DESIGN TECHNIQUES FOR ROUNDABOUTS IN SRI LANKA

by

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Abstract

Roundabout is one of the effective and a relatively low cost method of intersection control. Properly designed roundabouts generally have a good safety record. There are two roundabout design techniques that can be adopted for Sri Lanka. It is shown that the Australian method can be better suited than the British method because it takes account of the effects of approach speeds on the performance of roundabouts and also allow the calculation of queuing lengths. It is shown that when analysing, it is necessary to resort to a trial and error process since the results should simulate the actual driver behaviour at a roundabout. Otherwise, drivers might ignore the lane markings and other warning signs at the roundabout thus leading to congestion.

1.0 Introduction

Roundabout is one of the effective and a relatively low cost method of intersection control. Roundabout functions on the simple principle where vehicles giveway to those from the right. Roundabouts are particularly suitable for junctions where there is a considerable space to locate a roundabout with circulating carriage ways and also the flows in all roads are approximately equal. A properly designed roundabout will generally have a very good safety record. Roundabouts have been extensively used in the united Kingdom and becoming popular in Australia, Europe and the Asian Continent.

Roundabout should be designed to ensure smooth flow of traffic that is expected in each arm. However there are a number of roundabouts in Colombo that cause considerable delays due to various reasons. In the research work presented in this paper, analytical methods developed in two countries have been used to determine the performance of two busy roundabouts in Colombo. One of those has been used as a case study. Once these results are calibrated with the actual performance, it will be possible to present suitable roundabout design techniques to design new roundabouts in Sri Lanka. The same can be used for improving existing roundabouts.

2.0 Suitable Locations for Roundabouts

Roundabouts may not be an efficient intersection control measure unless certain conditions are satisfied. They are preferred under these conditions (NAASRA, 1993).

1. At intersections where traffic volumes on the major and minor intersecting roads are such that " STOP", "Give Way" or the T- junction rule" results in unacceptable delays for the minor road traffic.
2. At intersections where there are a high proportion of right turning traffic.
3. At intersections with more than four legs; traffic signals may be less efficient due to the large number of phases required, resulting in a high proportion of lost time.
4. At cross intersections where a disproportionately high number of accidents occur that involve either crossing traffic or turning movements.
5. At "T" or "Cross" intersections where the major traffic route turns through a right angle.

3.0 Roundabout Design Techniques

The key factors which will enable the engineer to determine the suitability of the geometric parameters selected for a roundabout, are the capacity and the delays experienced in each arm leading to the roundabout. There are two roundabout design techniques used for the evaluation. The method developed in Great Britain (British method) gives formulae to calculate the capacity for each arm based on the geometry of the roundabout. The method developed in Australia (Australian method) gives charts and formulae to calculate the capacity for each lane in each arm and the delays in each arm.

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3.1 British method

At a roundabout it is important to ensure that, the number of vehicles intending to enter it from any arm is not excessive which can cause queuing in that arm.

The equation for the prediction of entry flow into a roundabout as a function of the circulating flow and entry geometry is applicable to all types of at grade roundabouts. The capacity formula given in TA 23/81 and refers to Figure 1:

$$Qe = K(F - fcQc) \quad \text{When } fcQc < F$$
$$= 0 \quad \text{When } fcQc > F$$

where,

- Qe = Entry flow in pcu/hr
- Qc = circulating flow across the entry pcu/hr
- K = 1- 0.00347(-30) -0.978(1/l-0.05)
- F = 303x2
- fc = 0.210 tD(1+0.2x2)
- tD = 1+ 0.5/(1+M)
- M = exp((D-60)/10)
- x2 = v + (e-v)/(1+2s)
- s = 1.6(e-v)l1

- e - Entry width 4 to 15m.
- v - approach half width 2 to 7.3m.
- l1 - effective length of flare
- r - entry radius 6 to 100m.
- \- entry angle 10 to 60 degrees.
- D - Inscribed circle diameter 15 to 100m (Fig ure 1 - a,b,c,d)

3.2 Australian method

This method considers the behaviour of the driver at a roundabout, the influence of the geometry and traffic flows already in the roundabout (circulating flows) when determining the entry capacity. One of the most important parameters is gap acceptance which means driver's ability to enter the roundabout by accepting a suitable gap. The entry capacity of a roundabout is determined on the basis of following assumptions:

1) The entering vehicles generally giveway to all circulating vehicles. An exception is when vehicles are entering from an auxiliary 'left turn only' lane. If this auxiliary lane and the entry curve is designed so that entering drivers are protected from the circulating traffic, they will generally proceed without 'giving way' to any circulating vehicle.

