MODELLING THE TRAFFIC ROLE AND PERFORMANCE OF ROUNDABOUTS

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ABSTRACT

Roundabouts offer environmental enhancements and act as effective speed control devices in road networks. A number of factors affect the performance of roundabouts including the proportion of turning movements, unbalanced (tidal) flows (typical of peak flow patterns), and sight distance. The complexity of the traffic operation of roundabouts means that detailed analytical analysis is impractical, and suggests that simulation modelling may be needed to investigate the detailed performance of roundabouts.

This paper reviews the use of roundabouts as part of urban arterial road traffic control and in local area traffic management. Questions about how roundabouts fit to an urban arterial network are still not clearly understood. The results from a preliminary simulation model are described, and future developments and use of the simulation model are outlined.

INTRODUCTION

The research reported in this paper is part of an on-going project that aims to develop a microscopic simulation model for the analysis of roundabouts. The objectives of the project are:

(a) statistical analysis of the simulation results to better understand the performance of roundabouts;

(b) comparison of existing capacity analysis procedures with the model, and

(c) the development of a capacity prediction model that may be useful in the selection of roundabout control for an intersection, and the design of the roundabout.

The paper starts with a review of the use of roundabouts in Australia, concentrating on their roles in Local Area Traffic Management and as elements of an urban arterial road network. The development of a simulation model is then described, and preliminary results from this model are provided. A proposal for an extended model is outlined. The final section of the paper summarises the findings from the study and discussed the future research directions.

ROUNDABOUTS AND LOCAL ARAE TRAFFIC MANAGEMENT

Residents frequently demand better environmental and sociological conditions to increase their quality of life, and this often leads to the need to control the speed, volume and behaviour of traffic on local streets in their neighbourhood. The field of 'Local Area Traffic Management' (LATM) has become of considerable interest for local government, regional authorities and state transport agencies, witness the plethora of reports and planning and design guides for LATM (e.g. SA Department of Transport, 1986; Traffic Authority of NSW, 1983 and NAASRA, 1988).

Speed control on local streets may be attempted by a variety of means (Taylor, 1986), usually in terms of:

(a) physical devices (e.g. humps and closures) at points along a street section;

(b) 'streetscape' treatments along a street or in a traffic precinct, and

(c) physical and regulatory controls at intersections, both inside the traffic precinct and at its points of access or egress to the main road system.

The streetscape treatments are seen as expensive remedial measures for established areas, while many communities view the midblock devices as 'aggressive' or even as hazards to safe traffic movements.

Some residents believe that stop signs at junctions will reduce the speed on their streets, but a study by Beaubien (1976) showed that there are alarmingly high disobedience rates for these signs. Beaubien found that after the installation of stop signs, there was a slight increase in midblock speeds, possibly because motorists were trying to make up for the lost time. The difference in average speeds was not, however, statistically significant.

Stop signs were found to be effective in reducing speed but the range of effectiveness was small compared to that achievable using roundabouts (Marconi, 1977). Stop signs are only effective at an intersection whereas roundabouts had extended effects on vehicle speeds downstream from an intersection. This is because, at roundabouts, the driver has to decelerate to proceed through the roundabout and cannot begin acceleration until some distance after the vehicle has cleared the roundabout. This phenomenon is described as 'geometric delay'.

Aggressive devices and measures like humps and road closures may be unsuitable in many areas. They may divert traffic in the neighbourhood, so shifting traffic problems to other streets, and restrict internal movements and accessibility[1]. Hence roundabouts have been installed to act as speed control devices, by breaking up the long, straight road sections that encourage speeding. They also provide for a more equitable system of priority in a traffic precinct, and are seen as an acceptable compromise that is may be viewed more favourably than road closures or speed control humps.

Klyne (1988) stated that 'Roundabouts are self-enforcing devices which do not rely entirely on the psychological perception of motorist'. Many roundabouts have now been installed on local streets in urban Australia to reduce traffic speed. 'Before and after' studies carried out in Perth, Western Australia (Klyne, 1988; Richardson, 1982) have shown significant reductions in speed after the introduction of roundabouts.

