AT-GRADE INTERSECTIONS / WORLDWIDE REVIEW

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ABSTRACT

Current international knowledge on the safety of the different types of at-grade intersections and of the principal intersection design elements is reviewed and summarized. There appears to be substantial agreement between the results of accident studies carried out in different countries. Roundabouts appear to have considerable safety advantages over other types of at-grade intersection and are now being widely used in many countries. Little quantitative information is available on the relationships between a number of intersection parameters and safety.

An international comparison of at-grade intersection design practices including the principal elements of simple major-minor intersections, speed-change lanes and roundabouts is made. There are considerable differences in design practices due to differences in the design assumptions.

INTRODUCTION

The principal objective of intersection design is to minimize the number and severity of potential accidents while facilitating the movement of people traversing the intersection. Intersection design standards are based on a compromise between safety, capacity and cost. The results of studies into the safety of at-grade intersection types and the principal design elements are first reviewed. Methods for the selection of the intersection type are then briefly discussed and an international comparison of at-grade intersection design parameters is presented.

SAFETY

Many studies have investigated the relationships between intersection design and safety since a substantial proportion of all accidents occur at intersections. Grime (*1*) noted that 31 percent of serious and fatal injury accidents in United Kingdom (UK) non-built areas occurred at intersections, while TRB Special Report 214 (*2*), stated that 56 percent of urban accidents and 32 percent of rural accidents in the United States occur at intersections.

Generally it has been found that the number of accidents is dependent on the volume and distribution of traffic on the primary and secondary roads. For example, Hedman (*3*) includes a prediction model by which the accident rate for 3-way and 4-way rural intersections in Sweden can be estimated as a function of the total incoming traffic and the proportion of traffic on the secondary road. In the UK a cross product flow model has explained well the differences in the number of accidents between sites for all the types of intersection studied in depth by the UK Transport Research Laboratory (*4*); the cross product flow is the product of the sum of the AADT inflows on opposite arms of an intersection. However, as noted elsewhere (*5,6*) there is disagreement on the most appropriate exposure index.

Type of Intersection

In Sweden, the accident rates are 1.5 to 2 times higher on average for 4-way intersections than for 3-way intersections for the same traffic volume and distribution (*3*). The greater safety of 3-way intersections is widely accepted. TRB Special Report 214 (*2*) concluded that the hazard of at-grade intersections increases with the number of approaches. UK Transport Research Laboratory studies have shown that staggered intersections (offset about 36m) have lower accident rates than either the equivalent cross road or two well separated T intersections (*7*); however, slightly offset cross roads were found to be less safe than normal cross roads.

The UK Transport Research Laboratory has developed detailed accident prediction models for roundabouts, rural T-junctions and urban signalized intersections (*8,9,10*). These models use the sizes of various geometric parameters and traffic flows to estimate the number of accidents of each type which are likely to occur at these intersections; the geometric parameters included vary with the intersection type (for example, approach width, entry width and deflection are the principal parameters in the roundabout model). All of these models have been found effective at predicting accidents at intersections in the UK. However, the UK models may not be transferable to other countries due to differences in accident rates, types, etc. For example, a recent assessment of the UK roundabout accident model in Ireland showed significant differences between the numbers of predicted and actual accidents. However, the UK model was found to be reasonably effective at predicting the differences in the accident frequencies of different roundabout designs; consequently its use is considered valid for identifying the safest design.

UK studies have shown that roundabouts have a good safety record compared with other types of at-grade intersection (*4,8,11,12*). For example, Hughes (*12*), in an examination of rural road accidents, reported that the lowest accident severity index occurred for intersections controlled by roundabouts. However, pedal and motor cycles appeared to be disproportionately represented when compared with other intersection types. Walker and Pittam (*4*) compared the accident severity (the percentage of fatal and serious casualty accidents) for various types of single carriageway junctions. The severities for urban four-arm mini and small roundabouts and traffic signals junctions were similar (18 to 20 percent) except for conventional roundabouts (27 percent). Rural T-junctions had the highest severity (35 percent), over twice that of rural roundabouts (14 to 16 percent). A cross product flow model was also used to compare the various intersection types under the same conditions of traffic loading: for a cross product flow of 50 million $(vpd)^2$, the predicted accident frequencies of urban signalized intersections were over twice that of conventional urban roundabouts. In rural areas roundabouts were considerably safer than T-junctions.

