

SPEED CONTROL AT ROUNDABOUTS – USE OF MAXIMUM ENTRY PATH RADII

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ABSTRACT

Austrroads (1993) 'Guide to Traffic Engineering Practice – Part 6 – Roundabouts' provides the current national criteria for controlling speeds through roundabouts. This is achieved by the provision of 'deflection', which is measured as a maximum vehicle path radius of 100m through the circulating carriageway. This method of speed control is based on 1975 design recommendations by the UK Department of the Environment.

The current practice in the UK Department of Transport 'Design Manual for Roads and Bridges' provides speed control on the entry curve in lieu of the circulating carriageway. USA and Queensland also have criteria for speed control through roundabouts. This includes setting maximum values of the vehicle speed on the entry curve (and subsequent entry path radii). No mandatory speed control criterion is given for the circulating carriageway.

This paper proposes a method for speed control at roundabouts based on setting maximum values of entry path radii for roundabouts, in lieu of the current Austrroads deflection criteria. The method uses the results of a Queensland study of roundabouts titled 'Relationship between Roundabout Geometry and Accident Rates'.

INTRODUCTION

The purpose of this paper is to detail the development of new criteria for the control of speed through roundabouts.

This paper initially reviews current methods for the control of speeds through roundabouts in Australia, the UK, the USA and in Queensland. For each method, the potential effectiveness in reducing accident rates and the amount of work required to calculate the relevant design criteria are compared. A new method for the control of speeds at roundabouts is then presented, which sets maximum entry path radii for the design of new roundabouts. In association with these values, minimum central island radii are also provided.

Accident studies from throughout the world have identified that similar accident types occur at roundabouts. A Queensland study of roundabouts (Arndt, 1998) placed accidents into the following categories and these are referred to in this paper:

- Approaching Rear-End – two vehicles collide in a rear-end type accident on the entry curve.
- Entering/Circulating – an entering driver fails to give way and collides with a vehicle on the circulating carriageway.
- Single Vehicle – a driver of a vehicle loses control and either collides with part of the roundabout, or overturns.
- Exiting/Circulating – an exiting vehicle, driving from the inner circulating lane attempts to cross onto a departure leg and collides with a vehicle on the outer circulating lane which is continuing to circulate around the roundabout.
- Sideswipe – a collision between two vehicles travelling on a different path but in the same direction.

Some of the geometric elements of a roundabout described in this paper are shown in Figure 1.