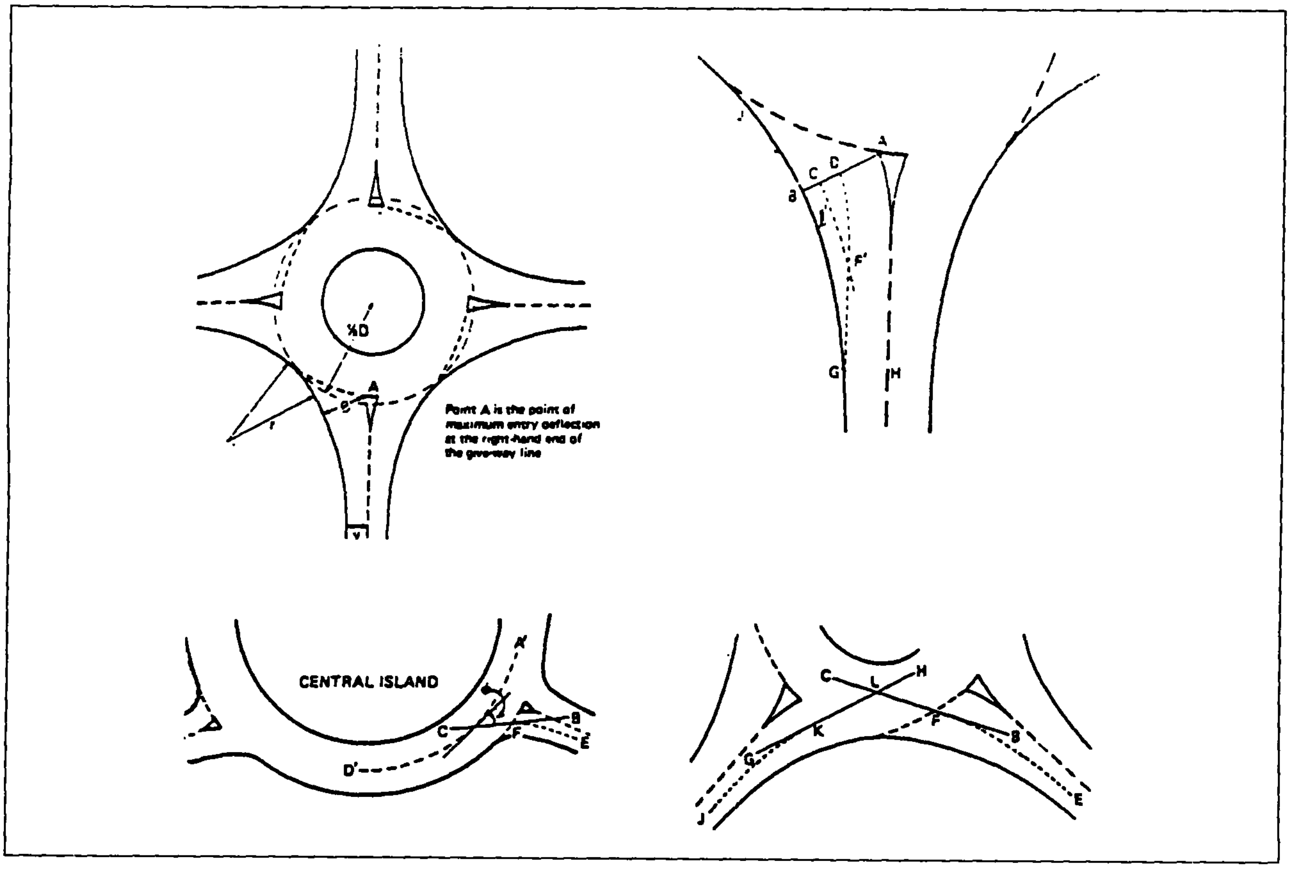


Figure 1. The Geometric Elements of a Roundabout (TA 23/81)

2) The exiting vehicles have no effect on drivers entering at same leg unless the negotiation speed is high or the roundabout is small and the entering drivers have difficulty in determining whether a vehicle is exiting or not.

3) Each entry lane will have a different capacity and vehicle delay. As a result, if the number of entry lanes is doubled then the capacity is not quit doubled.

3.2.1 Determination of entry capacity

The entry capacity depends on the number of entry and circulating lanes, the duration of the gap accepted by the drivers and the characteristics of circulating traffic. The effects of these parameters are considered in detail while presenting the Australian method which consist of the steps given below.

3.2.1.1 Determination of number of entry and circulating lanes.

The number of entry lanes will generally be determined from the number of lanes on the approach carriageway. However, the geometry of the roundabout should be selected so that there is sufficient number of circulating lanes which will ensure that the degree of saturation for each arm is maintained below 0.8. Thus, the number of circulating lanes required depends on the entry flow and circulating flow as shown in Figure 2. If a point within the shaded band is obtained, the number of lanes can be the the values on either side. For example entry flow 1500 veh/hr and circulating flow 1500 veh/hr, either 2 or 3 circulating lanes can be provided considering the space available at site.

