ENTRY AND CIRCULATING FLOW RELATIONSHIP AT A ROUNDABOUT

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Abstract: This study examined the two formulas stated in the Arahan Teknik (J) 11/87 of the Malaysian Public Work Department to estimate the capacity of small and conventional roundabouts. Field survey, which cover the roundabout inventories, and vehicle classification were carried out. Vehicle classification survey indicates lower entry flows at the single lane entries compared to the multilane entries for both morning and evening peak hours. Statistical analysis was used to identify the correlation between the circulating flows, entry flows and the entry width. Results showed that the capacity obtained from the weaving concept was generally higher than the regression equations for the single and multi entries. The difference between these results may be due to the regression equations that consider the interaction between the entry and circulating flow and the geometric parameters, while the Arahan Teknik (J) 11/87 only address the geometric parameter. The entry flows for both single and multilane entries were highly dependent on the circulating flows.

Keywords: *Roundabout; Weaving Concept; Circulating Flow; Entry Flow.*

Abstrak: Kajian ini menilai dua rumus dalam Arahan Teknik (J) 11/87 oleh Jabatan Kerja Raya Malaysia, bagi menganggarkan muatan bulatan kecil dan konvensional. Pemerhatian di lapangan termasuk inventori bulatan, dan klasifikasi kenderaan telah dijalankan ke atas beberapa bulatan. Kajian klasifikasi kenderaan menunjukkan paras aliran masuk yang rendah di jalan masuk tunggal berbanding jalan masuk berbilang semasa aliran puncak pagi dan petang. Analisa statistik digunakan bagi mengenal pasti hubungan di antara aliran mengeliling, aliran masuk dan lebar masuk. Keputusan menunjukkan kapasiti yang diperolehi dari konsep menjalin keseluruhan adalah lebih tinggi dari persamaan regresi untuk jalan masuk tunggal dan berbilang. Perbezaan ini mungkin disebabkan oleh persamaan regresi mengambil kira interaksi di antara aliran masuk dan mengeliling serta geometri bulatan, manakala Arahan Teknik (J) 11/87 hanya mengambil kira parameter geometri. Bagi kedua-dua jalan masuk tunggal dan berbilang, aliran masuk sangat bergantung kepada aliran mengeliling.

Katakunci: *Bulatan; Konsep Jalin; Aliran mengeliling; Aliran Masuk.*

1.0 Introduction

Locking is the main problem at a roundabout. Locking arises when vehicles were prevented from exiting by the entering vehicles. The locking phenomenon in a roundabout is shown in Figure 1. The offside priority rule (Kimber, 1980) was then introduced to eliminate the locking effect. This rule states that, the entering vehicles should give way to the circulating vehicles on the right hand side, which already in the roundabout. This concept is eventually the gap acceptance concept where the entering traffic waits for a suitable gap in the circulating traffic stream to enter into the system. This eliminates the locking and the traffic in the roundabout is able to exit easily. It also allows for the design of a smaller roundabout.