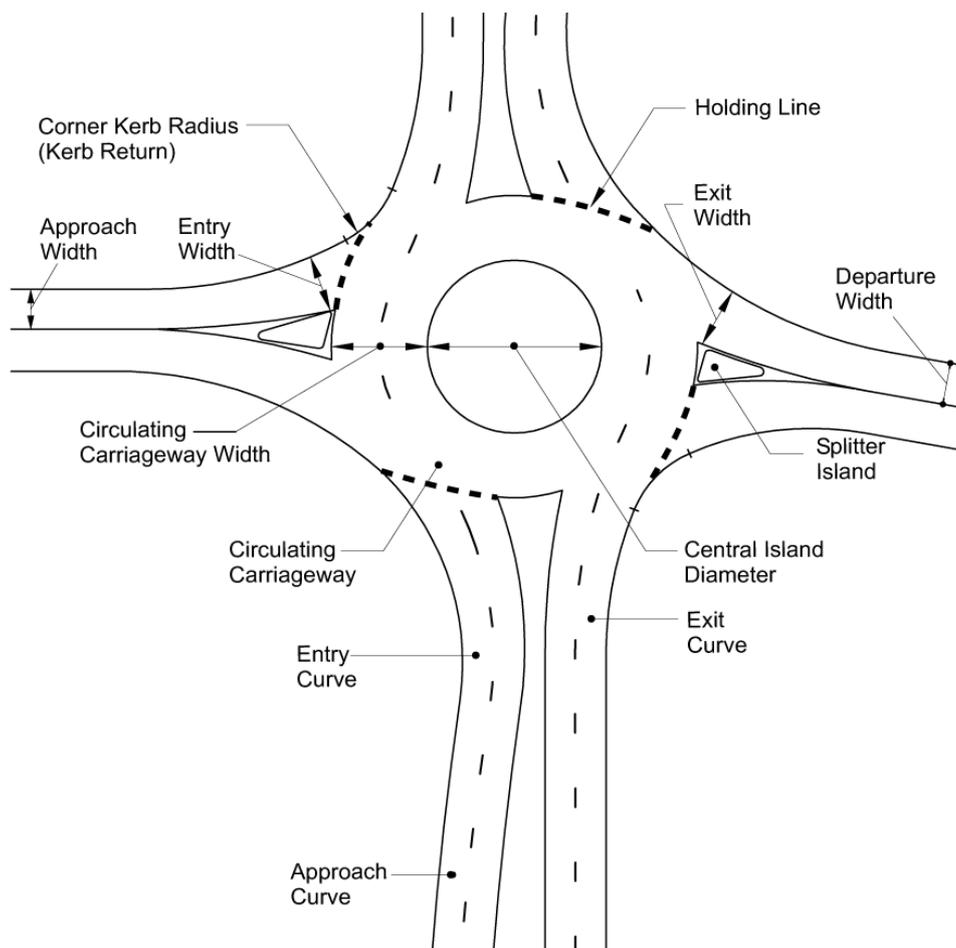


Figure 1 – Geometric Elements of a Roundabout

CURRENT METHODS FOR THE CONTROL OF SPEEDS THROUGH ROUNDABOUTS

This section details the current methods for controlling speeds through roundabouts used in Australia (the national approach), the UK, the USA and in Queensland.

Australian Method

The current national method of controlling speeds through roundabouts is given in Austroads (1993) 'Guide to Traffic Engineering Practice – Part 6 – Roundabouts'. This is achieved by the provision of 'deflection', which is measured as a maximum vehicle path radius of 100m through the circulating carriageway, given a number of parameters. This method of speed control is based on 1975 design recommendations by the UK Department of the Environment (UKDOE, 1975). A diagram of the deflection criteria for a single lane roundabout is given in Figure 2.

The aim of the maximum radius of 100m is to limit the driver speed through the circulating carriageway of the roundabout in order to minimise Entering/Circulating vehicle accidents.

UK Method

The method of using deflection through the circulating carriageway in UKDOE (1975) is no longer used in the United Kingdom. The current method for controlling speeds at roundabouts is to limit the maximum radius of the entry path curve to 100m, instead of the vehicle path on the circulating carriageway. Clauses 7.25 to 7.29 of Sub-section 7 of Part 3 of Section 2 of Volume 6 of the UK Design Manual (UKDOT, 1993) detail the requirements.

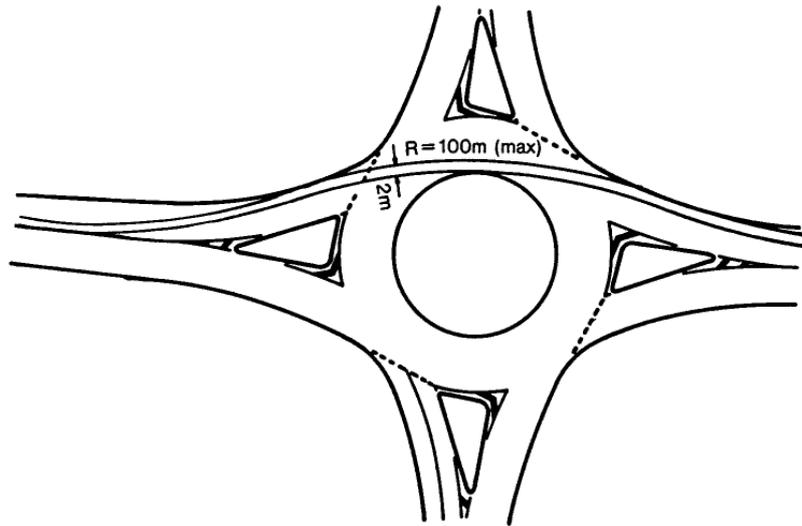


Figure 2 - Deflection Criteria for a Single Lane Roundabout (Austroads, 1993)

Figure 7/11 of UKDOT (1993) details the construction of the entry path curve (refer Figure 3). In this diagram, the entry path curve is shown from point X to point Y and the radius of this path must be limited to 100m.