Entry lanes are classified as dominant or sub- dominant when there are two or more entry lanes. The entry lane with the greatest flow is chosen to be the dominant stream other entry lanes will then be sub dominant.

3.2.1.2 Estimation of the critical gap acceptance parameters.

When a driver stops at a roundabout to give way to circulating traffic, he will wait until there is a sufficient gap between two consecutive circulating vehicles to enter the roundabout. The greater the number of circulating carriageway lanes, the shorter will be the average headway between bunched vehicles in all lanes. If there are two or more circulating lanes then the average headway between bunched vehicles is about 1 second and if there is only one lane the average head way is 2 seconds. However, if a circulating carriageway width is equal to or greater than 10m and carries a circulating flow greater than 1000 veh/hr, it can be assumed to effectively operate as two streams and the average headway between bunched vehicles as one second. The necessary charts are given in NAASRA 1993.

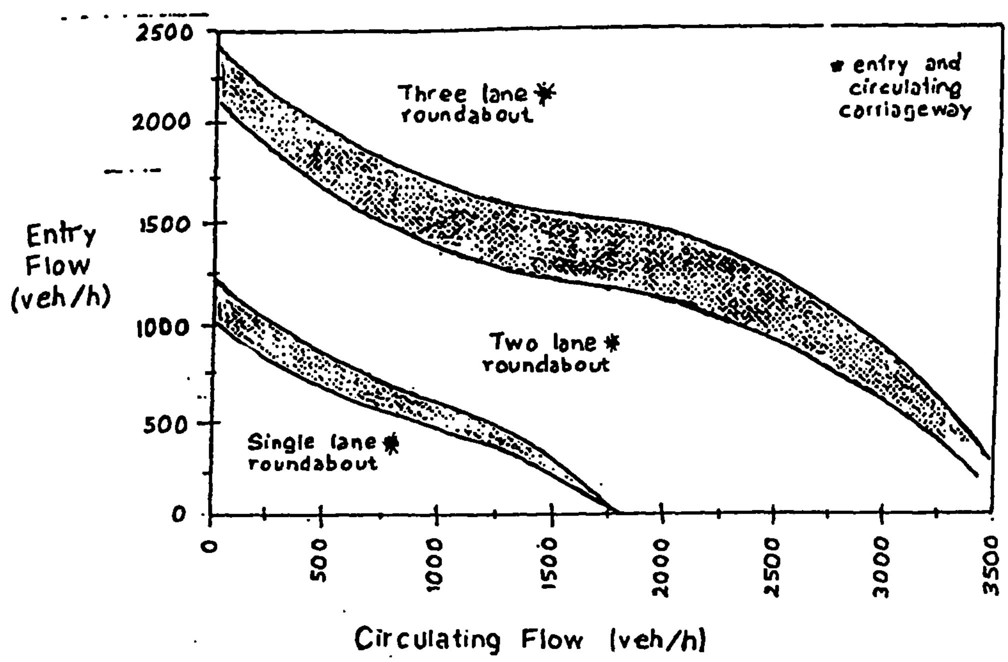


Figure 2. Required Number of Entry and Circulating Lanes (naasra, 1993)

3.2.1.3 Determination of characteristics of the circulating traffic

The circulating stream characteristics will change with flow and the number of circulating lanes. The average headway between bunched vehicles in the circulating traffic and the number of effective lanes in the circulating carriage way can be related as given in Table 1.

The proportion of bunched vehicles, is evaluated from the circulating flow, the number of effective circulating lanes and the proximity of roundabout to signalized intersections or other situations which increase bunching. The relationship of is given in Table 2. The proportion of bunched vehicles is expected to range from 0 for random traffic to about 0.8 for heavily platooned traffic. Values as high as 0.8 to 0.9 have been observed in extreme cases. This is equivalent to an average platoon length of 1 to about 3 or 4 vehicles in most conditions and up to 10 vehicles under the worst condition.

3.2.1.4 Determination of the absorption capacity

The absorption capacity of an entry lane is given by the following formula (NAASRA, 1993):

where,

$$C = \frac{3600\,(1-\theta)\,q_c\,e^{-\lambda(t_a - T)}}{1 - e^{-\lambda t_f}}$$

C - The absorption capacity of an entry lane veh/hr

- The proportion of bunched vehicles in the circulating stream

q_c - The flow of vehicles in the circulating stream in veh/sec

t_a - The critical acceptance gap relevant to the dominant or sub- dominant lanes

t_f - Follow on headway relevant to the domi nant or sub dominant lanes respectively

T - The minimum headway in the circulating streams

$$\lambda = \frac{(1-\theta)\,q_c}{1-\tau q_c}$$

Table 1 Average headway between bunched vehicles in the circulating traffic (NAASRA,1993)