Klyne also found a reduction in noise level of about 20 per cent after the installation of roundabouts. This comes about as the continuous flow of vehicles through roundabouts provide a quieter and cleaner environment than the stop-start movements and noisy revving of engines at uncontrolled intersections.

ROUNDABOUTS ON ARTERIAL ROADS

Roundabouts provide significant capacity to accommodate heavy traffic volume with high proportions of turning traffic (O'Brien and Richardson, 1985; Avent and Taylor, 1979).

Biggs and Bowyer (1986) used the INSECT simulation model (Cotterill, Moore and Tudge, 1984) to examine the performance of three individual intersections under different control systems (vehicle-actuated signals, major-minor priority and roundabout). They found that the optimum control type varied over time of day, in response to traffic demand, thus suggesting that the determination of an overall optimum traffic control system for a given intersection may depend on a variety of traffic, environmental and locational factors. To use INSECT for roundabout simulation, Biggs and Bowyer took the roundabout to consist of a connected series of T-junctions. As discussed by Troutbeck (1988), this is only an approximation to the operation of a roundabout, for the distribution of headways in the circulating traffic depends on the interactions

[1] The use of dense network planning tools such as MULATM (Taylor, 1987) provides one means for planning for the optimal location and selection of control devices to minimise traffic diversion and network dislocation.

between the traffic arriving at each approach leg to the roundabout[2]. Thus there is need to consider models that explicitly recognise the special characteristics of traffic flow at roundabouts.

At an intersection where minor road traffic is experiencing unacceptable delay and signals do not improve the level of service, a roundabout design can be a suitable alternative treatment. Another possible application is at cross intersections of local and arterial roads, where roundabouts can be used to reduce speed of the traffic entering the local street, improve the safety of the intersection and yield enough capacity to give a satisfactory level of service.

However, there are problems in using roundabouts in an arterial network because they may distort (or even nullify) signal progression systems. The main objective of area-wide traffic control in an arterial network is to maximise the green band available on each road, and roundabouts nay not be appropriate in such circumstances. Also, for a close grid network, roundabouts may not a suitable control device as the proportion of turning movements is likely to be low. Therefore roundabouts are more suitable for sparse grid networks with wide spacings between links, as the turning proportions would be higher.

There is very little understanding on how well roundabouts fit to an arterial network. The work of Troutbeck (1988) has provided a theoretical basis for considering the traffic performance of individual roundabouts, given certain necessary simplifications (e.g. about driver behaviour and vehicle performance). The development of a simulation model, as described later in this paper, will allow a better understanding of traffic performance at and near roundabouts. How and where roundabouts can be fitted into an arterial road network should then become more apparent.

SAFETY OF ROUNDABOUTS

Studies carried out in Australia, UK, France, Sweden and elsewhere have shown that roundabouts have a good safety record and accidents are usually of a minor nature, largely involving property damage only (Lalani, 1975; Green, 1977, Todd, 1979; Ogden and Bennett, 1984).

A recent Swedish study by Cendersund (1988) indicated that the number of accidents at roundabouts in relation to traffic volume is approximately the same at other types of junctions. However, the accident severity at roundabouts is significantly reduced.

Furthermore roundabouts contribute to pedestrian safety as pedestrians are able to cross one direction of traffic at a time because of the shelter provided by the splitter islands on the approach to roundabouts.

A vexed question for roundabout operations is that of safety for cyclists negotiating the roundabout. Certainly bicycle manoeuvres are more complicated at roundabouts, and although there seems to be little evidence of obvious safety problems from the available accident data, there is a belief that cyclists may experience greater risks when turning at roundabouts.

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[2] This is the same problem that made the analysis of give-way-to-the-right' intersection control most difficult see Dunne and Buckley (1972).

ROUNDABOUT CAPACITIES

A number of techniques have been suggested for the analysis of delays and capacities at roundabouts.

