linkoping, Sweden

Highway Users Federation for Safety and Mobility, 1970. *Traffic Control and Roadway Elements: Their Relationship to Highway Safety, Revised, Interchanges*, Washington, DC, USA

Institution of Highways and Transportation, 1987. *Roads and Traffic in Urban Areas*, IHT, London, UK

Institute of Transportation and Traffic Engineers, 1971. *Fundamentals of Geometric Design, Second Edition*, Washington, DC, USA

Institute of Transportation Engineers, 1993. *The Traffic Safety Toolbox: A Primer on Traffic Safety, ITE*, Washington, DC, USA

Jordan, PW, 1985. *Pedestrians and Cyclists at Roundabouts, Third National Local Government Engineers Conference*, Institution of Engineers, Canberra, Australia

Kuciemba, SR; and Cirillo, JA, 1992. *Safety Effectiveness of Highway Design Features, Volume 5: Intersections*, FHWA, Washington, DC, USA

Layfield, RE and Maycock, G, 1986. *Pedal Cyclists at Roundabouts,* Traffic Engineering and Control 27(6)

Lundy, RA, 1967. *Effect of Ramp Type and Geometry on Accidents, HRR 163*, National Research Council, Washington, DC, USA

NAASRA, 1988. *Guide to Traffic Engineering Practice: Part 5: Intersections at Grade*, Sydney, Australia

Neuman, TR, 1985. *Intersection Channelization Design Guide, NCHRP Report 279*, TRB, National Research Council, Washington, DC, USA

Nguyen, T; Hodge, G; and Hall, K, 1987. *The Road Safety Effectiveness of Traffic Signal Installation at Four-Leg Intersections in Victoria*, Victoria Ministry of Transport, Melbourne, Australia

Ogden, K W, 1996. *Safer Roads: A Guide to Road Safety Engineering*, Avebury Technical, Sydney, Australia

Pietrucha, MT; and Opiela, KS, 1993. *Safe Accommodation of Pedestrians at Intersections*, *Transportation Research Record 1385*, TRB, National Research Council, Washington, DC, USA

Slater, RJV, 1997. *A Simplified Approach to Assessing Warrants for Overhead Lighting of Major Roads,* Department of Transport, Pretoria, South Africa

Teale, GL, 1984. *Evaluation of the Effectiveness of MITERS Type Projects, Report CR 22*, Office of Road Safety, Canberra, Australia

Transport Research Laboratory, 1991. *Towards Safer Roads in Developing Countries*, TRL, Crowthorne, UK

Transportation Research Board, 1987. *Designing Safer Roads, Practices for Resurfacing, Restoration and Rehabilitation, Special Report 214*, National Research Council, Washington, DC, USA

Twoney, JM; Heckman, ML; Hayward, JC; and Zuk, RJ, 1993. *Accidents and Safety Associated with Interchanges, Transportation Research Record 1385*, TRB, National Research Council, Washington, DC, USA

Walker, JS; and Pittam, SR, 1989. *Accidents at Mini-Roundabouts: Frequencies and Rates, Contractor Report 161*, Transport and Road Research Laboratory, Crowthorne, UK

Willett, D, 1979. *Safety Benefits of Intersection Traffic Lights*, Main Roads Department, Perth, Australia

Yates, JG, 1970. *Relationship between Curvature and Accident Experience on Loop and Outer Connection Ramps, Highway Research Record 312*, HRB, National Research Council, Washington, DC, USA

5. VULNERABLE ROAD USERS

5.1 Introduction

As urban areas become more congested and polluted by increasing traffic demand, the public is making known its desire for improved quality of life, which includes revitalised transport options such as walking and cycling. In the United States, the Federal Highway Administration (FHWA, 1994a) encourages local and metropolitan councils and State Departments of Transport to promote the use of cycling and walking and to:

- Double the current percentage of total trips made by cycling and walking and
- At the same time reduce by 10% the number of cyclists and pedestrians killed or injured in traffic collisions.

5.2 Safeguarding Pedestrians

In South Africa, about 33 620 pedestrians were involved in road accidents during 1997. Of these, 3 772 were fatally injured, 10 656 seriously injured and 19 242 sustained minor injuries.

Pedestrian fatalities constitute:

- 38,9% of all road fatalities
- 8,2 per 100 000 of the population and
- 5,9 per 10 000 vehicles.

Pedestrian casualties represent 74,1 per 100 000 population.