Circulating flow lanes	Circulating carriageway width			
	less than 10m		greater than or equal to 10m	
	number of effective bunched	headway between effective vehicles	nember of between lanes	headway bunched vehicles
<1000veh/hr	1	2	2	1
>1000 veh/hr	1(or2)	2(or1)	2	1

Table 2 Proportion of bunched vehicles () (NAASRA,1993)

Number of effective circulating lanes	one	more than one
Average headway between bunched vehecles (s)	2.0	1.0
circulating flow(veh/hr)		
0	0.25	0.25
300	0.375	0.313
600	0.50	0.375
900	0.625	0.438
1200	0.750	0.500
1500	0.875	0.563
1800	1.00	0.625
2000		0.667
2200		0.708
2400		

Once the entry capacity is determined, it is possible to calculate the degree of saturation. It should be less than 0.9 and preferably 0.8. However, this is not always practicable.

The degree of saturation of an entry lane is :

$$x = Q_m/C$$

Where, Qm is entry lane arrival flow in veh/hr and C is entry lane capacity in veh/hr.

3.2.1.5 Delays at roundabouts

There are two components of delays experienced at roundabouts. These are queuing delay and geometric delay . Queuing delay is the delay to drivers waiting to accept a gap in the circulating traffic. The geometric delay is the delay due to drivers slowing down to stop at the end of the queue and after accepting a gap, accelerating to the negotiation speed proceeding through the roundabout and finally accelerating further to reach normal operating speed. This excludes the time to wait for an acceptable gap. Total delay is the sum of the queuing delay and the geometric delay, thus D_T=dg+Wm.

Queuing delay is calculated by the minimum queuing delay evaluated using the following equation (NAASRA, 1993):

$$W_h = \frac{e^{\lambda}(t_a - T)}{(1-\theta)q_c} - t_a - \frac{1}{\lambda} + \frac{\lambda T^2 - 2T\theta}{2(\lambda T + 1 - \theta)}$$

The average queuing delay w_m is given by;

where

$$W_m = W_h + 900\,T\,[\,Z + \sqrt{(}Z^2 + mx/CT\,)$$

w_m = average delay per vehicle in seconds

w_h = minimum delay in seconds when the en tering traffic is low

T = duration of the flow period in hours

Z = x-1

x = degree of saturation of the entry lane

C = entry lane capacity in vehicles per hour

m = a delay parameter given by m = wh C/ 450

Geometric delay for vehicles differs depending on whether the vehicles have to stop or not.

Geometric delay is given by the formula:

$$d_g = P_s d_s + (1-P_s) d_u$$

where:

P_s - the proportion of entering vehicles which must stop

d_s - the geometric delay for vehicles which must stop

$(1-P_s)$ - the proportion of entering vehicles which need not stop

d_u - is the geometric delay to vehicles which need not stop

Since majority of parameters are presented as empirical formulae, it is convenient to perform the calculations using a spreadsheet program. The calculations given in the case study are performed using a program written using Lotus 123.

4.0 Case studies

These information indicates that Australian and British methods can be adopted easily for the design of any roundabout. However, there are certain decisions that should be made as shown in the case study.

In order to determine the effects of various roundabout improvement techniques on the capacity, two busy roundabouts in Colombo have been analysed in detail. They are the roundabouts at Slave-Island junction and Ingurukade junction. It should be noted that the roundabouts at Slave Island and Ingurukade junctions have subsequently been replaced by traffic lights. In this paper, Slave Island roundabout has been used to explain the analytical procedure.

4.1 Slave Island roundabout

Slave island roundabout shown in Figure 3 was one of the busiest roundabouts before signalizing with six approaching arms. It is shown that this roundabout has certain geometric deficiencies that could have caused the unacceptable delays in certain arms. In this paper, the roundabout which was in existence is termed as existing roundabout.

The following geometric weaknesses can be highlighted about the existing roundabout:

1. There are two entry lanes from Kumaran Rathnam road to the roundabout. According to NAASRA 1993, there should be a circulating lane width of 10.3m for one articulated vehicle and one passenger car to move side by side. However, the circulating width available is less than 9.0m as shown in Figure 3 , feature A.

2. Due to large center island, circulating lanes need considerable deviation from a preferable travel path thus leading to single lane of traffic although the circulating width is sufficient for two circulating lanes. The vehicles turning to Union place from Kumaran Rathnam road has to make three movements in reverse directions as shown in Figure 3, feature B. Two of these movements namely first and last involves almost 90o turns.

3. There is a considerable number of vehicles moving from Sir James Peiris Mawatha to Kumaran Rathnam road which are approximately aligned. Thus, it would be preferable for these vehicles to move in a large radius curve. However, the size of central Island and the arrangement of pedestrian walkways force the drivers to move in a radius of about 12.5m as shown in Figure 3 , feature C.