Australian Capacity Prediction Model

The Australian roundabouts design guide (NAASRA, 1986) provides a model for predicting the capacity of roundabouts based on gap acceptance theory. The entry flow capacity per lane for single lane roundabouts is

$$qe = \frac{q_c (1 - q_c t) \exp[-q_c (T-t)]}{1 - \exp(-q_c T_o)} \qquad (1)$$

where q_c = circulating flow,
T = critical gap,
T_o = follow-up time,
t = minimum headway for circulating lane.

Design curves for the capacity of single and multi-lane circulating lane roundabouts derived from the above equation are provided in NAASRA (1986).

The values of T and T_o recommended by NAASRA are T = 4 seconds, T_o = 2 seconds, while the recommended value of t is 2 seconds for single lane roundabouts and 0 seconds for multi-lane roundabouts.

Troutbeck (1988) has extended the theoretical analysis of gap acceptance to include more general (and realistic) distributions of headways in arterial road traffic (e.g. the M3 model of Cowan (1975)). He also published data on observed gap acceptance behaviour at a number of roundabouts in the eastern states of Australia.

TRRL Capacity Prediction Model

The TRRL employed the empirical approach to infer the form of the entry/circulating flow relationship directly from observation. Kimber (1980) developed a capacity model that used the geometric characteristics of the roundabout to determine its capacity.

A comparison of the two models by Barker (1987) showed that the TRRL model tended to predict greater capacities than the observed capacities, and that the results from the Australian model provided a good approximation for single lane roundabouts. The study showed that there is no ground for rejecting the gap acceptance methods for estimating the capacity of roundabouts.

Troutbeck (1988) concluded that the gap acceptance approach provides a useful basis for modelling the operation of roundabouts in Australia.

DELAYS AT ROUNDABOUTS

Delays at roundabouts are divided into two components, queueing delay and geometric delay. The queueing delay is the time a vehicle is waiting in the queue and the head of the queue. The geometric delay is the time a vehicle decelerates from cruising speed, proceeds through the roundabout and accelerates back to cruising speed due to the physical presents of the roundabout. The two factors with the greatest effect on the geometric delay are the mean approach and exit speed, and total angle turned (McDonald and Noon, 1978). Hence, the total delay is the queueing delay plus the geometric delay and this delay should be used to compare roundabout with other intersections.

SIMULATION PROGRAM

A simulation program, 'Model B', written in the C computer programming language, has been developed to simulate a roundabout with one circulating lane and single lanes approaches. This model can generate vehicle arrivals using one of following four headway distributions:

(1) negative exponential;
(2) displaced negative exponential;
(3) Cowan M3 model (Cowan, 1975), and
(4) Borel-Tanner bunching distribution (Taylor, Miller and Ogden, 1974).

The Cowan M3 model and the Borel-Tanner distribution have two components, the tracking component and the free component. The tracking component represents a group of vehicles travelling in the same direction with a short headway between each vehicle, in a car-following mode, in which their speeds, spacing and accelerations are dependent on the vehicles immediately in front of them. The free component represent a single vehicle travelling free of the influence of other vehicles behind or in front.

The M3 model provides a reasonable description of traffic on multi-lane arterial roads, while the Borel-Tanner model is useful for describing traffic on two-way, two-lane rural roads.

Vehicles enter the roundabout on the basis of gap acceptance behaviour. The process mechanism of the model assumes that the movement of the vehicles in the roundabout is like a carrousel, as shown in Figure 1. When the vehicles merges with the circulating stream it is assigned to a 'slot' moving around the roundabout. Vehicles in the circulating lanes are travelling at the same speed regardless whether there is a vehicle in front of them or not. The vehicles designated to leave at the coming approach will be detached from the carrousel. This slot will be free to be used by other vehicles. The process is repeated until all the cars simulated at the approaches have been processed.