On rural roads, one out of every three pedestrians involved in an accident is killed, whereas in urban areas the ratio is one killed out of 10 pedestrians involved in accidents. Vehicle speed plays a major role in the higher severity ratio on rural roads.

An analysis of the statistics leads to the following conclusions:

- All provinces have a pedestrian safety problem in terms of various criteria.
- Provinces with the lowest vehicle ownership per capita are also the provinces with the highest incidence of pedestrian casualties per 10 000 vehicles.
- Most pedestrian casualties occur in more densely populated rural provinces (except Northern Province) and in the more urbanised provinces.
- About 40% of pedestrian fatalities occur on rural roads, but the majority of pedestrian injuries occur in towns and cities.
- Severity ratio of rural roads is normally higher than roads in urban areas (CSS, 1997).

5.2.1 Safety Principles of Pedestrian Facilities

Pedestrian facilities must:

- Warn drivers and pedestrians of each other’s presence at potential points of conflict
- Inform drivers of areas where pedestrian activity is likely to be heavy
- Guide drivers and pedestrians to minimise points of conflict
- Control drivers and pedestrian movements by the use of special facilities
- Not provide surprises to drivers, such as isolated and unexpected pedestrian facilities
- Not lead pedestrians into direct conflict with other road users
- Define clear travel paths for all road users (RTA, 1996).

5.2.2 Practical Guidelines

During the planning phases, the following aspects of pedestrian safety should be considered:

- Survey land use patterns and pedestrian desire lines to highlight the needs of pedestrians.
- Plan the provision of paved walkways near activity centres, such as schools, clinics, and shopping centres.
- Accommodate the pedestrian needs of communities separated from basic commodities, such as water, firewood or shops.
- Cuttings or fills can be used effectively to provide grade separated pedestrian facilities, such as footbridges or subways. These facilities should be positioned in line with desire lines. Subways should have clear sight distance from end to end to encourage pedestrians to use them.
- Take pedestrian desire lines into account when providing at-grade pedestrian facilities; otherwise they may not be fully utilised.
- Apply approved warrants for pedestrian crossing facilities to determine the appropriate type of crossing.
- Provide slightly wider cross section in mountainous terrain, especially in densely populated rural areas, to ensure that footways can be provided.

During the design and construction phases, the following aspects of pedestrian safety should be considered:

- Ensure that the layout of the facility complies with the standards and guidelines for roads traffic signs and markings in Department of Transport (1993) and Department of Transport (1992a).
- Ensure adequate visibility and stopping sight distance both by day and by night.
- Allow more pedestrian clearance time if a signalised crossing is located near a hospital/special school/old age home.
- Consider adding a refuge island to facilitate crossing a multi-lane road.
- Select the most appropriate speed limit.
- Ensure that the project is built as designed and monitor any design changes.
- Conduct a night-time inspection to ensure visibility, delineation and darkness related issues.

- Monitor new land use developments and rezoning that could affect desire lines and pedestrian volumes.

On existing rural roads the following aspects should be considered:

5.2.2.1 General

- Inappropriate speed limits and speeding.
- Inadequate road signing and delineation.
- Lack of crossing facilities.
- Lack of paved footways (even where warranted).
- Lack of protected pedestrian walking space on bridges.
- Insufficient lighting.
- Poor layout of bus stops and taxi bays.

5.2.2.2 Speed Zoning

- In densely populated rural areas, where large numbers of pedestrians use the roadway during peak hours, speed zoning should take account of these hazards. Footways should be provided away from the roadway.

5.2.2.3 Road Signs and Markings

- Ensure that appropriate road signs and markings are provided in terms of Department of Transport (1993) and Department of Transport (1992a).
- Consider providing high visibility warning signs to highlight the presence of a pedestrian sensitive area.

5.2.2.4 Crossing Facilities

- Analyse land use and pedestrian movement patterns.
- Consider the use of pedestrian refuge islands.
- Consider the use of pedestrian guide lines to channelise pedestrians to a safe crossing point.
- Use grade separated pedestrian facilities (footbridges and subways) where topography and desire lines are favourable.

5.2.2.5 Bus Stops

- Ensure that suitable deceleration lanes and merging areas are provided to facilitate bus exit and entry onto roadway.
- Ensure bus bays are located far enough from the roadway edge to eliminate sight distance problems, or that a physical barrier is constructed to force buses away from the road edge.