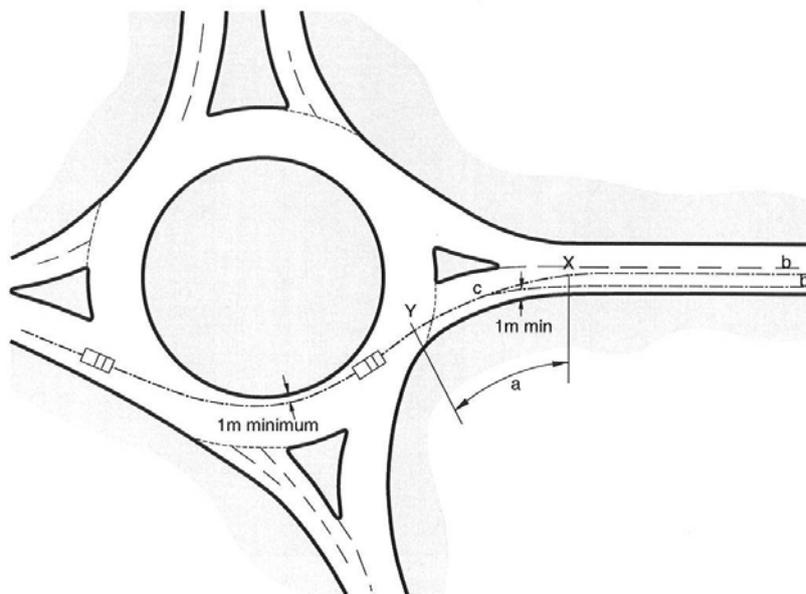


Figure 3 - UK Method of Determination of the Entry Path Curve (UKDOT, 1993)

The entry path curve for single and multi-lane roundabouts is the largest radius that can be drawn through the entry curve, based on given offsets to the lane edges. For multi-lane entries, the path cuts across all lanes. The exact path drawn is subject to personal judgement.

A UK study (Maycock and Hall, 1984) identified that entry path radius was a very important predictor of accidents at roundabouts. An entry path radius of approximately 70m for parallel entries of 5m width and approximately 30m for an entry flaring from 5m to 15m was found to produce minimum total accident rates. Refer to Figure 4 for a diagram of the entry path radius and entry width terms. Evidently, although UKDOT (1993) did adopt criteria for limiting the maximum radius of the entry path curve in lieu of the original deflection criteria, it did not adopt the optimum values found by Maycock and Hall (1984).

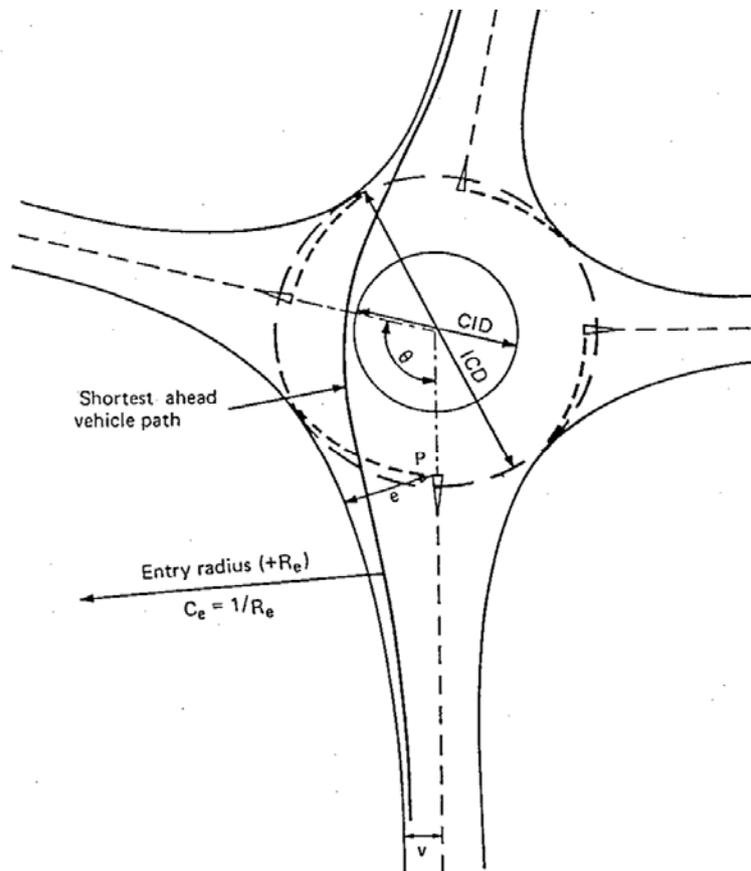


Figure 4 – Diagram from Maycock and Hall (1984) showing Various Geometric Terms (C_e = entry path curvature, e = entry width, v = approach half-width, θ = angle between arms, ICD = inscribed circle diameter, CID = central island diameter)

USA Method

Section 6.2.1 of the USA document 'Roundabouts: An Informational Guide' (FHWA, 2000) provides the following criteria for speed control through roundabouts:

- Maximum entry design speeds for various types of roundabouts (Exhibit 6-4 of FHWA [2000]). These criteria are shown in Table 1. The maximum speeds vary from 25km/h to 50km/h. The model is intended to minimise the relative speed between conflicting traffic streams (especially entering/circulating and exiting/circulating streams).
- A speed consistency model which limits the decrease in speed between successive horizontal elements to 20km/h to minimise single vehicle accidents (Section 6.2.1.5 of FHWA [2000]). Exhibit 6-13 of FHWA (2000) (shown in Table 2) gives maximum entry path radii to ensure that the decrease in speed between entering vehicles and right turning vehicles is limited to 20km/h. Vehicle path symbols in Exhibit 6-13 are explained in Exhibit 6-12 (refer Figure 5).