The problem with this process mechanism is that when modelling a multi-lane roundabout, vehicles in the inner lane will have to change to the outer lane when approaching their destination. This means that a vehicle will have to slow down if it is blocked by vehicles in the outer lane and wait until it is safe to change lanes. The vehicle might even stop if it is very close to the exit. The change in speed of vehicles in the roundabout is difficult to simulate with this model. A model that has the flexibility of variable speed and lane changing is necessary to model multi-lane roundabout. Thus this model is sufficient only for a single lane roundabout.

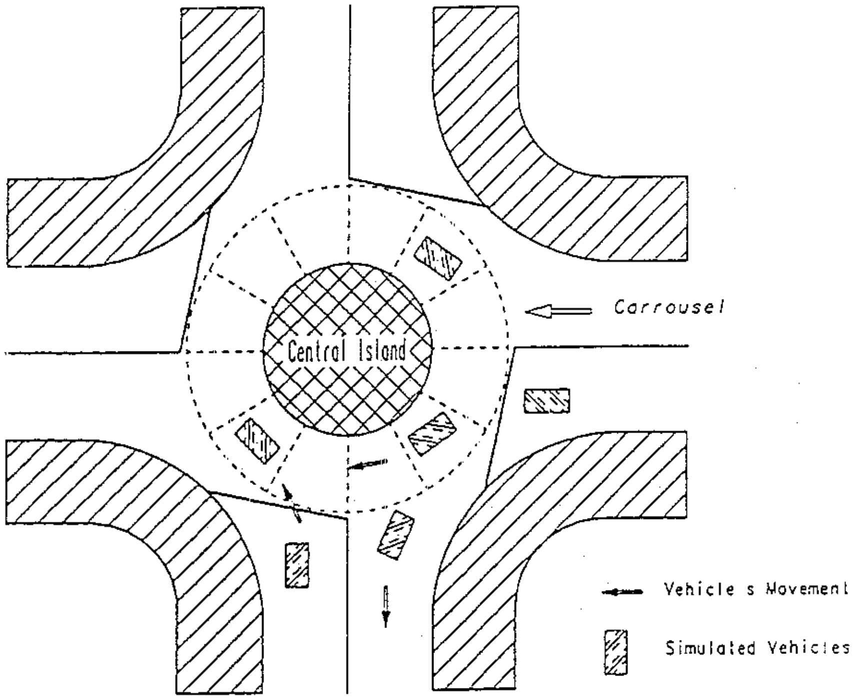

Figure 1: Process Mechanism for Model B.

Proposed Model

A proposed simulation program, 'Model C', will be able to model different traffic conditions, geometric layout and drivers behaviour. The following areas will be further developed to improve the model :

(1) *gap acceptance* - a few gap acceptance model taking into account of the variability of behaviour amongst drivers, pressure of traffic demand on lag and gap acceptance and speed of approaching vehicles. Studies by Troutbeck (1986, 1988) and Plank and Catchpole (1984) have shown that capacity increases slightly if drivers behave inconsistently and this implementation, a comparison of the capacity due to consistent and inconsistent drivers behaviour can be analysed.

(2) *car following.* - the proposed model will generates vehicles at a distance X from the stop line and the vehicles will move towards the roundabout. Along the travelled distance X, vehicles under the influence of slower vehicles will behave according to a car following model (e.g. Gipps, 1981). A car following model

includes the relative speed of the vehicles, distance headway between vehicles and human factors such as reaction time lag and driver sensitivity.

(3) *lane changing* - this feature is necessary for vehicles in the inner lane changing to the outer lane before departing at the designated exit, and the possibility of vehicles changing lane at approach either to move to a lane with shorter queue or to the lane that will lead them to their desired destination.

(4) *fuel consumption* - the information of fuel consumption is required in any attempt to maximises the system efficiency so as to satisfy energy related objectives in traffic management, and fuel is one of the most quantifiable user costs. Biggs and Bowyer (1986) have demonstrated the value of using simulation modelling in investigations of fuel efficiency in traffic systems operation.