5.2.2.6 Road Bridges

- Consider attaching a lightweight pedestrian walkway to an existing bridge.
- Ensure proper delineation of the roadway on bridge approaches to steer vehicles away from bridge parapets and to safeguard pedestrians approaching the bridge.

5.2.2.7 Walkways along Roads

- Investigate warrants for providing separate paved footways (one side or both sides) or at least surfaced shoulders to protect pedestrians.
- Ensure drainage details do not force pedestrians to walk in the road.
- Investigate whether part of the old road surface can be retained as a pedestrian walkway, when a road is relocated or reconstructed.

5.2.2.8 Lighting

- Investigate whether street lighting on urban fringes extends far enough to safeguard pedestrians.
- Consider providing lighting at hazardous pedestrian locations or where pedestrian footways and crossings are warranted in rural areas (Ribbens, 1998).

5.2.3 Pedestrians at Roadworks

The needs of pedestrians at roadworks are dealt with in Section 7.

5.2.4 Pedestrians at Intersections

The needs of pedestrians at intersections are dealt with in Section 4.6

5.3 Ensuring Safety of Cyclists

Approximately 250 cyclists were killed on the roads during 1995 (CSS, 1997). Many cyclists are young and inexperienced; older cyclists may have impaired vision and hearing abilities; and drivers should recognise this. Owing to the lack of bicycle facilities in South Africa, cycling is not used as much as it should. Since bicycles comprise such a small proportion of the traffic stream, drivers do not always expect to encounter cyclists on the road. Improving the visibility of the cyclists can offset this tendency.

There are examples in the United States where bicycles make up 15 to 20% of all commuter trips. From an intermodal point of view, bicycle use could do much to facilitate the use of public transport and reduce transport costs for a large segment of the population.

There is a greater demand today for urban design that accommodates the use of walking and cycling for shopping and travelling to school, work and parks.

5.3.1 Bicycle as a Design Vehicle

Bicyclists have similar reaction times to motorists.

- Dimensions:
  - ❖ Length = 1,8m, Width = 0,6m
  - ❖ Height clearance with rider = 2,0m
  - ❖ Acceptable grade = 6%

TABLE 5.1 BICYCLE BRAKING DISTANCES
(ITE, 1995)

DESIGN SPEED (km/h)	BRAKING DISTANCE (m)
10	0,6-0,8
15	1,1-1,4
20	2,0-2,6
25	3,2-5,0
30	5,4-7,0

A basic principle will guide the designer: Bicyclists have the same set of travel/destination and safety needs as motorists. Residential streets should be traffic calmed to reduce vehicle speeds. Bikeway surfaces should be free from expansion joints and drainage grates that can snag a bicycle wheel.

Strategies for bicycle safety include the following:

- Wearing helmets
- Improving cyclist visibility
- Providing bicycle facilities on:
  - ❖ Shoulders (also on bridges)
  - ❖ Cycle paths
  - ❖ Wider traffic lanes
  - ❖ Roadway sharing

Design Criteria

- Cycle path width = 1,2m
- Sight distance based on object height = 0
- Separation width between motorists and cyclists = 1,2m (for speed up to 60km/h)
- Separation width between motorists and cyclists = 1,8m (for speed over 60km/h) (Burden, 1993).

Safety Principles of Bicycle Facilities

Bicycle facilities should:

- Warn and inform cyclists and other road users of each other's presence at points of potential conflict
- Safely guide and control cyclists through points of conflict
- Provide a forgiving road environment for cyclists and other road users
- Not provide surprises to all road users, including cyclists, along their chosen travel path
- Provide the controlled release of information to all road users, including cyclists.

5.3.2 Hazards to Cycling

Ardekani et al (1995) produced a comprehensive list of roadway hazards that confront cyclists. These are summarised in Table 5.2 and may be grouped into the following categories:

- Bicycle characteristics
- Cyclist behaviour
- Environmental conditions
- Geometric design
- Motorist behaviour
- Other design elements
- Pavement conditions
- Policy and enforcement
- Road maintenance and
- Traffic control elements.