Table 1 - USA Criteria for Maximum Entry Design Speeds (FHWA, 2000)

Site Category	Recommended Maximum Entry Design Speed
Mini-Roundabout	25 km/h (15 mph)
Urban Compact	25 km/h (15 mph)
Urban Single Lane	35 km/h (20 mph)
Urban Double Lane	40 km/h (25 mph)
Rural Single Lane	40 km/h (25 mph)
Rural Double Lane	50 km/h (30 mph)

Table 2 - USA Criteria for Maximum Entry Path Radii to Limit the Decrease in Speed between Entering Vehicles and Left Turning Vehicles to 20km/h (FHWA, 2000)

Inscribed Circle Diameter (m)	Approximate R_1 Value		Maximum R_1 Value	
	Radius (m)	Speed (km/h)	Radius (m)	Speed (km/h)
Single-Lane Roundabout				
30	11	21	54	41
35	13	23	61	43
40	16	25	69	45
45	19	26	73	46
Double-Lane Roundabout				
45	15	24	65	44
50	17	25	69	45
55	20	27	78	47
60	23	28	83	48
65	25	29	88	49
70	28	30	93	50

USA Vehicle Path Model

To calculate speed values for a particular roundabout to compare to the maximum design values above, the following are provided:

- A vehicle path model as given in Section 6.2.1.3 of FHWA (2000).
- A speed prediction model as given in Section 6.2.1.4 of FHWA (2000).

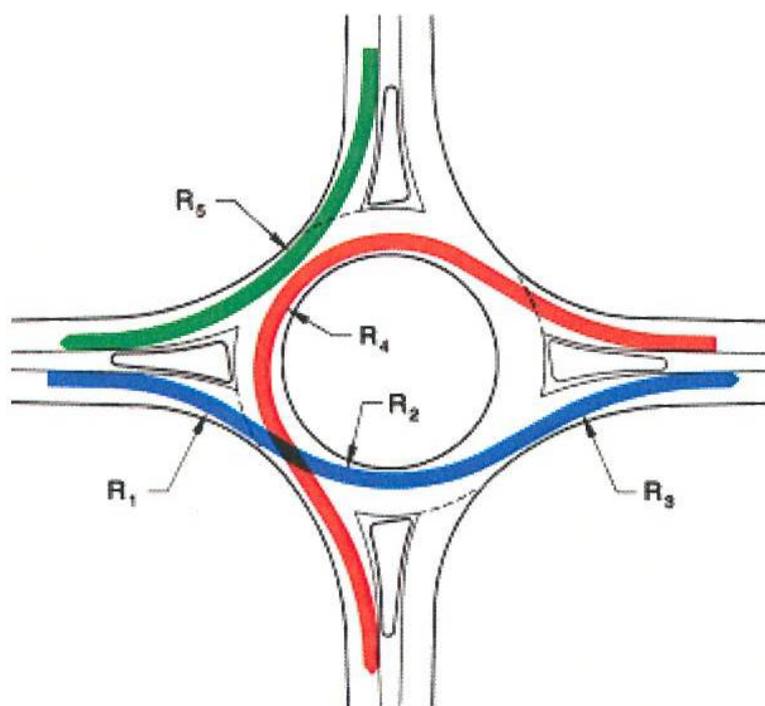


Figure 5 - USA Symbols used for Vehicle Path Radii (FHWA, 2000)

The vehicle path model is based on the following:

- For single and multi-lane roundabouts, a continuous vehicle path through the roundabout comprising the largest radius possible on each horizontal element, based on offsets to the lane edges. For multi-lane entries, the path cuts across all lanes on the circulating carriageway.
- Paths are drawn for all movements (right, through and left).
- The exact path drawn is subject to personal judgement.