4. The vehicles moving from Kumaran Rathnam to Sir James Peiris Mawatha also have to follow a similar path although the problem is less serious due to greater width available in front of Union Place as shown in Figure 3, feature D.

5. The drivers entering to the roundabout from Union Place have poor visibility, since the vehicles from Kumaran Rathnam and Kew roads deviate considerably while going round the roundabout. They have to look through almost 90o.

The above weaknesses of then existing geometry warrants a geometric redesign of this roundabout. The following changes can be suggested:

1. Increase the circulating carriageway width to at least 10.3m at all locations.
2. Minimise difficult manoeuvreing required for left turning and straight moving vehicles.

Since the site is restricted, a circulating width of 10.3 m can be provided only by reducing the central island diameter to 20m. However, NAASRA,1993 does not give a circulating width for one articulated and one car to move side by side for a 20.0m diameter. Thus a compromise was necessary which can be reached by considering the type of vehicles using the roundabout.

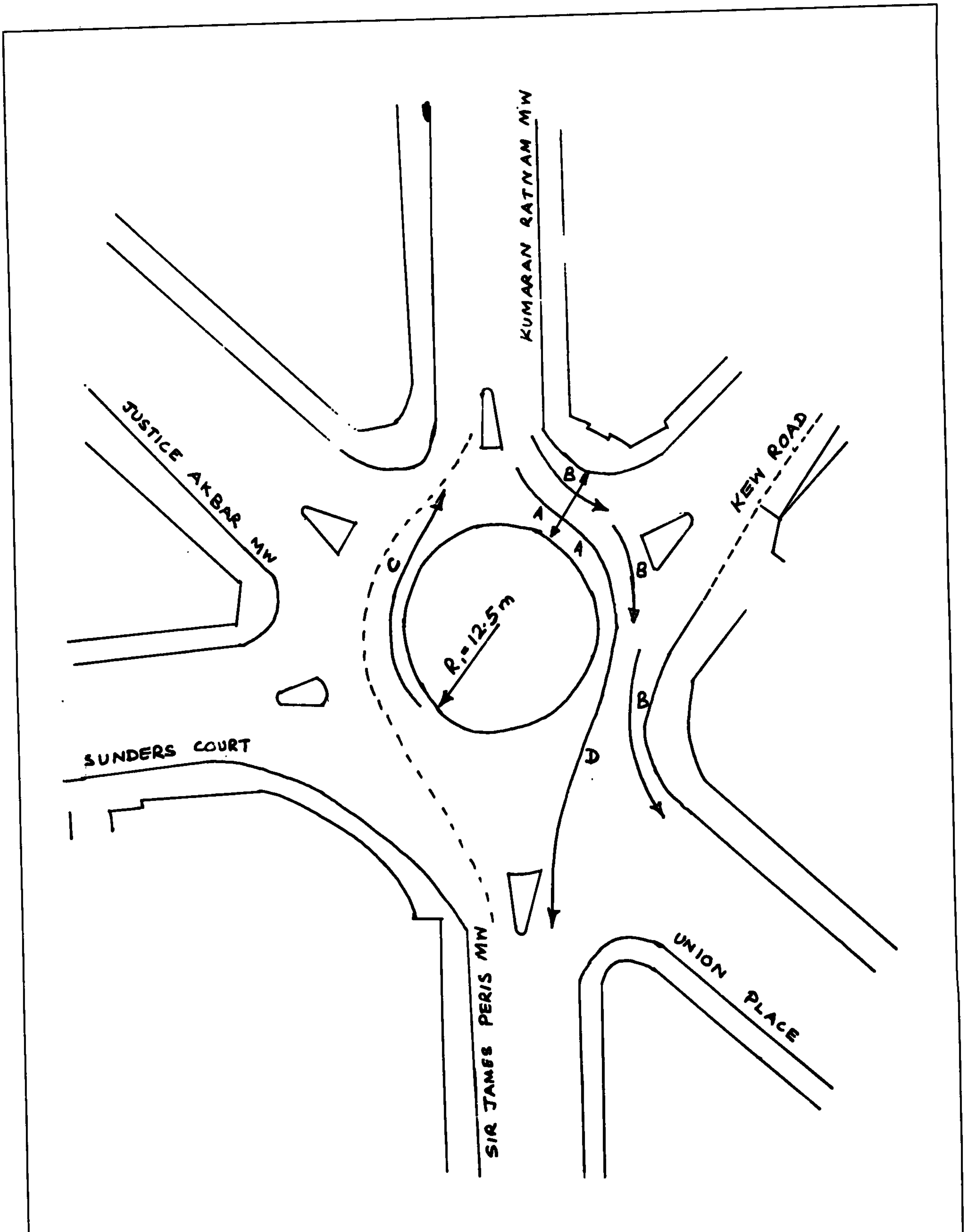
At present, majority of vehicles that use the roundabout consist of cars, vans and buses. However, the buses available in Sri Lanka consist mainly of single door buses which have a length of about 6.0m. These buses can move in small radius curves much easily than articulated vehicles. Therefore, it is suggested to use a circulating carriageway width of 10.3m which gives a circulating single lane width of 5.15m for a bus of width 2.4m. Traffic segregation will be required at this roundabout so that articulated vehicles will be using the outer lane thus those will be moving in a larger radius. The resulting arrangement is shown in Figure 4 which also shows that it would be necessary to acquire certain amount of land from pedestrian pavements to reduce the deviation of vehicles. When large vehicles use this roundabout, those will have to use the outer lane, thus giving a larger radius.