TABLE 5.2 HAZARDS TO CYCLING

(Ardekani et al, 1995)

HAZARDS	SYMPTOMS	REMEDIAL MEASURE
Surface roughness	Potholes>150 mm Ruts, cracks>6 mm	Patch/repair Warn cyclists Maintenance Spot improvements
Debris on roadway	Sand/gravel/objects Debris in bike lane	Regular sweeping Sweep roadworks Public reporting Wide outside lanes Bottle pickup
Drains with parallel bar grates	Bar inlets	Replace or make safe Warn cyclists
Poor surface Drainage	Improper design	Recess inlets Inlets away from cycle route Warn cyclists
Drains with steep entry slopes	Steep entry slopes Steeply sloped gutters	Cut for bicycles Limit use of strips 450 mm flush and 150 mm dip 5 mm deep Limit use of raised studs (use markings) Remove strips at gores and intersections Warn cyclists
Improperly designed rumble strips	Ponding	Patch or resurface Install drain and kerbs
Bicycle path interrupted by a kerb	Kerb obstruction	Install kerb ramp Warn cyclists meanwhile
Insufficient lighting	Dark areas where cyclists ride	Lighting on bike paths Add lighting at subways
Roadside objects with low clearance	Overhead obstructions Tree overhang> 1 m Signs<2 m away	Eliminate or warn cyclists Spot maintenance
Slippery pavements	Slippery when wet	Broom finish or seal coat Warn cyclists Stricter specifications
Poorly designed rail level crossing	Bumpy, skew	Square crossing Signs and markings Adjust levels Overpass/underpass Rubber mats/flanges

Bicycle insensitive signal detectors	Bicycle not detected	Detectors where cyclists ride
Poorly designed bicycle underpasses	Narrow<3 m Long, curved entry approach	Widen underpass Warning signs Additional lighting Paint walls white
Riding against traffic	Wrong-way riding	Wrong way/right way signs Education/enforcement
Cycling through roadworks	Little lighting Debris on roadway Rough surface Confusing patterns Improper drainage	Detour for cyclists Warning signs Spot maintenance Slow traffic with curves or police
Cycling along high-speed or high-volume roads	Cyclists on high-speed/high-volume roads	Alternative route Separate parallel route Restrict trucks along bicycle routes Special signage
Kerb parking along cycle routes	Kerb parking along bicycle routes	Prohibit car parking along bicycle routes Bold stripes both sides of cycle lanes

5.3.3 Conclusions and Recommendations

The following conclusions and recommendations are applicable:

- Behavioural factors contribute to most accidents between vehicles and bicycles
- Many bicycle accidents do not involve a motor vehicle
- Many bicycle accidents are as a result of loss of control or involve other bicycles or pedestrians
- Many such accidents result from a mix of behavioural factors, road design, and roadway conditions
- Many of the hazardous conditions can be corrected or improved
- Proper maintenance can contribute more to safety than physical elements
- Awareness of the needs of cyclists compared to those of motorists should be created
- Identification of problems by maintenance personnel can help to improve safety
- A manual for maintenance personnel is a useful tool for focusing on bicycle hazards
- Safety-conscious design can prevent accidents before they happen
- Proper planning of bicycle facilities can enhance safety and mobility
- Guidelines are required to deal with new construction and existing facilities
- Bicycle facilities are part of an intermodal transport system (Ardekani et al, 1995).

5.4 Enabling Persons with Disabilities

An estimated 5 to 12% of South Africans are moderately to severely disabled. Despite this large percentage of disabled people, few services and opportunities exist for people with disabilities to participate equally in society.

> ***"The disabled population has often been overlooked in the design of transport facilities. To improve the quality of life the mobility needs of the disabled population will be integrated into the design of new infrastructure, especially in urban areas and in public transport interchanges."***
>
> Department of Transport, 1996

Since the ability to use services, or attend school or work, is largely dependent on the ability to get there, the lack of accessible transport is a major barrier to the full integration into society of people with disabilities. As a result, the safety of these people is seriously compromised.

Department of Transport, 1996 places the main responsibility for identifying the needs of specific categories of passengers on the respective metropolitan and local governments.

> **"The way in which the environment is developed and organised contributes, to a large extent, to the level of independence and equality that people with disabilities enjoy.**
>
> **There are a number of barriers in the environment, which prevent disabled people from enjoying equal opportunities with non-disabled people. Some of these barriers are the following:**
>
> - **Structural barriers in the built environment, such as flights of stairs, inaccessible toilets and bathrooms, high kerbs, uneven sidewalks**
> - **Inaccessible service points, such as high service counters, public telephones and information displays**
> - **Inaccessible entrances owing to security systems, such as turnstiles, microphone loudspeaker systems**
> - **Poor town planning, such as schools, clinics located at the highest positions in town, narrow sidewalk areas, lack of demarcated special parking bays and**
> - **Poor interior designs, such as fixed seats in restaurants and clustered rooms."**
>
> Office of the Deputy President, 1997

The purpose of Section S of the *National Building Regulations*, and its associated *Code 0400* (SABS, 1990), includes regulations setting out requirements for an accessible built environment.