USA Speed Model

The speed model is based on the point mass formula (refer Equation 1 below) and values of the side friction factor as documented in the AASHTO document 'A Policy on Geometric Design of Highways and Streets' (AASHTO, 1994). The speed model is not based on actual measurements of vehicle speeds at roundabouts.

$$V^2 = 127 \times R \times (e + f) \quad \text{Equation 1}$$

Where

V = design speed (km/h)

R = radius (m)

E = superelevation (m/m)

f = side friction factor

Queensland Method

Section 14.8 of the Queensland Department of Main Roads 'Road Planning and Design Manual' (QDMR, 2006) provides the following speed control limits at roundabouts:

- A maximum entry speed of 60km/h to minimise Approaching Rear-End vehicle accidents.
- A maximum decrease in speed between successive horizontal elements of 20km/h to minimise Single Vehicle accidents (30km/h allowed for a right-turn movement from the entry curve to the circulating carriageway).
- A maximum relative speed between entering and circulating vehicles of 50km/h to minimise accidents between these vehicle streams.
- A maximum relative speed between exiting and circulating vehicles of 35km/h to minimise accidents between these vehicle streams. Criterion is for multi-lane roundabouts only.
- A maximum difference in potential side friction of 0.7 (a measure of the degree that drivers will cut lanes on a multi-lane roundabout leading to higher Sideswipe vehicle accidents). Criterion is for multi-lane roundabouts only.

The above criteria were the outcomes of a major study of roundabouts in Queensland (Arndt, 1998). A summary of the findings is given in Arndt (2001). A mathematical relationship between each of the speed parameters listed above and the associated accident types was established in the study. The maximum values of the speed parameters were considered to be an appropriate balance between minimising the rates of each of the accident types and achieving a practical layout.

Arndt (1998) found that greater deflection (measured according to the Austroads (1993) deflection method) did lower Entering/Circulating vehicle accident rates. However, providing tighter entry path radii had a much greater influence in lowering Entering/Circulating accident rates, in addition to lowering Approaching Rear-End and Exiting/Circulating vehicle accident rates. In fact, out of all of the geometric parameters used in the study, the entry path radius was found to have the most effect in lowering overall accident rates.

To calculate speed values for a particular roundabout to compare to the maximum values above, QDMR (2006) provides the following:

- A vehicle path model as given in Appendix 14B of the manual.
- A speed prediction model as given in Appendix 14B of the manual.

Queensland Vehicle Path Model

The vehicle path model requires paths to be drawn for most movements through the roundabout as follows:

- For single lane roundabouts, a continuous vehicle path through the roundabout comprising the largest radius possible on each horizontal element based on offsets to the lane edges. Figure 14.31 of QDMR (2006) provides such details for a through movement, as shown in Figure 6.
- For multi-lane roundabouts, three separate vehicle path types are drawn. These include staying in the right lane, staying in the left lane, and cutting across lanes. All are based on a continuous vehicle path through the roundabout based on offsets to the lane edges. Figure 14.33 of QDMR (2006) provides details of the construction of vehicle paths for the right lane of multi-lane roundabouts for the through movement, as shown in Figure 7.
- Paths are drawn for through and right turn movements only (ie no left turn movements are drawn).
- The exact path drawn is subject to minimal personal judgement, as the construction technique is fully outlined.

Queensland Speed Model

The speed model is based on a modified version of the original Austroads speed environment model for rural roads. It was modified to predict speeds on small radius horizontal curves in high speed environments. Figure 14.34 of the QDMR (2006) provides a graph to determine 85th percentile speeds based on the vehicle path radii and the speed environment prior to the approach. This is shown as Figure 8.

