

# THE SAFE USE OF DOUBLE RIGHT-TURN LANES BY GAP ACCEPTANCE AT SIGNALISED INTERSECTIONS ON ARTERIAL ROADS

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## 1. INTRODUCTION

Road authorities are faced with the quandary of ever-increasing traffic volumes on a road network where upgrading is limited by financial and physical constraints. There is a clear need to extract optimum performance from existing infrastructure.

This can be achieved through better management, implementation of new systems and changes to standards and procedures. Actions to optimise usage include demand management and supply improvements. In traffic signal operation, improvements can be made by responsive traffic control, optimised phasing measures and revised standards and procedures.

The right-turning movement can be considered as one of the more difficult manoeuvres. Drivers are faced with various phasing measures and operational conditions which influence their driving behaviour and decisions.

The City Council of Pretoria has a comprehensive urban arterial road network and double right- and left-turning lanes have been implemented at a number of intersections due to high vehicular turning flow demand, especially during the morning and evening peak hours. It is considered necessary to establish possible means for increasing throughput.

The current policy of the City Council of Pretoria is to protect double left- and right-turning movements at signalised intersections through the provision of an protected turning phase, when opposing traffic movements are stopped. On the basis of anticipated safety concerns, drivers are usually not permitted to take gaps in the opposing traffic stream.

Extensive complaints have been received from motorists concerning both high delays and the danger of right-turning movements at intersections with double turn lanes. The competing functions of solving safety and congestion problems require a framework through which these can be quantified.

## 2. OBJECTIVES

The aim of the project was to investigate whether it is safe to allow two lanes of right-turning traffic to accept gaps in opposing flow at traffic signals and to provide guidelines for their implementation. Although the project considered double left-turn lane configurations as well, they are not discussed in this paper.

The objectives of the study included the following:

- Determine the factors contributing to the safe and successful operation of double right-turning and double left-turning lanes at signalised intersection
- Conduct surveys at signalised intersections, both inside and outside of Pretoria,
- Provide guidelines for the implementation of double-turning lanes, and
- Establish the legal position with regard to such a form of control.

In order to gain a proper understanding of the operational and safety issues, an extensive literature study was undertaken. Local experience and practice was taken into account through questionnaires and interviews with a number of metropolitan authorities.

## 3. OPERATIONAL CONSIDERATIONS

The implementation and design considerations for right-turn facilities are well described in literature such as the Highway Capacity Manual (HCM), the AASHTO “*Green Book*” on geometric design and other widely used sources.

The most critical geometric parameter is sight distance. The sight distance at right-turning lanes is limited and frequently blocked by opposing right-turning vehicles, the median island and physical features on the median island. The effect of opposing turning traffic is aggravated by the presence of heavy vehicles, which may require special treatment in cases where there is a high percentage of heavy vehicle traffic.

The major operational considerations for accommodating right-turning traffic include signal phasing and safety parameters. There are a number of different phasing strategies for right-turning traffic that is applied locally, namely: permitted only (P), protected/ permitted (P/P), protected only (PO), as well as leading or lagging right-turn phases. These phasing options are briefly described below.

Permitted right-turn phasing: The permitted right-turn phasing has no protected right-turn phase. Therefore right-turning vehicles have to use gaps in the opposing traffic stream to execute right-turns. Its use is therefore appropriate at intersections with adequate sight-distance, low right-turn volumes, and low opposing volumes.

Protected/permitted right-turn phasing: The protected/permitted (P/P) phase is a combination phase where right-turning traffic has both a protected or exclusive phase, and a permitted phase. Its intended use is to accommodate light right-turn movements during the permitted phase, and to use the protected phase when right-turn volumes are higher. The use of the P/P phasing is appropriate for intersections with: adequate sight distance, a maximum of two opposing lanes to be crossed by right-turning vehicles, opposing speed not high (generally less than 70 km/h), few or no pedestrians crossing the path of right-turning vehicles, and moderate traffic volumes.

Protected-only (PO) right-turn phasing: The PO phasing is a protected right-turn phase in which right-turns may only be made when a flashing green arrow indication is displayed. The use of PO

phasing is appropriate for intersections with: poor sight distance, sight distance restricted by opposing right-turn vehicles, high right-turn accident rates, more than two opposing lanes to be crossed, high opposing speeds (generally speeds higher than 70 km/h), high opposing traffic volumes, large percentage of heavy vehicles turning, and large pedestrian volumes crossing the right-turn movement.