4.1.1 Determination of degrees of saturation and queue lengths

Degrees of saturation can be calculated on the basis of British or Australian methods. The calculations presented here are based on the Australian method since it allows to take account of vehicle speeds and geometry when evaluating the degrees of saturation, delays and queuing lengths. According to the results given in Table 3 degree of saturation for Kumaran Rathnam dominant lane is 1.03 whereas subdominant lane it is 0.78. These would give queuing delay of 99 seconds and 14 seconds respectively. However, it is somewhat unrealistic to have such a different delay in two adjacent lanes since drivers will be changing the lanes and make the queues of equal length irrespective of the lane marking. Once the queuing delay is calculated, the corresponding queue length can be obtained by using the equation 3.7 of NAASRA (1986) which is given below.

Table 3 Summary of degree of saturations

APPROACH		SURVEY 1	SURVEY 2	SURVEY 3
Union Place	Dom	0.80	0.76	0.65
	Sub	0.38	0.385	0.41
James Peris	Dom	0.98	1.004	0.66
	Sub	0.62	1.097	0.726
Sounders Court	Dom	0.041	0.057	0.034
	Sub	0.043	0.026	0.03
Justice Akbar	Dom	0.438	0.37	0.335
	Sub	0.375	0.22	0.333
Kumaran Rathnam	Dom	1.028	0.56	0.617
	Sub	0.775	0.52	0.568
Kew road	Dom	0.482	0.17	0.330
	Sub	0.484	0.15	0.414



Figur 3. Geometric Defiencies at Slave Island Roundabout

Equation 3.7 of NAASRA (1986);

$n_w = w_m Q_m$

where n_w - queue length

w_m - queuing delay

Q_m - traffic flow

The corresponding queuing length for Kumaran Rathnam dominant and sub dominant lanes are

25 veh/sec and 2 veh/sec respectively. This indicates that the segregation of traffic using lane markings should assume that the queue lengths are approximately the same for dominant and subdominant lanes.

It should be noted that the drivers always like to queue in the shortest queue at a roundabout. Therefore, the way that the traffic is segregated using lane markings should comply with the above behaviour. Otherwise drivers tend to ignore the lane markings thus causing unnecessary delays at the roundabout. When analysing the roundabout the following trial and error procedure should be used to determine the way that the traffic will be segregated.

1. Carry out the analysis on the basis of a suitable traffic segregation arrangement. Calculate delays and queuing lengths in each arm.
2. If there is a considerable discrepancy in the queuing length of lanes of approach arm, repeat the calculations until the queue length become more or less equal. Then select the lane markings to suit the above method of traffic segregation.

The degrees of saturation obtained for geometrically improved Slave island roundabout are given in Figure 4, summarised in Table 4.

It can be seen from the above results that the degree of saturation of Kumaran Rathnam road is greater than 1. In the peak time the dominant lane will have 25 vehicle queue and sub dominant lane will have 2 vehicle queue if all through vehicles use the right lane as assumed in the analysis. Therefore it is advisable to allow through traffic on both lanes; left turning on left and right turning on right lane.

Next question is in which proportion the straight vehicles would be divided. If we consider the behaviour of the drivers of vehicles going straight, they would ensure that they are on the shortest queue, which will ultimately lead to the same queue length on both lanes. Therefore the proportion of vehicles on dominant and subdominant lanes should be calculated using trial and error so that the queue length will be the same for dominant and subdominant lanes. Segregation should be ensured by using lane markings and traffic signs. New degrees of saturation at Kumaran Rathnam are 0.94 and 0.83 as shown in the Table 4.

However, even with all these measures, degree of saturation is still high for Kumaran Rathnam road. In this type of situation some other alternatives should be tried; the options include diverting some amount of traffic and having auxiliary left turning lanes.