Results

The results from Model B show that the delay predicted from the model is greater than the NAASRA (1986) value. Using the notations used for the traffic flow at a roundabout in Figure 2, a simulation was carried out for the flow distribution shown in Figure 3 and listed in Table 1. The results in Table 1 show that for approach 0, 2 and 3, the simulated average queueing delay is very close to the value predicted by NAASRA (1986). For approach 1 where the circulating flow equals 0, the model estimated a delay of 3.7 seconds whereas in theory the queueing delay should be zero for no circulating flow. If 50 per cent of the exiting vehicles in approach 1 is added to the circulating flow, the theoretical average queueing delay gives 2.6 seconds compared to 3.7 seconds from the simulation model (see Table 1).

In a real system, when an approaching vehicle from the circulating stream exits at the immediate approach, the entering vehicle will not enter the roundabout until the exiting vehicle has fully committed itself as illustrated in Figure 4.

Table 1: Flow Rates and Simulated Average Queueing Delay, Simulation Run No. 2

Approach	Traffic Flow (veh/h)				Average Queueing Delay (s)		
Leg No.	q_e	q_c	q_{ex}	$q_c + .5q_{ex}$	d_{sim}	d_{th1}	d_{th2}
0	295	663	0	663	4.4	4.6	4.6
1	309	0	958	479	3.7	0.0	2.6
2	308	309	0	309	1.8	1.4	1.4
3	47	617	0	617	3.4	2.5	2.5

d_{sim} = simulated mean queueing delay
d_{th1} = theoretical mean delay based on NAASRA (1986)
d_{th2} = theoretical mean delay based on circulating 'main stream' flow of $q_c + .5q_{ex}$, based on NAASRA (1986)

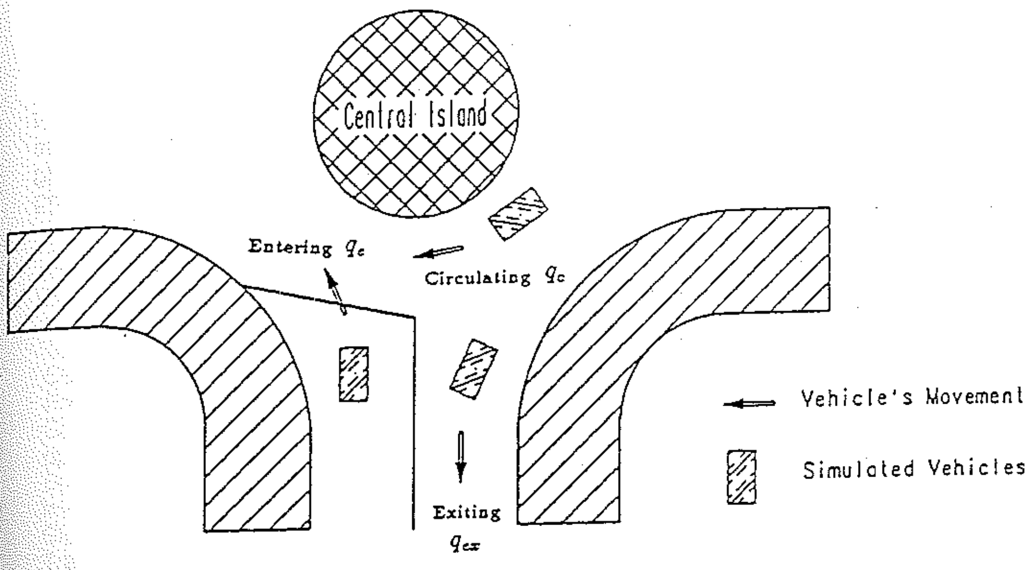

Figure 2: Definitions of Traffic Flow at a Roundabout.