For overall accident rates, a reduction of 43 percent was observed at roundabouts in Australia compared with an increase of 66 percent at control sites (*13*); for injury accidents, a decrease of 45 percent was observed for roundabout sites compared with an increase of 57 percent at the control sites. However, it was noted that some roundabouts tend to increase accidents, especially at those intersections with no recorded accidents "before" construction.

Hedman (*3*), reporting Swedish research, stated that roundabouts at 4-way intersections in semi-urban areas with a high percentage of secondary road traffic, will reduce injury consequences (number killed and injured per accident) by some 50 percent; however, the construction of a roundabout may not result in any change in the total number of accidents. A recent before and after study of 181 intersections converted to roundabouts in the Netherlands (*14*) reported a 47% reduction in the number of accidents and a 71% reduction in the number of casualties (trend corrected percentages). In the "before" situation most intersections had priority control, while in the "after" situation traffic on the roundabouts had priority over traffic on the approach roads. The roundabouts were characterized by the following properties: one lane radial approach roads and small diameters (the most common outside diameter was approximately 30m). The reduction in the number of casualties outside built-up areas was considerably greater than inside built-up areas (89% versus 69%). However, the reduction in casualties for moped riders (63%) and cyclists (30%) was less than for car occupants (95%) and pedestrians (89%). The provision of a separate cycle path gave a 90% reduction in the number of casualties compared with only a 25% reduction for a cycle lane on the roundabout and a 44% reduction for no specific measures for cyclists. Intersections previously controlled by traffic signals (only nine in number) had only a 33% reduction in casualties while moped/cycle casualties increased by 4%.

The Safety of Intersection Design Elements

The main difficulties associated with modeling the effects of specific design parameters are due to the large numbers of physical and operational features that affect safety at intersections and regression to mean inaccuracies. Apart from the UK Transport Research Laboratory models previously discussed (*8,9,10*), comprehensive quantitative relationships are generally not available although a number of more limited relationships have been established.

Sight Distance

David and Norman (*15*) studied the relationship between the accident rate and various intersection geometric and traffic features in the United States. They found significant accident rate differences between "obstructed" and "clear" intersections for various levels of sight distance restriction. However, they also noted that because of the influence of different variables (such as number of lanes and speed limit) on the accident rates, the conclusions about sight distance may be misleading. In another US study, Wu (*16*) investigated the relationship between the accident rate and what he termed "clear vision right-of-way" at 192 signalized intersections. This study concluded that intersections where vision is poor have significantly higher injury, property damage and total accident rates.

In the UK, Maycock and Hall (*8*) found that accidents increased appreciably with sight distance on roundabout approaches; they stated that "the mechanism giving rise to this result is not known". For rural T-junctions, Pickering et al. (*9*) showed that longer stopping sight distances were generally associated with lower accident rates which is in agreement with the above U.S. results.

Angle of Intersection

It is widely accepted that the preferred angle of intersecting legs at an intersection is 90 degrees (*2*). However, NCHRP Report 197 (*17*) contradicted this by stating that skew four-legged intersections experience lower accident rates than intersections with straight approaches. For roundabouts it has been shown that as the angle between an arm and the next arm increases, the accident frequency decreases (*8*); this is because the entering-circulating interaction becomes less of a crossing conflict and more a merger. However, the angle between the roundabout arms was a relatively minor accident variable.

Number of Entry Lanes / Auxiliary Lanes

TRB Special Report 214 (*2*) stated that the intersection accident rate, expressed as the number of accidents per million entering vehicles, is typically greater when the approaching roadways have a larger number of lanes. Also the establishment of central turning lanes provides significant reductions in accident rates, particularly at unsignalized intersections. No information was located on the relationship between the length and width of auxiliary lanes (acceleration, deceleration and central turning lanes) and safety.