4.1.2 Further improvements to the geometry with left turning lanes.

As can be seen in Table 3, degree of saturation for Sir James Peiris mawatha is greater than 1. The entry flow from Sir James Peiris Mawatha includes higher proportion of left turning traffic. Therefore, as the next solution to reduce the traffic congestion, it is recommended to have an auxiliary left turn from Sir James Peiris mawatha to Justice Akbar mawatha since

Table 4 Summary of degrees of saturation after adopting the proposed changes

APPROACH		Introducing Auxiliary left lane	Left lane and traffic segregation at K.R
		survey 1	survey 1
Union Place			
	Dom	0.80	0.80
	Sub	0.38	0.38
James Peris			
	Dom	0.648	0.648
	Sub	0.478	0.478
Sounders Court	Dom	0	0
	Sub	0	0
Justice Akbar			
	Dom	0.438	0.438
	Sub	0.375	0.375
Kumaran Rathnam			
	Dom	1.028	0.945
	Sub	0.775	0.828
Kew road			
	Dom	0.482	0.482
	Sub	0.484	0.484

there is a substantial amount of left turning traffic on this approach. The traffic flows are as follows during three periods of time:

From Sir James Peiris Mawatha to Justice Akbar Mawatha

survey	1	2	3
time	2.30-3.25 pm	7.30-8.25 am	9.45-10.40 am
flow	351	757	696

The degree of saturation after introducing the auxiliary lane for the dominant lane of Sir James Peiris mawatha is 0.648 (Table 4). Alternative approach route for vehicles coming to Sounders Court from Union Place, Kumaran Rathnam and Kew road have to be provided. This can be done using other roads at this particular junction.

4.1.3 Further improvements to the roundabout with traffic management measures and geometric changes.

The two methods used to determine the degrees of saturation and delays are based on the performance of existing roundabout. According to BD 16/84, margin of error in British method is + or - 15%. Therefore, it could be possible to have even a greater capacity than the predicted values, using proper traffic management measures and disciplined drivers. The driver behaviour has to be improved with suitable education programmes carried out through national media.

Further improvements may be possible with the following traffic management measures:

1. Segregation of large and small vehicles.

   - large vehicles using left lane unless turning right, thus those will be travelling in a larger diameter.
2. Strategically placing the bus halts with parking bays.
3. Proper location of pedestrian crossings so that pedestrian movement will not obstruct the traffic movement in the roundabout.
4. Widening the entrance to the arm locally.

Guidelines for bus halts and pedestrian movement will have to be determined for Sri Lankan conditions with further studies.

5.0 Conclusions

A properly designed roundabout is safe and an efficient form of intersection control. Roundabouts have been extensively used in United Kingdom, Australia and becoming more popular in Europe and the Asian Continent. Roundabouts have been in existence in Sri Lanka from the colonial days. Due to enormous increase in the traffic in the recent times, most of the existing roundabouts have become congested and is viewed as a cause for delays. In order to overcome these delays, roundabouts should be improved geometrically and also by increasing the number of approach and circulating lanes. These changes should be carried out only after detailed studies. The cost of changes can be evaluated with the other alternatives such as traffic lights.

Two roundabout design methods, which have been developed in Australia and Great Britain, are presently available. These roundabout design techniques deal with geometry, driver behaviour and traffic flows. The Australian method allows a wide range of speeds some of which are quite applicable to speeds in Sri Lanka. In this study, the possible improvements by changing the geometry, left turning auxiliary lanes and traffic diversions have been highlighted. It was shown that at Slave Island roundabout at the time of this study, there were serious geometric shortcomings. It was shown that considerable improvements would be possible by changing the geometry and providing left turning auxiliary lanes when the land use allows it. It is also shown that enlarging the center island of the roundabout unnecessarily may lead to traffic congestion. The importance of improving the alternative traffic routes is also highlighted, since sometimes the amount of traffic can be too much for roundabouts.

The Australian method allows the calculation of queuing lengths and queuing delays. This is particularly advantageous when traffic moving in a certain direction is allowed in more than one lane. The behaviour of drivers under those circumstances would be to form a queue where the length of both dominant and sub-dominant would be almost the same. This means that the capacity should be determined in a trial and error basis where the analysis simulates the actual driver behaviour. Thus, the use of Australian method for the analysis of a roundabout may be more appropriate specially in places like Colombo where the introduction of additional lanes could mean acquisition of land that is very expensive. Thus, the roundabout designer would have to justify his claim with detailed calculations.