Although there is an operational advantage in using P/P phasing at intersections with double right-turn lanes, a safety penalty is incurred through the use of P/P phasing at intersections where sight distance is obstructed by opposing right-turn vehicles. Most authorities therefore apply PO phasing at intersections where the sight-distance of right-turning vehicles is obstructed by opposing right-turning vehicles.

#### Leading or Lagging Right-Turn Phases

Protected right-turn lanes are normally provided to accommodate heavy right-turn movements without disruption from through- and left-turning vehicles. Double right-turn lanes should be implemented where right-turn volumes exceed 300 vehicles per hour. Researchers investigating arterial roads where leading or lagging right-turn phases are used have found no significant differences in the traffic operation or safety. There is no indication that either the leading or lagging right-turn phase is more suited for use at double right-turn lanes.

The choice should therefore be based on signal co-ordination, consistency (better to standardise throughout the area), and balance (leading preferred if right-turn on one side only, and lagging if both sides).

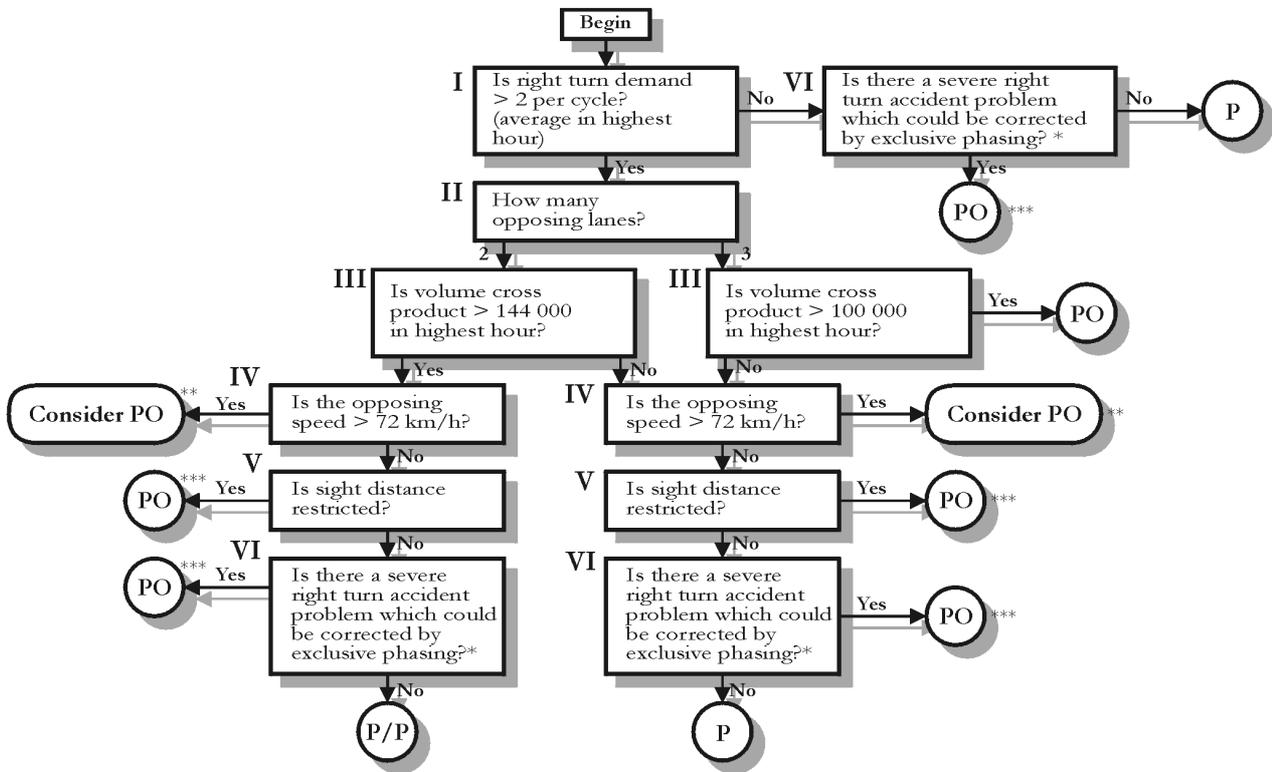
In the selection of a phasing strategy, the benefits of P/P over PO phasing must be considered. Researchers have identified the trade off between operational efficiency and traffic safety. The two main operational advantages of P/P phasing over PO phasing are that (i) progression along arterial roads is improved using P/P phasing rather than PO phasing at individual intersections and (ii) right-turn delay as well as overall delay is decreased when using P/P phasing.