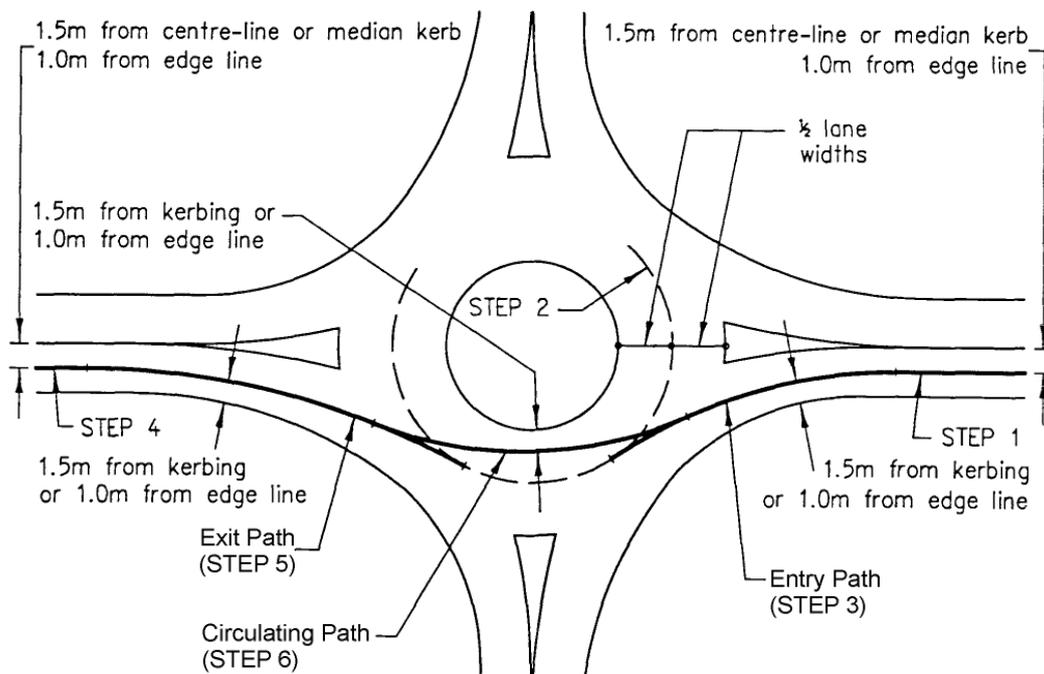


Figure 6 – Queensland Vehicle Path Construction Through Single Lane Roundabouts (QDMR, 2006) – through movement shown

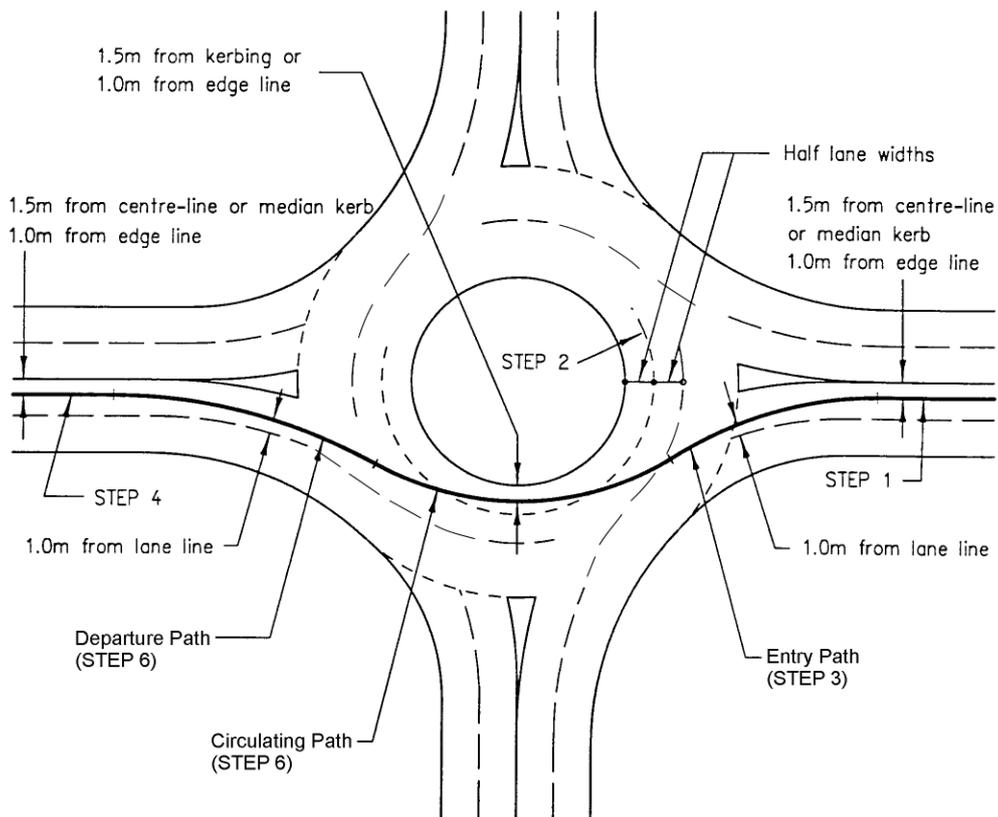


Figure 7 - Vehicle path construction for the right lane of multi-lane roundabouts (QDMR, 2006) – through movement shown