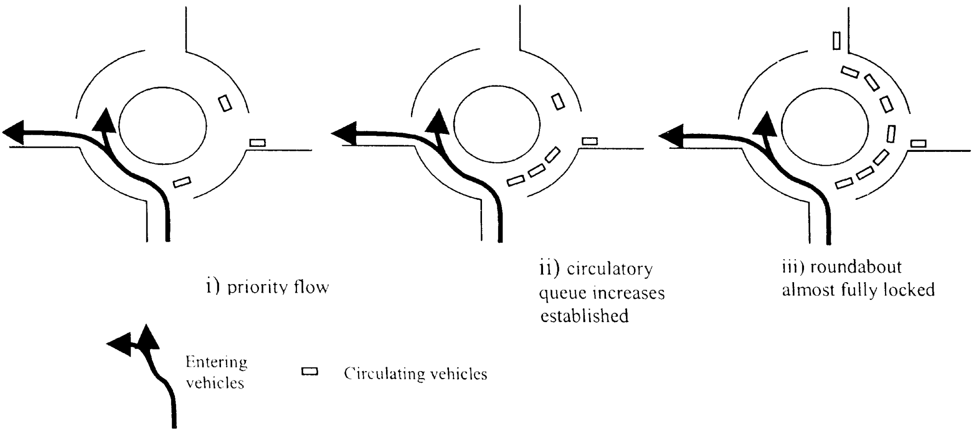

Figure 1: Locking phenomenon at a roundabout

There are numerous roundabouts in Malaysia, particularly in the urban areas. In Kuala Lumpur, most of the major roundabouts are located at the intersections between radial and ring roads. These roundabouts are basically at grade, but gradually upgraded to be of grade separated roundabouts, as the traffic volume increases. For examples, the Jalan Kuching and Jalan Parlimen, Jalan Kinabalu and Jalan Syed Putra and Jalan Maharaja Lela and Jalan Hang Tuah. Apart from the major roundabout in Kuala Lumpur and Petaling Jaya, roundabouts are also commonly used in residential and new townships with good landscape. However, it is observed that the trend of using a roundabout is declining. This may be due to the fact that, a roundabout occupies larger area compares to other types of intersection control. According to Arahan Teknik (J) 11/87 (Jabatan Kerja Raya, 1987), a roundabout can accommodate higher traffic volume than priority junctions. Roundabout also operates efficiently if the total traffic on the two-way major roads and heavier on the minor roads of less than 5,000 vehicle per hour (vph). Table 1 shows the guidelines for selecting the type of intersection control. A designer should carry out a detail study to select the appropriate type of intersection, as signalized control is only able to accommodate a slightly higher traffic volume. The performance of an intersection with respect to delays, queue length, construction and land cost should be taken into consideration when selecting the type of intersection control.

Table 1: Guidelines for selecting the type of intersection control (Arahan Teknik (J) 11/87)

Intersection	Total of two way traffic on major road and heavier approach volume on minor road (vph)							
Type		1000	2000	3000	4000	5000	6000	7000
Stop Control	────	──▶						
Signalized Intersection		◀──	────	────	────	──▶		
Interchange				◀──	────	────	────	────
Roundabout	────	────	────	────	────	──▶		

Source (Jabatan Kerja Raya, 1987)

The formula for calculating the capacity of a roundabout can be referred to the Arahan Teknik (J) 11/87. The formula for estimating the capacity of a conventional roundabout is based on the weaving section, which is no longer appropriate in view of the offside priority rule. The capacity for a small roundabout is based on the simplified equation, which only considers the geometric parameters of the roundabout. This equation shows the overall performance of the roundabout, which in reality will always vary due to the traffic characteristics and volume on each arm.

Based on the weaving concepts, there are three types of roundabout that are commonly used (Ashley, 1994). These are:

a) Conventional roundabout - Weaving section is provided along the large central island. The diameter of the central island exceeds 25 m and the approaches are normally not flared.
b) Small roundabout - The diameter of small central island varies from 4 m to 25 m. The approaches are normally flared to allow for multiple entries.
c) Mini roundabout - The diameter of the central island is less than 4 m and the central island is usually flush or slightly raised above the road to allow some vehicle movement deflection.

With the introduction of offside priority rule, the designed are now based on the gap acceptance method. The classification of roundabout was redefined as follows:

a) Normal roundabout - The diameter of the central island is greater than or equal to 4 m. Usually, flared approach is provided on all arms to allow for multiple entries and to improve the capacity of the roundabout.
b) Mini roundabout - The definition is similar to the mini roundabout definition by weaving concepts. The diameter of the central circle is less than 4 m. The central island may be flush with the road surface or slightly raised by a maximum of 125 mm to facilitate the swept path of larger vehicles in the roundabout.
c) Double roundabout - Double roundabout is formed when two normal or mini roundabouts are placed within the same intersection. These two normal roundabout are linked by a central link road or kerb island. Double roundabout is suitable for the improvement of existing staggered intersection without realigning the approach roads.

The objectives of the study are: i) to establish a relationship between the maximum entry flows at the entry approach and the size of roundabout as stated by Arahan Teknik (J) 11/87, ii) to verify the capacity calculation by Arahan Teknik (J) 11/87, and iii) to assess the maximum entry flows at the entry approach of roundabout based on the traffic interaction and geometric parameters.

Presently, the Arahan Teknik (J) 11/87 does not specify the capacity calculation in relation to the diameter of the central circle as defined by other guidelines such as Australian roads and Transport Road Research Laboratory, U.K. The results will be useful to designers in selecting the types of roundabout based on the individual entry approach. It is also essential to assess the capacity of a roundabout in terms of entry capacity. As the traffic differ on each arm, it is appropriate to determine the entry capacity based on the traffic interaction and geometric parameters.