Median Width / Opening Length

A recent study in the United States (*18*) concluded that at rural unsignalized intersections, the frequency of both multiple vehicle accidents and undesirable behavior decreases as the median width increases. However, the opposite was found for suburban signalized intersections. Also that the frequency of undesirable driving behavior increases with increasing median opening length at rural intersections but decreases with increasing median opening length at suburban intersections.

Lane Width / Approach Width

Greater width on the major road at T-junctions has a substantial beneficial effect according to UK studies (*9*).

TRB Special Report 214 (*2*) concluded that incremental changes in lane width appear to have little effect on the accident pattern at intersections. Maycock and Hall (*8*) showed that for roundabouts the approach road half width and the entry width have a strong effect on accidents: as the entry width increased from 5m to 10m, the total accident frequency increased by about one-third.

Approach Gradient

It is generally assumed that level intersection approaches are safer. For example, downhill approaches to UK rural T-junctions have been shown to have higher accident rates (*9*). However, gradients on roundabout approaches tend not to increase the total number of accidents (*8*).

Channelization

It is widely accepted that intersection channelization is beneficial. However, Hedman (*3*), reporting Swedish accident studies on rural two lane roads, stated that traffic islands in the secondary road have been shown to reduce accidents at 4-way intersections by some 10 percen, but seem not to have any significant effect at 3-way intersections. Also the safety effects of central turning lanes on the primary road seem to depend on whether the channelization was achieved by raised curbstones or by road markings; in many cases curbstone islands resulted in more severe accidents, especially at 4-way intersections. Pickering et al. (*9*) showed that ghost islands on the major roads at UK rural T-junctions result in 70 percent fewer accidents in the vicinity of the intersection.

Approach Speed / Intersection Speed Limit

It is generally accepted that the hazard of at-grade intersections increases as the approach speed increases (*2*). Following a study of roundabout accidents in Australia, Arndt and Troutbeck (*25*) suggested that the decrease in 85th percentile speeds between successive geometric elements is an important parameter when designing intersection approaches in high speed environments; they suggested that this is best achieved by using a series of reducing radii horizontal curves. For single vehicle accidents on roundabouts, they suggested that a maximum allowable decrease in 85th percentile speed of 20 km/h between successive geometric elements would achieve a balance between safety and construction costs. A UK study showed that yellow bar markings on roundabout approaches can reduce speed-related accidents by 57 percent (*19*). No information was located on the effect of imposing a speed limit in the intersection area.

Summary of the Relationships Between Intersections and Accidents

- The number of accidents at an intersection is proportional to the volume and distribution of traffic on the primary and secondary roads but there is some disagreement on the most appropriate exposure indices.
- Roundabouts have considerable safety advantages over other types of at-grade intersections. In rural areas roundabouts are followed in descending safety order by T-junctions, staggered intersections and cross roads.
- Due to the large number of physical and operational features, it is extremely difficult to model the safety effects of specific design parameters but there is substantial agreement between the available quantitative relationships.
- Intersections where the sight distance is poor have significantly higher injury and total accident rates. However, accidents may increase with sight distance on roundabout approaches.
- There is disagreement on the optimum angle of approach at intersections.
- Median widths should be as wide as practical at rural

unsignalized intersections but not wider than necessary at signalized intersections.

- Channelization is usually beneficial but the construction of raised solid islands in the primary road may be hazardous in rural areas.
- The hazard of an at-grade intersection increases as the approach speed increases.

SELECTION OF INTERSECTION TYPE

Typically the cheapest intersection type capable of providing the required level of service is chosen. The standards of some countries include charts showing broad volume ranges over which different intersection types may be appropriate. It is generally accepted that driver behavior at all types of unsignalized intersections is one of gap acceptance and design standards include charts / computer programs for estimating the capacities of both signalized and priority controlled intersections. Because of perceived safety and cost advantages, many roundabouts have been constructed during the past few years. In urban areas they are used instead of isolated signalized intersections where there are high turning volumes or as a method of traffic calming to reduce speeds; in rural areas they are often considered appropriate at major intersections both on undivided roads and on divided four lane roads. However, roundabouts may not operate satisfactorily where there is a heavy dominant traffic flow direction; in such cases roundabouts often have to be signalized. Also pedestrians and two-wheel vehicles may require special provisions at roundabouts. It is now generally accepted that the drivers who exit at a conventional round about leg have little influence on the behavior of drivers entering at the same leg. An Australian study (*20*) concluded that the capacity and delay on each entry lane should be predicted separately and that the behavior of drivers at higher circulating flows is one of priority reversal or priority sharing, leading to greatly decreased average delays.