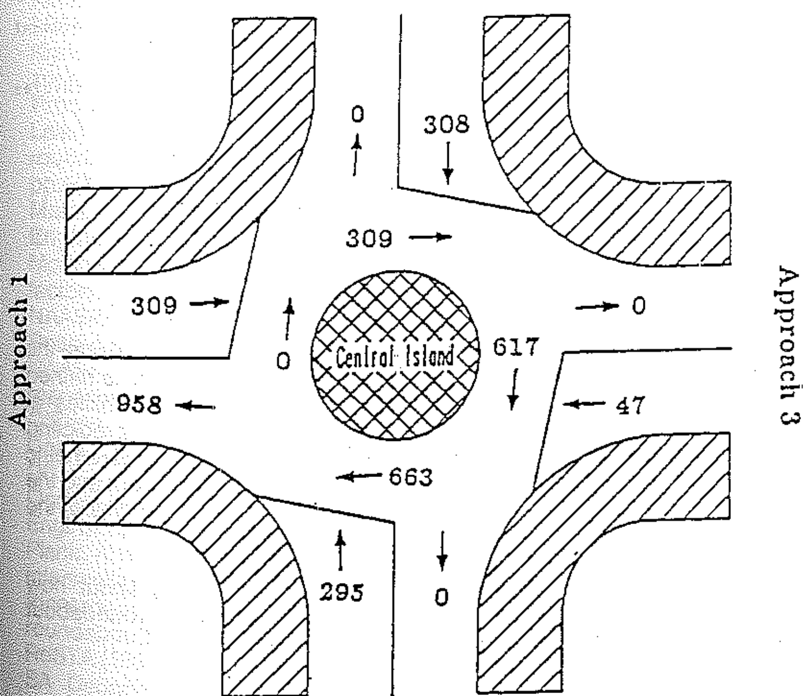

Figure 3: Simulation Run No 2.

In other words, an exiting vehicle at the approach has some effect on the entering vehicles even though the exiting vehicle is not in the conflicting stream. The factor of 50 per cent used is an arbitrary value and it depends largely on the assumption made by the process mechanism. An empirical study on the contribution of the exiting vehicles to the circulating flow would help in understanding its effect and in developing a more accurate process mechanism.

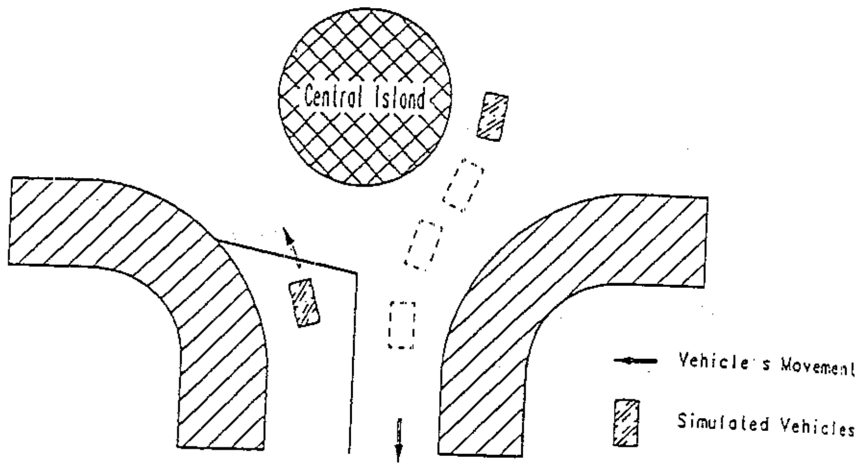

Figure 4: Driver's Behaviour Entering the Roundabout.

CONCLUSIONS

The results from Model B show that the proportion of exiting vehicles affects the average queueing delay of the entering vehicles. The proposed model, with its refined features, is necessary in order to study the performance of individual vehicles at roundabouts. The geometric configuration of the roundabout is important in predicting the geometric delay and this will be implemented in the proposed model. Geometric delay also requires considerations of the connections between the roundabout and the surrounding intersections and road network. This provides the lead in to studies of the role and performance of roundabouts in urban arterial road networks.

The future research work will attempt to answer these key questions about how roundabouts fit into an arterial network and the relationship between the roundabout and the surrounding road system.

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