2.0 Development of Capacity Analysis

Wardrop (1957) developed empirical formula to estimate the capacity of a roundabout based on the weaving section. This capacity estimation relied on the geometric parameters including the shape and size of the roundabout. This equation also include the proportion of traffic require to weave and the heavy good vehicles. In the calculation, it is assumed that the entry to the roundabout has no major effect to the capacity. The most important traffic parameter is only the proportion of traffic requires to weave, (p) in the weaving section. The capacity based on isolated weave section developed by Wardrop (1975) is:

$$q = \frac{105w(1+\frac{e}{w})(1-\frac{3w}{4l})(1-\frac{p}{3})}{(l+1.8h)} \quad (1)$$

where q is capacity of the weaving section in pcuhr^{-1}; e is average effective entry width; w is the width of the weaving section; l is the length of the weaving section; p is the proportion of the weaving traffic, and h is the proportion of heavy vehicles.

By introducing the offside priority rule, the traffic interaction has changed fundamentally. The traffic at the entry has to give way to the traffic on the right, and based on the acceptable gap in circulation, may enter the roundabout without weaving.

The early capacity calculation for roundabout operating with offside priority rule was expressed in term of full capacity. Blackmore (1971) developed a formula in estimating the full capacity, which is based on the basic road width and the area of widening at the intersection.

This equation only provides an overall estimate of the capacity, which does not show the individual entry arm. The equation is as follows (Perdoza, 1977):

$$q = k\left(\sum w + a^{\frac{1}{2}}\right) \quad (2)$$

where q is full capacity of any four arms roundabout in pcuhr^{-1}; Σw is the sum of the basic road width; a is the area of widening of the roundabout, and k is constant.

The entry capacity of a roundabout was developed in considering the variability of vehicle interaction at each arm and is termed as the maximum number of vehicles that able to enter into the circulatory stream from an entry approach. Department of Transport (1984) has developed an acceptable equation based on the geometric and the gap acceptance behaviour. The effect of heavy goods vehicles (HGV) is also an important parameter in capacity calculation.

Troutbeck (1993) shows that the effect of HGV is significance if the percentage exceeds 5% in the traffic stream. The traffic composition factor is given by:

$$f_c = 1 + (p_{HV} - 0.05)(e_{HV} - 1) \quad (3)$$

where f_c is traffic composition factor; p_{HV} is the proportion of HGV (>5%), and e_{HV} is passenger car unit of a heavy vehicle (between 1.5 and 2).

2.1 Capacity Analysis in Malaysia

The classification is similar to the weaving section design concept. The recommendation of the type of roundabout is entirely based on the size of the roundabout. The equations are shown below:

a) Conventional Roundabout (Arahan Teknik (J) 11/87)

$$Q_p = \frac{160W\left(1+\frac{e}{W}\right)}{1+\frac{W}{L}} \qquad (4)$$

where Q_p is capacity of the weaving section (vph); W is the width of weaving section (m); e is average entry width (m), and L is the length of weaving section (m).

b) Mini and small roundabout (Arahan Teknik (J) 11/87)

$$Q_p = K\left(W+\sqrt{A}\right) \qquad (5)$$

where Q_p is the capacity of whole intersection (vph); W is the sum of basic full widths of all approaches (m); A is area added to basic intersection by flared approaches (m^2), and K is specific factor relies on the type of roundabout and number of legs.

The equations for capacities estimation basically provide an overall capacity. The guidelines also do not show the capacity of the roundabout or the entry capacity. It should have taken into consideration the gap acceptance behaviour, entry-circulating flow relationship and the individual entry capacity.

3.0 Study Approach

This study requires the collection of data passing the entry approach and circulating traffic. The following exercises have been carried out to fulfill the stipulated objectives. They are to determine the appropriate locations and time for data collection; to organize a team of competent observers; to adopt the appropriate method for recording the data accurately and to analyze and deduce the conclusions from the observed data.