The following roundabout analysis steps can be followed when analysing the existing roundabouts:

1. Obtain the traffic and geometric data for the existing roundabout.

2. Check the suitability of existing roundabout geometry considering the following:

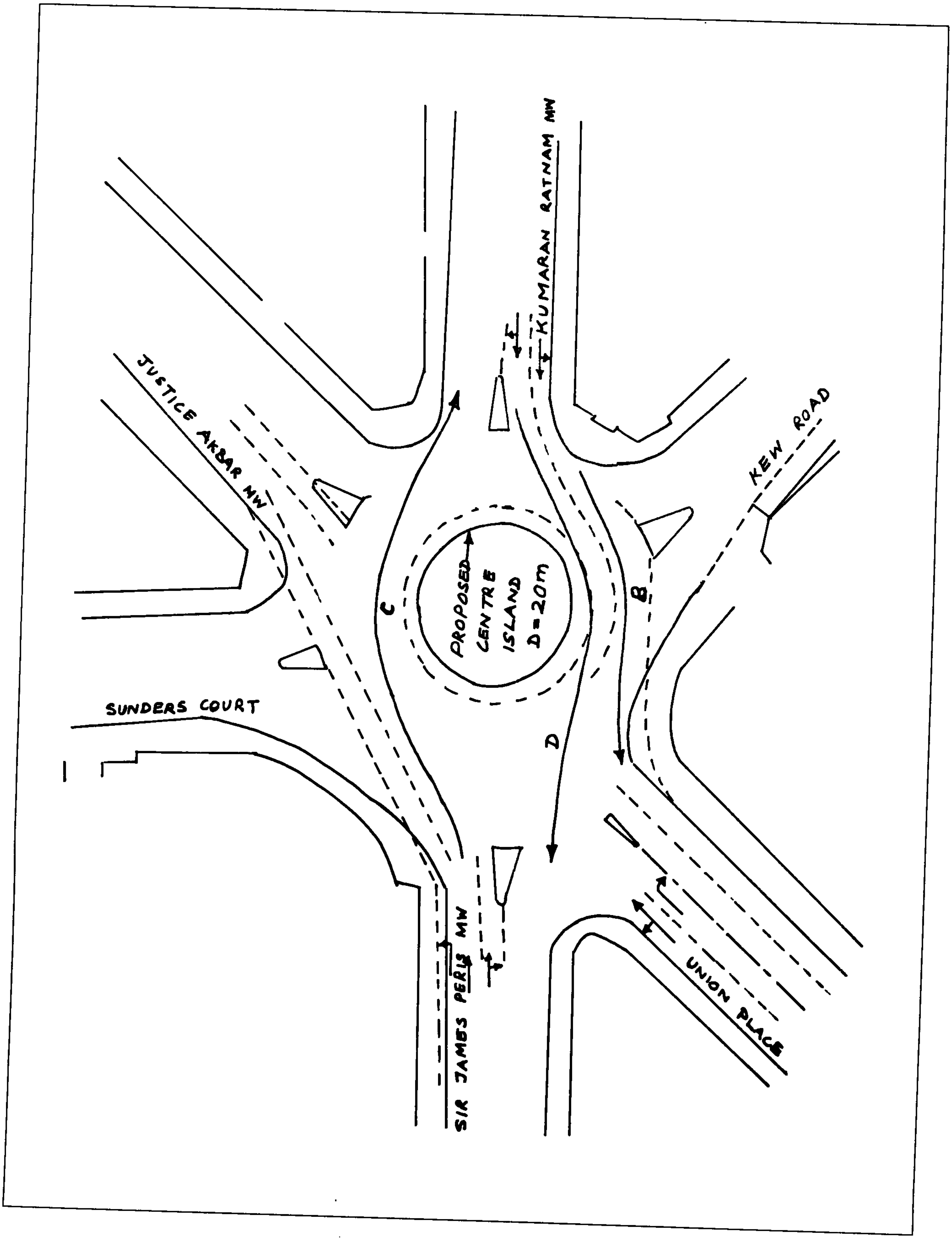


Figure 4. Proposed Gemeric Changes at Slave Island Roundabout

a. Would there be excessive deviations and reverse turns due to geometry.

b. Would the vehicles be forced to follow circulating paths with small radius due to existing geometry and pedestrian pavements.

c. Would the drivers get sufficient visibility when approaching the roundabout and at the give way sign.

3. Check the traffic pattern and determine whether there is tidal flow and large left or right turning flows. If so, provide enough number of approach and circulating lanes for those paths.

4. Calculate the capacity of roundabout at each and every improvement to determine the suitability of improvements.

5. Stop the process when the degrees of saturations are sufficiently low to accommodate future increases of traffic.

6. If it is not possible to reduce the degrees of saturation sufficiently, consider traffic diversions or other intersection control measures like traffic lights.

The above method of roundabout improvements will need a considerable number of detailed calculations. This may prove very tedious with hand calculations. A computer program developed using a spread sheet package could be extremely useful to perform these calculations in a relatively short time.

The calculation techniques and case study presented in this paper could be used as guidance for the improvement of roundabouts in Sri Lanka.

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