INTERNATIONAL COMPARISON OF INTERSECTION DESIGN ELEMENTS

Four types of intersection layout are compared in this paper:

- Simple major / minor intersections
- Acceleration / deceleration lanes
- Central turning lanes
- Roundabouts

For each of the above, values of the most significant geometric parameters were compared for a number of countries. An attempt was also made to identify the reasons for the national differences. This comparison comprises of eight European countries (*21*) and Australia (*22*) while comparable AASHTO (*23*) values are estimated to represent the United States. It highlights large differences between the national standards.

Simple Major / Minor Intersections

Rural major/minor intersections with yield sign control, where the minor road intersects with the major road at 90 degrees, were selected for investigating national differences. The parameters selected as a basis for comparison were:

- Minimum sight distances along the primary and secondary roads (undivided two lane roads, level approach legs)
- Minimum exit radius (from the minor road onto the major)
- Minimum entry radius (from the major road onto the minor)

Table 1 shows a comparison between countries for the above parameters.

Large differences were found for the specified sight distances, particularly along the secondary road., these values ranged from 3m (Denmark) to 25m (Finland). Sight distance along the primary road for the 100 km/h design speed varied from 167m (France) to 370m (estimated AASHTO value). These differences were mainly due to differences in the selected design parameter values rather than different design approaches. All countries specify a single value or range independent of design speed for both the entry and exit radii; these varied from 6 -10m (Australia) to 10 - 30m (Ireland).

Acceleration and Deceleration Lanes

The parameters chosen for comparison were:

- Lengths of acceleration and deceleration lanes
- Minimum radius at the end of deceleration lanes and at the start of acceleration lanes

Table 2 shows the lane lengths (including taper) specified by country and also equivalent lengths estimated from AASHTO (*23*); the latter values being considerably greater.

TABLE 1(a) Simple Major/Minor Intersections: Sight Distance(m)

	Sight Distance Along Primary Road (m)									Sight Distance Along Secondary Road (m)								
Design Speed (km/h)	120	110	100	90	85	80	70	60	50	120	110	100	90	85	80	70	60	50
AUSTRALIA	330	290	250	210	175	140	115	90	70	to 7m; 7m desirable								
DENMARK			270			240		210				3			3		3	
FINLAND	370		270			200		130	105	25		25			25		25	25
FRANCE			167			134		100										
ICELAND			270	230		190		125	100			20	20		20		20	20
IRELAND	340		280			230		170		12		12			12		6	
NORWAY				201		164	131	96	74				10		10	10	10	10
SWEDEN		320	240		170			110			5	5		5			5	
UNITED KINGDOM	295		215		160		120	90	70			9		9		9	9	9
AASHTO[a]		460	370			250		160										

[a]Estimated from AASHTO, 1990

*1m = 3.28ft

TABLE 1(b) Simple Major/Minor Intersections: Minimum Curve Radius (m)

	Minimum Exit Radius (m)[a]									Minimum Entry Radius (m)[b]								
Design Speed (km/h)	120	110	100	90	85	80	70	60	50	120	110	100	90	85	80	70	60	50
AUSTRALIA	6 - 10																	
DENMARK			12			12		12				12			12		12	
FINLAND	10		10			10		10	10	10		10			10		10	10
ICELAND			12	12		12		12	12			12	12		12		12	12
IRELAND	10 - 30 (varies with road classification)																	
SWEDEN		10	10		10			10			10	10		10			10	
UNITED KINGDOM			15		15		15	15	15			15		15		15	15	15
AASHTO[c]	9.2 (passenger car) ; 15.2 (single unit truck) ; not practical to use simple arcs for semi trailer combinations																	

[a]Radius from the minor to the major road
[b]Radius from the major to the minor road
[c]Estimated from AASHTO, 1990
*1m = 3.28ft

Large differences were found between the lengths of the acceleration lanes specified by each country. For example, taking the 100 km/h design speed, the highest value, 460m (Australia) - which is similar to the estimated AASHTO value - is more than five times the lowest value, 86m (United Kingdom). The range of values for the lengths of deceleration lanes is just as wide, with values for the 100 km/h design speed varying from 40m (United Kingdom) to about 200m (Finland, AASHTO). All countries except Sweden specify lengths of deceleration lanes which are shorter than acceleration lanes for the same design speed.