Upchurch (1986) presented a useful phasing selection procedure for right-turn movements, depicted as a flow diagram in Figure 1.

## **4. SAFETY CONCERNS**

The greatest risk of an accident occurs when motorists are required to only utilise gaps in the opposing traffic stream. The risk decreases when motorists are given a protected phase, even if only for part of the phase. Research in the USA concerning safety of right-turning traffic shows the effect of choice of right-turn phasing on the accident rate at intersections.

The work done by Shebeeb (1995) involved a detailed investigation at 56 intersections in Texas and Louisiana. He considered the number of right-turn accidents as a function of the volume cross product. The accident rate is calculated according to the number of accidents divided by the product of the right-turning and opposing traffic volumes, for the three phasing strategies. The results of this study are shown in Table 1.



**P** - Permitted

**P/P** - Protected/Permitted

**PO** - Protected Only

Restrictive Sight Distance is:

**< 75 m** when speeds are **55 km/h** or less.

**< 120 m** when speeds are **65 km/h** or more.

\* See reference for definitions of severe right-turn accident problem.

\*\* An opposing speed > 72 km/h indicates a potential right turn accident problem. Consider exclusive phasing, realizing that non-right turn accidents may increase.

\*\*\* Use exclusive phasing with the understanding that non-right turn accidents may increase.

Note: This procedure applies to locations that have separate right-turn lanes

**Figure 1.** Procedure for determining type of right turn phasing. [Upchurch, 1986]

**Table 1.** *Accident rate by volume cross product (Shebeeb, 1995)*

Type of right-turning phase at intersection	Accident rate {accidents per million (vph) <sup>2</sup> *}	Relative accident risk
Permitted (P)	49.2	2.71
Protected / Permitted (P/P)	45.0	2.51
Protected only (PO)	17.9	1.00

\* (vph)<sup>2</sup> = cross product of right-turn flow (vph) x opposing through and left-turn flow (vph)

In comparison, the inclusion of a portion of the turning stage during which motorists can take gaps leads to a substantial increase in the accident rate of 2.5 times. The relative risk for allowing all motorists to turn on gap acceptance rather than providing a protected phase as well appears to be very small.

A separate study by Upchurch investigated right-turn accident performance for the various phasing strategies at six intersections over a three-year period. He found a similar pattern to the risk for phasing. The results of this work are shown in Table 2.

**Table 2.** *Accident rate by volume of right-turning traffic (Upchurch, 1996)*

Type of right-turning phase at intersection	Accident rate {accidents per million right-turning vehicles}	Relative accident risk
Permitted (P)	3.68	3.79
Protected / Permitted (P/P)	2.24	2.31
Protected only (PO)	0.97	1.00

From a traffic safety viewpoint, research shows ample evidence that the protected right-turn movements during PO phasing is safer than using P/P phasing where, during the unprotected main phase, right-turners are allowed to utilise gaps in opposing traffic to make right-turns.

The two studies showed that the P/P phasing increases the accident risk by 2.3 to 2.5 times, whilst the increased risk through the use of permitted phasing shows more variable results, ranging between 2.7 to 3.9 times.

It is conclusive that PO phasing is substantially safer than allowing motorists discretion in executing the right-turn movement. The use of these accident rates permits one to evaluate the trade-off between safety and operational efficiency that is fundamental to choice of economical and effective signal design.

## 5. ECONOMIC ANALYSIS

As part of the study the trade-off between safety and operational efficiency was further investigated by means of a cost-benefit analysis comparing costs and benefits of protected-only and permitted/protected phasing options at double right-turn lane intersections.

The Sidra software (ARRB, 1999) has been used to analyse a limited number of scenarios to illustrate the effect right-turn and opposing traffic has on the operational efficiency at signalised intersections with double right-turning lanes as indicated in Table 4.