The stipulated objectives require the following roundabout criteria; at grade and four arm roundabout; should not be a signalized roundabout; the traffic volume on each approach should be reasonably high; at least 240m away from any existing junction and no effect of slope. Based on the selection criteria the following roundabouts (Table 2) have been chosen:

Table 2: The selected study locations

Site No	Locations
A	Jalan Selangor/Jalan Templer
B	Jalan 14/47/Jalan 51A/227
C	Jalan SS4a/1/Jalan SS3/39
D	Persiaran Hishamuddin/Persiaran kayangan

4.0 Data Presentation

4.1 Geometric and Traffic Data

Table 3 provides the geometric data of the roundabout. The traffic volumes observed during the morning peak are shown in Table 4. The volume ranges between 248 and 1798 vph. The volume for evening peak hour is shown in Table 5. The flow during the peak hour ranges between 247 and 1724 vph. Theoretically, the single lane entry and circulation will have less traffic volume. However, sites A and C seemed to have no effect on the number of lanes compare to multilane entry

The traffic compositions during the morning and evening peak hour are shown in Table 6. As expected, a high proportion of passenger cars and taxis were recorded against other vehicles. This is because the study sites are located in residential areas.

Table 3: Summary of the geometric data at selected roundabouts

Direction	Geometric parameter	Roundabout			
		A	B	C	D
	Diameter (m)	48	34	85	92.5
North/South	No of entry lane	2	1	2	2
	Entry width (m)	11.1	6.0	7.2	12.8
	No of circulating lane	1	1	1	2
	Circulating width (m)	9.8	9.0	8.0	11.5
	Weaving width (m)	9.8	9.0	8.0	11.50
	Weaving length (m)	32.50	27.0	53.0	63.0
East/West	No of entry lane	3	1	1	2
	Entry width (m)	11.75	6.0	6.5	12.8
	No of circulating lane	1	1	1	1
	Circulating width (m)	9.8	9.0	8.0	11.5
	Weaving width (m)	9.8	9.0	8.0	11.5
	Weaving length (m)	32.5	27.0	53.0	58.0

Table 4: Summary of entry flow and circulating flow during morning peak

Direction	Morning Peak Hour Traffic			
	7:00 A.M – 8:00 A.M		8:00 A.M – 9:00 A.M	
	Circulating (vph)	Entry (vph)	Circulating (vph)	Entry (vph)
Site A				
Northbound	1033	1050	811	1272
Eastbound	863	1232	1082	1392
Southbound	1296	783	1398	1012
Westbound	544	1674	681	1798
Site B				
Northbound	372	1066	447	1060
Eastbound	829	248	856	348
Southbound	214	789	349	847
Westbound	411	939	846	651
Site C				
Northbound	833	1083	1114	1067
Eastbound	674	434	1040	672
Southbound	971	846	1244	866
Westbound	1191	651	1339	1015
Site D				
Northbound	922	877	1319	812
Eastbound	820	1389	1011	1303
Southbound	1378	492	2084	337
Westbound	827	1344	1157	1305

5.0 Statistical Analysis

Statistical analysis was used to identify the correlation between the dependent and independent variables for the entry and circulating flows.The entry-circulating relationship described the effect of vehicle-vehicle interaction that takes place at the entry. This interaction relies on the gap in the circulating traffic. Kimber (1980) has shown that this relationship is in the form of linear relationship. Linear regression has been performed on the entry and circulating flow. The analysis has been sub-divided into the single lane and multilane (two or more lanes) entry.

5.1 Multi-Lane Entry

The regression results on these data are shown in Table 7. The intercept is between 2 278.9 $pcuhr^{-1}$ and 2 462.1 $pcuhr^{-1}$. The intercept for overall entry flow is also lower than the individual peak hour, which is only 2 044.9 $pcuhr^{-1}$.

Table 5: Summary of entry flow and circulating flow during evening peak

Direction	Evening Peak Hour Traffic			
	4.30P.M – 5:30 P.M		5.30 P.M – 6.30 P.M	
	Circulating (vph)	Entry (vph)	Circulating (vph)	Entry (vph)
Site A				
Northbound	1079	1341	891	1469
Eastbound	1172	1267	1386	1452
Southbound	1313	744	1685	994
Westbound	1252	1074	1068	1724
Site B				
Northbound	296	976	162	985
Eastbound	256	807	237	767
Southbound	328	587	537	485
Westbound	786	247	875	358
Site C				
Northbound	669	1431	674	1568
Eastbound	967	407	1182	445
Southbound	324	510	221	503
Westbound	1281	686	1372	892
Site D				
Northbound	1052	1052	1300	1100
Eastbound	1173	1327	1403	1336
Southbound	1465	514	2200	422
Westbound	887	1516	1049	1700