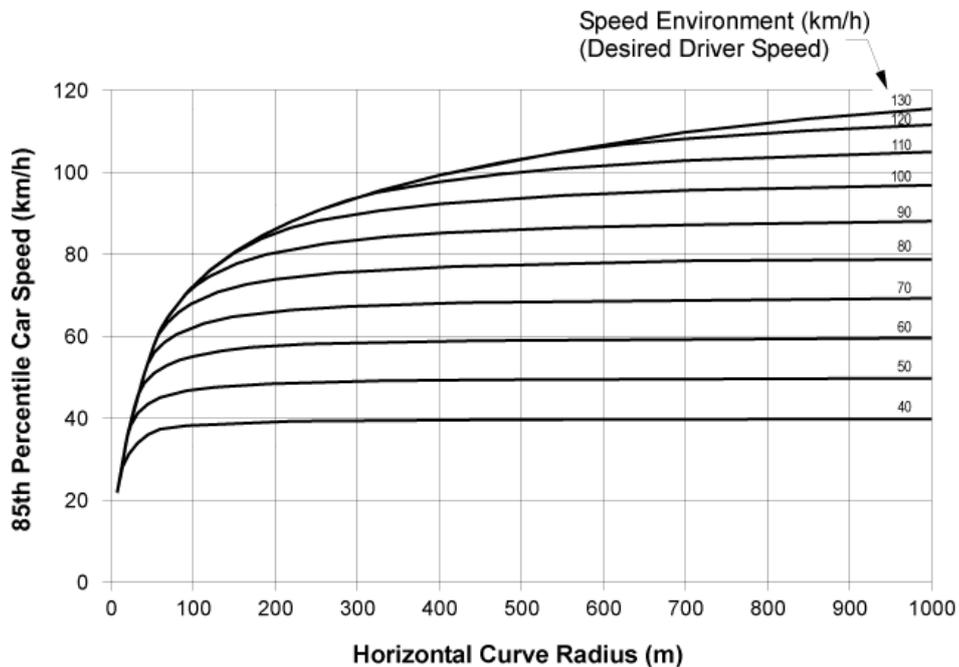


Figure 8 – Queensland Speed Prediction Model for Roundabouts (QDMR, 2006)

ARNDT Roundabout Program

Because of the amount of design effort required to manually calculate the values of all of the speed parameters in QDMR (2006), the computer program ARNDT 'A Roundabout Numerical Design Tool' was developed. Users of the program input geometric, traffic volume and speed environment data for a particular roundabout. The program outputs values of the speed parameters and identifies any parameters exceeding the maximum limits.

COMPARISON OF THE METHODS OF SPEED CONTROL AT ROUNDABOUTS

A summary and comparison of the various methods of speed control through roundabouts is given in Table 3. A discussion of the results in Table 3 is given below.

Table 3 - Summary and Comparison of the Methods of Speed Control

Criteria	Australian Method (Austroads, 1993)	UK Method (UKDOT, 1993)	USA Method (FHWA, 2000)	Qld Method (QDMR, 2006)
Speed control methods.	Deflection	Maximum entry path radius	Various maximum entry speeds Maximum decrease in speed between elements	Maximum entry speed. Maximum decrease in speed between elements. Maximum relative speeds between entering/circulating and exiting/circulating vehicle paths. Maximum difference in potential side friction.
Likely effectiveness in minimising overall accident rates	Moderate	Moderate - high	High	Very high
Amount of effort required to calculate all of the relevant design criteria	Low - moderate	Low - moderate	High	Very high, unless the ARNDT roundabout program is used (applicable to circular roundabouts only). If ARNDT is used, the amount of effort is moderate.
Amount of subjectivity in drawing the vehicle paths	Little	Significant	Significant	Little

Australian Method

Of the four approaches described above, the Australian Method (Austroads, 1993) is least likely to be effective in minimising total accident rates at roundabouts. This is because using deflection as a measure to control speeds through roundabouts is less effective than applying appropriate entry path radii. Maycock and Hall (1984) and Arndt (1998), both show the importance of using appropriate entry path radii to control speeds at roundabouts.

The United Kingdom, which originally developed the deflection criteria, now uses maximum entry path radius instead. Therefore, it is recommended that the method for speed control at roundabouts in Australia be changed to one that uses criteria for the entry curve, in lieu of the circulating carriageway.

UK Method

The UK method is the simplest to apply but is the least comprehensive in dealing with the various accident types that occur at roundabouts (at least based on Queensland experience and studies). It does not consider criteria to minimise single vehicle and sideswipe accidents. In addition, it relies solely on maximum entry path radius to minimise entering/circulating and exiting/circulating vehicle accidents. Under this criterion, rates for the latter accident types may still be high if sharp corner kerb radii (refer Figure 1) are used.

Sharp corner kerb radii produce high relative speeds between entering and circulating vehicles and between exiting and circulating vehicles because of the large angle at which the paths meet. Also, the 100m maximum entry path radius may not restrict vehicle speeds enough under particular scenarios, especially for smaller single lane roundabouts.