Three cases have been analysed based on a standard intersection layout. The standard intersection modelled has double right-turn lanes on both approaches of the major road. Low volumes were used in case 1, medium volumes in case 2, and high volumes in case 3. In each case the turning movement volumes (left and right) was increased by 100 vph and the through movement kept at 1200 vph. The side road volume was kept constant at 1100 vph.

A summary of the Sidra results is given in Table 3, and the data input described below.

Case 1: Main road volume = 1700 vph (100 left, 1200 through, 400 right)  
 Side road = 1200 vph (100 left, 1000 through, 100 right)  
 Right-turn cross-product\* = 520,000 (vph)<sup>2</sup>

Case 2: Main road volume = 1900 vph (200 left, 1200 through, 500 right)  
 Side road = 1200 vph (100 left, 1000 through, 100 right)  
 Right-turn cross-product\* = 700,000 (vph)<sup>2</sup>

Case 3: Main road volume = 2100 vph (300 left, 1200 through, 600 right)  
 Side road = 1200 vph (100 left, 1000 through, 100 right)  
 Right-turn cross-product\* = 900,000 (vph)<sup>2</sup>

\* Right-turn cross product = right-turn flow multiplied with sum of the opposing through and left-turn flow.

**Table 3.** *SIDRA analyses results of protected only vs. protected/permitted phasing.*

Case	Description	DRT phasing	DRT delay (sec)	Effective stop rate	Junction delay (sec)	Effective stop rate junction
1	520,000 (vph) <sup>2</sup>	PO	49.6	0.92	35.5	0.96
		P/P	28.9	0.87	27.3	0.86
		P/P – PO	(20.7)	(0.05)	(8.2)	(0.10)
2	700,000 (vph) <sup>2</sup>	PO	57.3	1.06	38.3	1.00
		P/P	33.0	0.93	30.0	0.90
		P/P – PO	(24.3)	(0.13)	(8.3)	(0.10)
3	900,000 (vph) <sup>2</sup>	PO	60.8	1.12	43.5	1.05
		P/P	35.5	0.96	34.3	0.96
		P/P – PO	(25.3)	(0.16)	(9.2)	(0.09)
Note: Values in brackets indicate a benefit (saving) to the road user						

The analysis used data from Costdata (CSIR, 1989) to calculate annual road user costs and compared it with the expected cost of accidents, as indicated in Table 4. The analysis shows that PO phases have lower accident costs, whereas P/P phases have lower road user costs.

The expected benefits in terms of fuel consumption costs during idling and stopping, and time costs of vehicles occupants outweigh the disadvantage of increased accident costs between 1,6 to 17,1 times for the cases investigated.

**Table 4.** *Economic analysis of protected-only vs. protected/permitted phasing*

Case	Phase	Nett Annual Road User Costs or Savings (R million)				Annual accident costs	Ratio of user saving to accident cost
		Idling	Stops	Time	Total		
1	PO	0.89	1.61	7.56	10.06	0.09	-
	P/P	0.69	1.44	5.81	7.94	0.21	-
	<i>P/P-PO</i>	<i>(0.20)</i>	<i>(0.17)</i>	<i>(1.75)</i>	<i>(2.12)</i>	<i>0.12</i>	<i>17.1</i>
2	PO	1.03	1.79	8.71	11.53	0.12	-
	P/P	0.81	1.61	6.83	9.25	0.27	-
	<i>P/P-PO</i>	<i>(0.22)</i>	<i>(0.18)</i>	<i>(1.88)</i>	<i>(2.28)</i>	<i>0.15</i>	<i>15.2</i>
3	PO	1.24	2.00	10.53	13.77	0.14	-
	P/P	0.98	1.83	8.30	11.11	0.32	-
	<i>P/P-PO</i>	<i>(0.26)</i>	<i>(0.17)</i>	<i>(2.23)</i>	<i>(2.66)</i>	<i>0.18</i>	<i>14.8</i>

A definitive trade-off exist between operational benefits and safety (increased accidents). In terms of the costs-benefit analysis the monetary benefit of better operational efficiency with the P/P phasing for right-turning vehicles far outweighs the benefit of safety improvements brought about by using PO phasing.

## 6. LEGAL POSITION

### Tort liability

Tort liability is a major consideration in the design and operation of road facilities overseas. The concept of tort liability is however relatively new in South Africa. Legislation focusing on tort liability has not yet been introduced locally. The issues related to tort liability are however covered by the Common Law of South Africa.