Table 5.3 provides a checklist of the transport facility needs of persons with disabilities.

TABLE 5.3 FACILITIES NEEDED BY PERSONS WITH DISABILITIES

(Department of Transport, 1992b)

LOCATION		WHEELCHAIR USERS, WALKING WITH CRUTCHES, AGED AND SLOW MOVING	BLIND AND SIGHT IMPAIRED
STREETS	RESIDENTIAL AREA CBD INTERSECTIONS OVER SIDEWALKS INTO BUILDINGS	Ramps over median on divided roads	Tactile surface Warning Audible traffic signals Ramps, dropped kerbs
SIDEWALKS	RESIDENTIAL AREA CBD ARCADES SHOP ENTRANCES OTHER BUILDING ENTRANCES	Ramps Benches to rest Sufficient width Good signage placing Slots in manholes on sidewalks at right angles to wheels of wheelchairs Handrails	Tacctile surface warning Audible traffic signals Ramps, rails, no parking Warning of overhanging objects Minimum of roadworks Manhole and valve covers closed Directional information in braille
BUILDING, HOUSES, SHOPS, OFFICES	DOORS LIFTS PASSAGES	Ramps, handrails Space for wheelchair Signage Low lift buttons, Telephones, counters Door knobs of lever type Cloak rooms	Warning of free standing objects in way Ramps, rails Minimum furniture changes Braille in lifts Braille on telephones
CARS	PARKING, DRIVING	Demarcated bays	No parking on sidewalk
BUSES	ENTRANCE SEATS STEPS STOPS COMMUNICATION	Driver training, handrails, low step rise, wide seat spacing, assistants	Driver training Rails Audible announcements Bell button conveniently placed Assistants
TRAINS	PARKING STATIONS SEATS ENTRANCE	Demarcated bays, ramps Remove seats for wheelchairs space Porter training Toilet facilities	No parking on sidewalk Porter training Audible announcements of station names Braille on telephones Directional information in braile
AIRCRAFT	PARKING TERMINAL BUILDINGS SEATS ENTRANCE	Demarcated parking space, ramps Remove seats for wheelchairs space Hostess training Assistants Toilet facilities	Demarcated bays Hstess training Audible announcements of schedule changes Braille emergency information Assistants
TOURING	LONG ROAD HOTELS, RESORTS, SCENERY	Toilet facilities Access to cafes/restaurants	Information in braille Assistance by hotel staff Guide training, assistants

TABLE 5.3 FACILITIES NEEDED BY PERSONS WITH DISABILITIES
(Department of Transport, 1992b)

LOCATION		DEAF, HEARING AND READING IMPAIRED	MENTALLY AND INTELLECTUALLY IMPAIRED	SHORT PERSONS AND CHILDREN
STREETS	RESIDENTIAL AREA CBD INTERSECTIONS OVER SIDEWALKS INTO BUILDINGS	Written signs Symbol signage	Driving training Symbol signage	
SIDEWALKS	RESIDENTIAL AREA CBD, ARCADES SHOP ENTRANCES OFFICE ENTRANCES OTHER BUILDING ENTRANCES	Written signs Symbol signage	Ramps Benches to rest Fence off roadworks	
BUILDINGS, HOUSES, SHOPS, OFFICES	DOORS LIFTS PASSAGES	Written signs Symbol signage	Symbol signage Rails at steps Ramps	Low door knobs, lift buttons, mirrors, telephones, counters Shallower supermarket trollies
CARS	PARKING DRIVING	Drivers careful Interpreter allowed during driving test	Drivers careful	Drivers careful
BUSES	ENTRANCE, SEATS, STEPS, STOPS COMMUNICATION	Written signs Symbol signage	Driver training Handrails Assistants	Lower step rises Low bell buttons
TRAINS	PARKING STATIONS SEATS ENTRANCE	Written signs Symbol signage Special attention in emergencies	Porter training Assistants	Lower step rises Low telephones, counters
AIRCRAFT	PARKING, TERMINAL BUILDINGS, SEATS, ENTRANCE	Written signs Symbol signage Assistants	Hostess training Assistants	Hostess training Low door knobs, lift buttons, mirrors, telephones, counters
TOURING	LONG ROAD HOTELS RESORTS SCENERY	Wake up calls Guide training	Staff training Safe public places Guide training Assistants	Low telephones Low auto tellers Low notice boards Guide training

The concept of designing for safety should be extended to include providing for the needs of disabled road users and pedestrians, since they are especially vulnerable in the traffic situation.