For minimum radii, the national standards examined generally specify 25m regardless of design speed for both acceleration and deceleration lanes. Exceptions are the United Kingdom, where 20m is considered adequate for the minimum radius at the end of the deceleration lane, and Ireland, which does not specify a minimum radius at the start of the acceleration lane.

TABLE 2 Acceleration / Deceleration Lanes Lengths (m)

	Length of Acceleration Lane (m)									Length of Deceleration Lane (m)								
Design Speed (km/h)	120	110	100	90	85	80	70	60	50	120	110	100	90	85	80	70	60	50
AUSTRALIA			460	330		260	180	130	105			170	140		120	100	80	60
DENMARK			270			220		170				69			41		26	
FINLAND	Not Used											200			130		70	50
ICELAND			175	120		100		60				135	110		90		70	60
IRELAND	500		350			200				220		150			100			
NORWAY			250	225		190	160					160	140		100			
SWEDEN			120		70							120		70				
UNITED KINGDOM	114		86		86					55		40		35		35	35	35
AASHTO[a]		560	480	400		320		190			225	210	190		170		125	

[a]Estimated from AASHTO, 1990 (acceleration from stop + 91m taper; average running speed on exit curve of 30 km/h, 55m taper)

*1m = 3.28ft

Central Turning Lanes

These are additional lanes in the center of a road which are indicated by road markings and ghost islands or inserted into medians. The parameters compared are the length and width. Table 3 shows the values specified by country for these parameters. Equivalent estimated AASHTO (*23*) values are also included.

Large differences in minimum length values were found. For example, national values for the 100 km/h design speed ranged from 69m (Denmark) to 190m (Ireland). The lane is generally divided into two parts, a deceleration length which varies with design speed and a turning length to allow long vehicles to position themselves correctly for the turn once they have almost stopped. An additional storage length is generally provided for high turning volumes. Values for the width ranged from 2.75m (Norway) to 5.5m (Finland). Finland was the only country to alter the width for lower design speeds, reducing it to 5m for the 60 km/h and 50 km/h design speeds.

Roundabouts

The following design parameters are compared:

- Visibility
- Minimum entry and exit radius
- Minimum entry and exit widths
- Minimum central island diameter

Table 4 shows the values specified by country for these parameters; roundabouts are not included in AASHTO (*23*).

TABLE 3 Central Turning Lanes

Design Speed (km/h)	Length of Central Turning Lane (m)*									Width of Central Turing Lane (m)								
	120	110	100	90	85	80	70	60	50	120	110	100	90	85	80	70	60	50
AUSTRALIA																		
DENMARK			69			41		26		3.5								
FINLAND			130			90		50	30			5.5			5.5		5	5
ICELAND			135	110		90		70	60	3.5								
IRELAND	250		190			125		75		3.0								
NORWAY			135	110		90	80	70	60	2.75m Minimum								
SWEDEN	Based on Traffic Composition - 70m Minimum									3.5								
UNITED KINGDOM	120		90		65		50	35	35	3.5								
AASHTO[a]		240	225	205		185		140		3.0 - 3.7								

[a]Estimated from AASHTO, 1990 (deceleration lane length on Table 2 + 15m storage length)