To have a valid tort-action, the following four conditions must exist:

- The plaintiff suffered damages in a vehicle collision,
- The defendant owed a legal duty to the plaintiff. Roadway agencies have a duty to the motoring public to provide reasonably safe travel conditions,
- The defendant was negligent because of a breach of duty. The roadway agency failed to design, construct, or maintain a safe roadway, and
- The negligence of the roadway agency was a proximate cause of the collision. A proximate cause is an element in a natural or continuous sequence that produced the collision, without which the collision would not have occurred.

The responsibility of road authorities is to provide a safe driving environment to a reasonable extent. In order to avoid tort liability, the roadway agency (the local authority) must ensure that the roadway facility i.e. double right-turn lanes, is designed and implemented correctly in accordance with reasonable safety considerations.

There are, however, no clear prescriptions that will avoid the road authority being exposed to tort liability claims.

### Road Traffic Act requirements

The Road Traffic Act, especially Chapter VII on the Rules of the Road, stipulates the responsibilities of the motorists on the road. Particular articles of relevance to right turning traffic are Article 92 (Crossing or entering public roads) and Article 95 (Procedures when turning).

Although the legislation (Regulations and Articles) controls the use and implementation of traffic control signs, signals, and driving rules, it does not specifically refer to the controlling authority's legal responsibilities, i.e. operation and maintenance, in this regard, apart from a traffic policing point of view.

Local authorities can however minimise their legal risk by staying within the Regulations of the Road Traffic Act, 1989 and the provisions and standards contained in the SARTSM.

## **7. SOUTH AFRICAN PRACTICE**

### Survey questionnaire

The questionnaires sent to various metropolitan authorities and selected interviews revealed the following aspects regarding local practice.

- There is no uniform guideline used by local authorities to determine single and double right-turn requirements; apart from the SARTSM guidelines, the Highway Capacity Manual and SIDRA is widely used.
- Variations that differ from the SARTSM, such as the use of a dotted line with stopline within the intersection to show right-turning drivers where to “wait” during the permitted right-turn phase.
- A variety of factors are taken into consideration by authorities when deciding between the use of PO and P/P right-turn phases at intersections. The main factors appear to be volumes, speed, progression, sight-distance requirements and lane configuration.
- Authorities have varying approaches for the signalling of double right-turn lanes. Most agencies prefer the use of protected-only green phases (using separate signals). Protected/permitted phases are however gaining popularity and acceptance. In problem locations, protected-only phasing is used.
- There are different approaches by the authorities with regard to the skipping of the protected portion of a P/P phase during different times of day. The larger metropolitan councils tend to avoid it in order to limit complexities which confuse the motorists and which require extra maintenance. Some local authorities skip or introduce the protected phasing portion of P/P right-turn phases by time of day.
- None of the authorities reported major safety, operational or legal problems with regard to double right-turning lanes.

### Traffic signal displays

#### *Traffic Signals for the protected/permitted phase*

The SARTSM reserves the use of signal face type S8 for cases where right-turn movements may utilise gaps in the opposing traffic stream, before or after a protected right-turn phase.

#### *Traffic signals for the protected-only phase*

The SARTSM prescribes the use of signal types S13, S14 or S15 for right-turn movements, which are only permitted during the protected right-turn phase. Right-turn movements are only allowed during the protected phase when a separate flashing green arrow is displayed.