Table 6: Traffic compositions on the observed roundabouts

Vehicle Class	Entry Flow (%)	Circulating Flow (%)
Motorcycles	15.2	15.2
Cars	81.6	81.8
Light trucks	2.2	1.9
Heavy trucks	0.3	0.4
Buses	0.7	0.7

Table 7: Summary of the regression analysis on multi-lane entry

Parameter	7:00 – 8:00 A.M	8:00 – 9:00 A.M	4:30 – 5:30 P.M	5:30 – 6:30 P.M	Average
Slope	-1.2997	-0.9482	-1.1597	-0.8478	-0.7743
Intercept	2 337.9	2278.9	2 462.0	2 391.3	2 044.9
R^2	0.8180	0.8122	0.6527	0.7439	0.5037
Standard Deviation	291.4	362.1	272.9	415.1	347.6

5.2 *Single Lane Entry*

The regression results on these data are shown in Table 8. The intercept values were between 954.0 $pcuhr^{-1}$ and 1325.6 $pcuhr^{-1}$.

Table 8: Summary of the regression analysis on single-lane entry

Parameter	7:00 – 8:00 A.M	8:00 – 9:00 A.M	4:30 – 5:30 P.M	5:30 – 6:30 P.M	Average
Slope	-1.2159	-0.7096	-0.7681	-0.5352	-0.6481
Intercept	1325.6	1258.6	1,035.1	954.0	1,061.1
R^2	0.7197	0.5224	0.7380	0.7297	0.5268
Standard Deviation	303.2685	269.5343	308.3439	349.8315	302.7427

5.3 *Linear Regression Equations*

Figures 2 and 3 show the scatter plots for the entry and circulating flow for the multi and single lane entry. Based on the linear regression, the relationships between the entry and circulating flow for both the single and multi-lane were derived as follows:

Multi-lane: $Q_e = -0.7743Q_c + 2{,}044.9$ (6)

Single lane: $Q_e = -0.6481Q_c + 1{,}061.2$ (7)

where Q_e is the maximum entry flow in $pcuhr^{-1}$ and Q_c is the maximum circulating flow in $pcuhr^{-1}$.

The average maximum entry flows can be achieved if there is no circulating flow on the circulating path. Thus, the approximate maximum entry flow for single lane entry was 1061.2 $pcuhr^{-1}$ and 2044.9 $pcuhr^{-1}$ for the multilane entry. The above two regression results indicate that the range of standard deviation for the single lane entry was generally lower than the multi lane entry. This is also similar for the slope and intercepts. The correlation results, either for the single or the multi lane showed high interactions between the entry and the circulating volume.

Table 9: Results of capacity analysis based on Arahan Teknik (J) 11/87

Direction	Entry capacity at each arm of the site (vph)			
	Site A	Site B	Site C	Site D
Northbound	2,489 (2L-11.10)	1,980 (1L-6.00)	2,169 (2L-7.20)	3,200 (2L-12.80)
Eastbound	2,529 (3L-11.75)	1,980 (1L-6.00)	2,120 (1L-6.50)	3,158 (2L-12.80)
Southbound	2,489 (2L-11.10)	1,980 (1L-6.00)	2,169 (2L-7.20)	3,175 (2L-12.80)
Westbound	2,529 (3L-11.75)	1,980 (1L-6.00)	2,176 (2L-7.30)	3,139 (2L-12.80)
Total	10,036	7,920	8,634	12,672

Note: (2L-11.10) = (number of entry lane – width of the entry carriageway in meters)