*1m = 3.28ft

TABLE 4 Roundabouts

	Sight Distance To Left[a] (m)*	Distance from Yield Line (m)	Min. Entry Radius (m)	Min. Exit Radius (m)	Min. Entry Width (m)	Min. Exi Width (m)	Min Central Diameter (m)
AUSTRALIA	70	5	30	-	3.4 - 4	3.4 - 4	5 - 10
DENMARK	55	2.5	12 - 20	12 - 20	3.25 - 3.75	3.5 - 4.0	5 - 10
FINLAND	60	5	10	40	6	4.5	30
FRANCE	21	SSD[b]	15	25	4	5	15
ICELAND	60	5	15	100	6	5.5	20 - 30
IRELAND	60	15	20	40	10[c]	9.2[c]	20
NORWAY	50	10	20	40	7 - 8	-	10 - 25
SPAIN			20 - 25	20 (40 recommended)	2.5m per lane	-	5
SWEDEN	60	5	15 - 25	100 - 200	7 - 9.5	7	10
UNITED KINGDOM	50	15	6 - 10	20	6	7 (S/C)[d] 10 (D/C)[e]	4

[a]S.D. to Right for countries which drive on the left
[b]French value is based on the stopping sight distance at the approach speed
[c]Typical values, no minimum values specified
[d]S/C = Single carriageways
[e]D/C = Dual carriageways
*1m = 3.28ft

It was found that different countries choose to classify roundabouts in different ways. For example, Norway classifies roundabouts by the diameter of the inscribed circle leading to a choice of mini / small / medium / large; Finland classifies them in terms of interurban or urban; Denmark in terms of design speed.

As regards visibility requirements, the specified sight distances show close agreement; all the national values except for France are between 50 and 70 meters. However, the distance back from the yield line where this visibility must be available varied from 2.5m in Denmark to 15m in Ireland and the United Kingdom. There is also disagreement on whether drivers approaching a roundabout should be able to see entering vehicles on the preceding approach well before they reach the "give way" line. For example, the Australian standard requires approaching drivers (at 45m from the yield line) to be able to see the preceding roundabout entrance while the UK standard states that excessive visibility at entry or visibility between adjacent entries can result in approach and entry speeds greater than desirable.

Minimum entry radius shows reasonably close agreement. Although the United Kingdom standard states that values between 6 - 10m can be chosen, 20m is recommended as a practical design figure. Of the other countries studied, Finland had the smallest entry radius at 10m, Denmark specified a range of 12 - 20m and Australia has the largest value, 30m. There are substantial differences in the specified minimum exit radius. Finland, Ireland and Norway agree on 40m as a minimum. While 20m is specified as a minimum in the United Kingdom, the standard adds that 40m is the desirable value. Denmark is the only country which does not have exit radii larger than entry radii, the value being the same for both radii. Iceland and Sweden specify minimum exit radii which are more than twice that of the other countries. The large Swedish values (100-200m) are to allow good traffic dispersement according to the national standard.

Minimum entry widths ranged from 3.25m in Denmark to 7m in Norway and Sweden. Minimum exit width values ranged from 3.5m (Denmark) to 7.0m in the UK (single carriage way roads). There is little agreement on the sizes of the minimum entry and exit widths.

There was a wide range in the values for minimum central island diameter. Australia, Denmark, the United Kingdom and Sweden specify values between 4m to 10m while Finland and Iceland specify values of 30m.

SUGGESTED DISCUSSION TOPICS

I. Speed reduction on intersection approaches
II. Design for older road users
III. The role and design of roundabouts (sight distances, the width of circulating lanes, the relationship between the number of entry, circulating and exit lanes, provision for pedestrians and cyclists, signalization)
IV. Minimum lengths of acceleration and deceleration lanes
V. Parameters for driver behavior observations
VI. Safety audits (including control immediately after opening)

CONCLUSION

At-grade intersections are the most dangerous part of the road network. Although based on the same principles, intersection design standards differ substantially between countries. These standards are mainly based on logical assumptions and experience in each country rather than on accident studies. However, there is broad agreement between the results of the safety studies carried out in different countries and applying the available international knowledge should result in safer at-grade intersections.