### *Problems with the signalling of protected-only phasing for right-turn lanes*

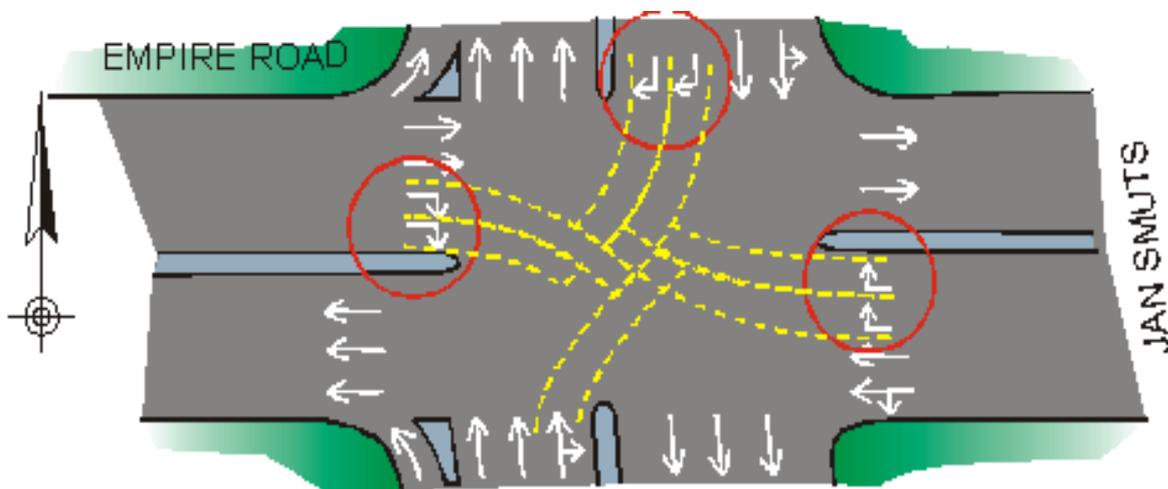
Many authorities have found that this regulation of the right-turn movement, i.e. through omission, is either misunderstood or ignored by motorists. They have found that in using the prescribed signals S13, S14 or S15, the right-turning motorists; instead of waiting for the flashing green arrow of the protected right-turn phase; often move over the stop line during the main green phase and then attempt to utilise gaps in the opposing traffic stream.

In order to enforce the stopping of right-turning vehicles behind the stop line at the right-turn lanes during the main green phase, some authorities have now resorted to using a full, steady red disc or steady red arrow above the flashing green and yellow arrows of S13-15. The full steady red is confusing as it conflicts with the green straight and /or left arrows. This can result in accidents when straight through traffic stops. The alternative of a red arrow signal indication is not permitted by the SARTSM.

The present signal requirements of the SARTSM also do not make allowance for the PO right-turn phase to be replaced by a P/P right-turn phase at a different time of day. The required main signal aspects for the through-traffic are different (full circular aspects for P/P and steady green arrows for PO).

## 8. SITE SURVEY

The intersection of Empire Road (M71) & Jan Smuts Avenue (M27) in Johannesburg was one of the intersections surveyed as part of the study.



**Figure 2.** Layout of Jan Smuts (M27) & Empire (M71), Johannesburg

Lagging P/P phases is used, allowing right-turn (RT) vehicles to enter and move into intersection during main green phase. Dotted guidelines inside the intersection area are used to guide RT movements. Yield lines in the RT lanes within the intersection area are used to indicate safe stopping place for RT vehicles without impeding opposing straight-on vehicles.

It was found that RT vehicles mostly use the permitted phase during periods when the opposing flows are lower. During the peak period when flows are at a maximum, almost no gaps are utilised by RT vehicles during the permitted phase; instead, all turning movements are made during the protected RT phase (see Table 5).

Although almost no gaps are taken by RT vehicles during the permitted portion of the P/P phase during the peak period, this phasing does appear to increase the flow during the protected phase.

The main advantage of the P/P phase during peak periods appears to be the 6 to 8 vehicles that are waiting within the painted guidelines inside the intersection when the protected phase starts. This allows the P/P phase to clear more vehicles per cycle than a PO phase, where the vehicles are not permitted to move into the intersection during the main green phase, thereby increasing intersection capacity.

**Table 5.** *Case study: Double right-turn traffic flows during different signal phases*

Hourly flow (start time)	Approach	Number of vehicles turning during phase (vph)	
		Permitted	Protected
08:00	Westbound	0	855
	Eastbound	0	399
09:00	Westbound	28	533
	Eastbound	13	285
17:00	Westbound	0	486
	Eastbound	18	203
18:00	Westbound	0	427
	Eastbound	100	427

## 9. CONCLUSION

In deciding between protected-only (PO) versus protected/permitted (P/P) double right-turn phasing, a trade-off exists between operational efficiency and safety:

- From a traffic operational aspect, P/P phasing which allows motorists to utilise gaps in the opposing traffic streams, result in less overall delay and better progression along arterials than PO phasing for double right-turns.
- From a traffic safety viewpoint, the protected double right-turn movement during PO phasing is safer than using P/P phasing where, during the unprotected main phase, right-turners are allowed to utilise gaps in opposing traffic to make right-turns. The accident risk of drivers turning right at an intersection is considerably increased when opposing right-turn vehicles, heavy vehicles, other physical features and the intersection layout restrict the available sight distance. High pedestrian volumes also influence the type of phasing that can safely be applied.