5.4.1 Pedestrians with Disabilities

The needs of pedestrians with disabilities are dealt with in Section 6.10.

5.5 References

AASHTO, 1991. *Guide for the Development of Bicycle Facilities*, Washington, DC, USA

Ardekani, SA; Govind, S; Mattingly, SP; Demers, A; Mahmassani, HS; and Taylor, D, 1995. *Detection and Mitigation of Roadway Hazards for Bicyclists, Research Report 1394-2F*, Center for Transportation Research, University of Texas at Austin, Texas, USA

Burden, D, 1993. *Bicycling Element* in *The Traffic Safety Toolbox: A Primer on Traffic Safety*, ITE, Washington, DC, USA

Central Statistical Services, 1997. *Road Traffic Collisions, 1996*, Pretoria, South Africa

Department of Trade and Industry, 1986. *National Building Regulations*, Pretoria, South Africa

Department of Transport, 1984. *Manual for the Planning and Design of Bicycle Facilities in Urban Areas,* PG3/84, Pretoria, South Africa

Department of Transport, 1992a. *Pedestrian Facilities Guidelines Manual, RR92/660*, Pretoria, South Africa

Department of Transport, 1992b. *Transport for the Disabled*, *GD 1/92,* Pretoria, South Africa

Department of Transport, 1993. *South African Road Traffic Signs Manual, Volume 1,* Pretoria, South Africa

Department of Transport, 1996. *White Paper on National Transport Policy,* Pretoria, South Africa

Federal Highway Administration, 1989. *Planning, Design and Maintenance of Pedestrian Facilities*, FHWA, Washington, DC, USA

Federal Highway Administration, 1994a. The National Bicycling and Walking Study: Transportation Choices for a Changing America, FHWA, Washington, DC, USA

Federal Highway Administration, 1994b. *Selecting Roadway Design Treatments to Accommodate Bicycles*, FHWA, Washington, DC, USA

Fruin, JJ, 1971. *Pedestrian Planning and Design*, Metropolitan Association of Urban Designers and Planners, Inc, New York, NY, USA

Institute of Transportation Engineers, 1993 The Traffic Safety Toolbox: A Primer on Traffic Safety, ITE, Washington, DC, USA

Institute of Transportation Engineers, 1998. *Design and Safety of Pedestrian Facilities*, ITE, Washington, DC, USA

Office of the Deputy President, 1997. *White Paper on an Integrated National Disability Strategy*, Pretoria, South Africa

Ribbens, H, 1990. *Die Evaluering van Stadsbeplannings- en Ontwerpmaatreëls met betrekking tot Voetgangerveiligheid in Suid-Afrika, Ph D Proefskrif,* Universiteit van Pretoria, Pretoria, Suid-Afrika

Ribbens, H, 1998: *Road Safety Audits for Pedestrians*, SAICE Road Safety Audit Course, Pretoria, South Africa

Roads and Traffic Authority, 1996. *Road Environment Safety*, *A Practitioners Reference Guide to Safer Roads,* RTA, Haymarket, New South Wales, Australia

Schermers, G; and De Beer, EJH, 1998. *Gauteng Pedestrian Management Plan, Report CR 98/029,* Department of Transport and Public Works, Johannesburg, South Africa

Smith, SA; Opiela, KS; Impett, LL; Pietrucha, MT; Knoblauch, RL; and Kubat, C, 1987. *Planning and Implementing Pedestrian Facilities in Suburban and Developing Rural Areas, NCHRP Report 294A, Research Report*, TRB, National Research Council, Washington, DC, USA

Smith, SA; Opiela, KS; Impett, LL; Pietrucha, MT; Knoblauch, RL; and Kubat, C, 1987. *Planning and Implementing Pedestrian Facilities in Suburban and Developing Rural Areas,NCHRP Report 294B, State of the Art Report*, TRB, National Research Council, Washington, DC, USA

South African Bureau of Standards, 1990. *Code of Practice for Application of National Building Regulations, 0400*, Pretoria, South Africa

US Equal Opportunity Commission and the US Department of Justice, 1994. *Americans with Disabilities Handbook*, Washington, DC, USA