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REFERENCES

1. Grime, G. Handbook of Road Safety Research. Butterworths, London. 1987.
2. Transportation Research Board (TRB). Special Report 214, Designing Safer Roads, Practices for Resurfacing, Restoration and Rehabilitation. National Research Council, Washington. 1984.
3. Hedman, K.O. Road Design and Safety. Proceedings of Strategic Highway Research Program and Traffic Safety on Two Continents. Gothenburg, 1989. VTI Report 315A. 1990.
4. Walker, J.S. and Pittam, S.R. Accidents at Mini-Roundabouts: Frequencies and Rates. CR 161. Transport Research Laboratory, Crowthorne, 1989.
5. Glennon et al. Relationship between Safety and Key Highway Features. A Synthesis of Prior Research. State of the Art Report 6. Transport Research Board, National Research Council, Washington D.C. 1987.
6. Jadaan, K.S. and A.J. Nicholson. Relationships between Road Accidents and Traffic Flows in an Urban Network. Traffic Engineering and Control, 33 (9). 1992.
7. Stark, D. Relating Speed to Accident Risk at Priority Junctions. Proc. Seminar J, 22nd PTRC European Transport Forum. PTRC Education and Research Services Ltd. London. 1994.
8. Maycock, G. and R.D. Hall. Accidents at 4-arm Roundabouts. TRRL Report LR1120, Transport and Road Research Laboratory, Crowthorne. 1984.
9. Pickering, D., Hall, R. D. and Grimmer, M. Accidents at Rural T-junctions. TRRL Research Report 65. Transport and Road Research Laboratory, Crowthorne, England, 1986.
10. Hall, R.D. Accidents at 4-arm Single Carriageway Urban Traffic Signals. TRRL Contractor Report 65. Transport and Road Research Laboratory, Crowthorne, England, 1986.
11. Hall, R.D. and R.A.J. Surl. Accidents at Four-arm Roundabouts and Dual-Carriageway Junctions: Some Preliminary Findings. Traff. Engng. Control, **22 (6)**, 1981.
12. Hughes, W. Accidents on Rural Roads. AA Foundation for Road Safety Research, Basingstoke. 1994.

13. Tudge, R.T., Accidents at Roundabouts in New South Wales. Proceedings of the 15th ARRB Conference, Pt. 5, Darwin. 1990.
14. Schoon, C. and J. Van Minnen. The Safety of Roundabouts in the Netherlands. Traff. Engng Control, 35(3), 1994.
15. David, N.A and Norman J.R., Motor Vehicle Accidents in Relation to Geometric and Traffic Features of Highway Intersections. FHWA-RD-76-128, FHWA, U.S. Department of Transportation. 1975.
16. Wu, Y.S., Effect of Clear Vision Right-of-Way on Traffic Accidents at Urban and Rural Signalized Intersections. Michigan Department of State Highways, Lansing. 1973.
17. NCHRP Report 197, Cost and Safety Effectiveness of Highway Design Elements. Transportation Research Board, National Research Council, Washington D.C. 1987.
18. Harwood, D.W., M.T. Pietrucha, K. Fitzpatrick and M.D. Wooldridge. Design of Intersections on Divided Highways. International Symposium on Highway Geometric Design Practices. Boston, Massachusetts. 1995.
19. Helliar-Symons, R.D. Yellow Bar Experimental Carriageway Markings - Accident Study. Laboratory Report 1010. Transport and Road Research Laboratory. Crowthorne, England. 1981.
20. Troutbeck, R. J. Traffic Interactions on Roundabouts. Procs. 15th AARB Conference, Part 5. Darwin. 1990.
21. O'Cinneide, D., N. McAuliffe and D. O'Dwyer. Comparison of Road Design Standards and Operational Regulations in EC and EFTA Countries. Deliverable 8, EC DRIVE II Project V2002 (HOPES). 1993.
22. Austroads (1988). Guide to Traffic Engineering Practice, Part 5. Intersections At Grade. Sydney. 1988.
23. AASHTO. A Policy on Geometric Design of Highways and Streets. AASHTO. Washington D.C. 1990.
24. O'Cinneide, D. and E. Murphy. The Relationship between Geometric Road Design Standards and Driver / Vehicle Behavior, Level of Service and Safety. Deliverable 13 EC DRIVE II Project V2002 (HOPES). 1994.
25. Arndt, O.W. and R.J. Troutbeck. Relationship between Roundabout Geometry and Accident Rates. International Symposium on Highway Geometric Design Practices. Boston, Massachusetts. 1995.