The site surveys performed, i.e. at the intersection of Jan Smuts and Empire Roads showed that even at high volume intersections with a combined high incident occurrence, operational benefits could be obtained by allowing permitted/protected phasing without compromising safety. The questionnaire and interviews also pointed out that double right-turn lanes have been implemented with success under permitted and permitted/protected phasing locally.

In terms of the costs-benefit analysis of this report, the monetary benefit of improved operational efficiency with the P/P phasing for double right-turning vehicles generally far outweighs the benefit of safety improvements brought about by using PO phasing.

The study pointed out that there are no uniform or clear guidelines applied in the USA or locally. A “grey area” exists in deciding between the trade-off between operational efficiency and the perceived safety risk. This non-clearcut trade-off and site specific features, also makes it difficult to determine what uniform right-turn phasing guidelines should be.

The dilemma faced by traffic engineers is that high accident rates are an emotional issue, with social and moral connotations; their justification in pure monetary terms may not be acceptable to the general public. It is perceived that serious and fatal accidents have a higher “weighting” than only monetary considerations.

In view of this dilemma it is recommended that at intersections with newly implemented phasing at double right-turn lanes a trial implementation strategy be followed. The phasing strategy should limit potential risk and liability to “acceptable levels”. A decision to implement a particular phasing strategy requires a quantification of this “acceptable level” based on the trade-off between operational efficiency and safety. Engineering judgement and local experience is therefore a crucial requirement in deciding between permitted/protected and protected-only phasing at double right-turning lanes.

Following the trial implementation process, double right-turns may initially be phased as permitted or protected/permitted to determine the acceptability thereof based on safety and operational performance. Should the performance of the phasing option not be acceptable the next level of control, protected/permitted or protected-only, should be implemented.

## **10. REFERENCES**

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Previous experience gained in the consulting engineering firm African Consulting Engineers (Jordaan & Joubert), now Gibb Africa, included a range of traffic engineering studies, transportation modelling, various research projects for the Department of Transport, involvement in the further development of the software CB-Roads (used for the economic analysis of roads projects). Other work included public transport studies, geometric design of roads, as well as labour-intensive construction projects in the former Venda and Gazankulu.

Mehboob is involved in a number of professional organisations, and is currently a council member of the South African Institution of Civil Engineering (SAICE) and is also active in the Pretoria branch of SAICE. He has presented previously at the ATC, and won an award for the best paper by a young engineer in 1991.

## **TOBIE M UECKERMANN**

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Tobie Ueckermann obtained his Bachelor's degree in Civil Engineering from the Rand Afrikaans University in Johannesburg, Gauteng at the end of 1995. After graduating he was employed by the South African Department of Transport (DoT) in Pretoria.

In the two years he worked at the Department in the Directorate: Roads (now the South African National Roads Agency Ltd.) in Pretoria, as an Assistant-Engineer. His main area of work concerned the national road network and aspects related thereto. Emphasis was placed on the geometric design and traffic aspects of National Roads.

He is currently furthering his education by studying towards a M.Eng. (Transportation Engineering) degree, at the University of Pretoria, in the field of Transportation after completing the B.Eng.(Hons)(Transportation Engineering) at the end of 1999.

He joined the services of Jeffares & Green in 1998 and his involvement is in the transportation division. His work comprises transportation and traffic studies and projects for a wide range of clients. These studies and projects may include inter alia aspects of: traffic counts and analysis, travel surveys, origin and destination surveys, capacity analysis, traffic signals & modelling, traffic safety, parking, cost-benefit analysis, sensitivity analysis, policy formulation, demand forecasting, and feasibility studies.

Tobie is a Graduate member of the South African Institution of Civil Engineering (SAICE), since March 1997, and is also a 2000/2001-committee member of the Transportation Technical Division of SAICE. He has been a member of the SARF since 1996. He is a committee member of the SARF Gauteng Branch Committee and National SARF Council Committee representing Jeffares & Green as sponsor member.