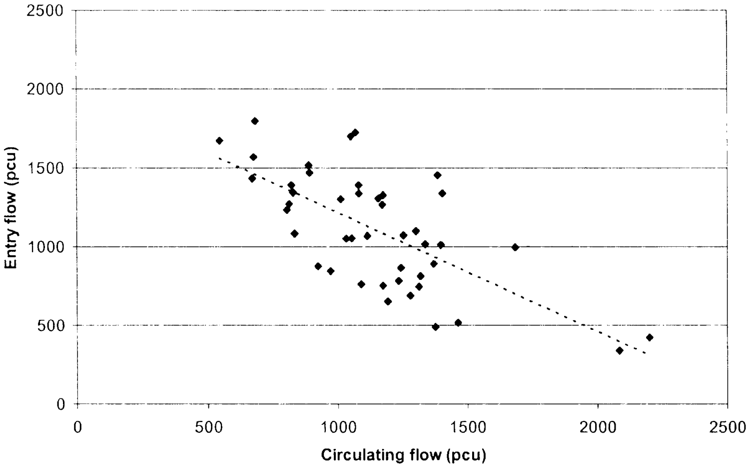

Figure 2. The scatter plots for entry and circulating flow at multi lane entry

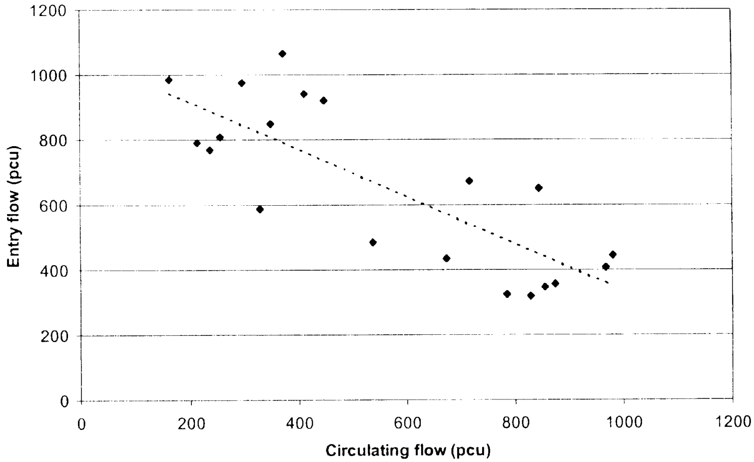

Figure 3. The scatter plots for entry and circulating flow at single lane entry

5.4 *Predicted Entry Capacity by Arahan Teknik (J) 11/87*

The capacity estimation for the observed sites following the Arahan Teknik (J) 11/87 is shown in Table 9. This estimation is based on the weaving section, which did not take into consideration of the interaction between the entry and the circulating flow.

5.5 *Comparison of the Maximum Entry Flow*

The entry capacities obtained from the regression equations on the single and multi lanes entries were compared with those calculated from Arahan Teknik (J) 11/87 equation and shown in Table 10. The regression equations yield a lower entry capacity values compared to the Arahan Teknik (J) 11/87. The difference between the two results may be due to the regression equations consider the interaction between the entry and circulating flow and the geometric parameters, while the Arahan Teknik (J) 11/87 only address the geometric parameter.

Table 10: Comparison on the entry capacity

Type of entry	Regression (pcu/hr)	Arahan Teknik (J) 11/87 (pcu/hr)	Difference (%)
Single	1061	1980	46
Multi	2044	2120-3175	22

6. Conclusion

It is highlighted that the capacity calculation by the JKR Arahan Teknik is based on entry capacity at the weaving section only. This capacity calculation has not taken into consideration the vehicle interaction and strictly based on the geometric parameters such as entry width, weaving length etc. The gap acceptances have been widely used in capacity analysis in the U.K. and Australia, hence it is appropriate to review the capacity estimation for roundabouts in Malaysia.

References

Ashley, C.A. (1994) *Traffic and Highway Engineering for Developments*. Blackwell Sci. Pub.

Blackmore, F.C. (1971). Experiment at Brook Hill Roundabout Sheffield Yorkshire. *TRRL Report LR* 562, Transport and Road Research Laboratory, Department of the Environment, UK.

Jabatan Kerja Raya Malaysia (1987) Arahan Teknik (Jalan) 11/87 – A Guide to the Design of at-Grade Intersections, Cawangan Jalan, Ibu Pejabat J.K.R.

Kimber, R.M. (1980) The traffic capacity of roundabouts. Transport and Road Research Laboratory, *TRRL Laboratory Report* 942, Department of Environment, Department and Transport, UK

Perdoza, J. (1977) Traffic Delays at Road Junction – A Literature Survey. Wooten, Jeffreys and Partners, Department of the Environment, UK

Troutbeck, R.J. (1993) Effect of heavy vehicles at Australian circles and unsignalized Intersections. *Transportation Research Record* No 1398, Transportation Research Board, National Research Council.

Wardrop, J.G. (1957). The traffic capacity of weaving sections of roundabout. Proceedings of the First International Conference on Operational Research. Oxford English University Press.