USA Method

The USA method is more comprehensive in dealing with the various accident types than the UK method, but also requires a greater design effort. It presents criteria to minimise single vehicle accidents by ensuring that the decrease in speed between successive elements is limited to 20km/h. As in the UK method, however, it relies solely on maximum entry path radius to minimise entering/circulating and exiting/circulating vehicle accidents.

Under this criterion, Entering/Circulating and Exiting/Circulating vehicle accident rates may still be high if sharp corner kerb radii are used (as discussed above under the UK method). However, it is likely to give a better result than the UK method because smaller values of maximum entry speed are given for smaller sized roundabouts, which will partially overcome the problems associated with any use of sharp corner kerb radii.

Queensland Method

The Queensland method is the most comprehensive in dealing with the various accident types. It will potentially produce the safest design, especially for smaller to moderate sized roundabouts. This is due to the inclusion of the criterion for the relative speed between entering and circulating vehicles. Fundamentally, the lower relative speeds for these vehicle paths is the primary reason why roundabouts are generally safer than all other forms of at-grade intersections.

The Queensland method requires much less subjectivity when drawing the vehicle paths compared to the UK and USA methods.

The amount of design effort required under the Queensland method is very high. In fact, QDMR (2006) recommends against manually calculating the various speed parameters by this method because of the complexity involved. That is why QDMR (2006) recommends that the ARNDT roundabout program is used. Unfortunately, at this stage the program only analyses circular roundabouts.

Discussion

All of the current methods discussed in this section have particular limitations as stated above. Ideally, a method for the control of speed at roundabouts would comprise the safety advantages of the Queensland method, the simplicity of design effort similar to the UK method and require little subjectivity in drawing of the vehicle paths. The development of such a method of controlling speeds at roundabouts is detailed in the next section.

PROPOSED METHOD FOR SPEED CONTROL AT ROUNDABOUTS

The proposed method for the control of speeds at roundabouts involves developing design criteria for the following parameters:

- Absolute and desirable maximum entry path radii for various approach speeds and number of lanes based on vehicle path models.
- Absolute and desirable minimum central island radii for various approach speeds and number of lanes.

The development of the proposed method has involved the use of the Queensland accident equations, vehicle path and speed prediction models in QDMR (2006) and Arndt (1998), as incorporated in the ARNDT roundabout program. The program was also used in the development of the proposed speed control method.

Briefly, the process used to development the proposed design criteria is as follows:

- Trial many combinations of central island radii and entry curve radii to cater for both the swept path of a single unit truck and a 19m semi-trailer.
- To determine the absolute limits of the proposed design criteria, identify combinations of minimum central island radii and maximum entry path curvature that meet all of the speed control limits given in the Section titled “Queensland Method”, as taken from QDMR (2006).
- To determine the desirable limits of the proposed design criteria, identify combinations of minimum central island radii and maximum entry path curvature that avoid the use of corner kerb radii and allow sufficient splitter island size for pedestrians, whilst still meeting the speed control limits given in QDMR (2006). Figure 1 shows a diagram identifying corner kerb radii. To avoid the use of corner kerb radii, the left edges of the entry and exit curves were made tangential to the outer edge of the circulating carriageway and were not overlapped.
- A number of assumptions as to the geometry of the roundabouts were made and these are given in Appendix B1.

Maximum Entry Path Radius

Design criteria for the maximum entry path radii at roundabouts under the proposed speed control method are given in Table 4.

Table 4 - Maximum Entry Path Radii for One and Two lane Roundabouts

Desired Driver Speed on the Leg Prior to the Roundabout (km/h)	Maximum Entry Path Radius (m)		
	Single Lane Entries ⁽²⁾		Two-lane Entry - Cutting Across Lanes ⁽⁴⁾
	Two-lane Entry - Staying in Correct lane ⁽³⁾		
	Desirable	Absolute	
≤40	55	100	1.9 times the actual entry path radius staying in the correct lane
50	55	80	1.8 times the actual entry path radius staying in the correct lane
60	55	80	1.6 times the actual entry path radius staying in the correct lane
70	55	70	1.5 times the actual entry path radius staying in the correct lane
80	55	55	1.5 times the actual entry path radius staying in the correct lane
≥90	55	55	1.5 times the actual entry path radius staying in the correct lane

Notes:

1. Appendix A provides guidance on how to apply the criteria in this table and how to modify roundabout geometry that does not meet these criteria.
2. The vehicle path model used for determining the entry path radius of a single lane entry on a one or two lane roundabout is given in Figure A1 of Appendix A.
3. The vehicle path model used for determining the entry path radius staying in the correct lane of a two-lane entry is given in Figure A2 of Appendix A.
4. The vehicle path model used for determining the entry path radius cutting across lanes of a two-lane entry is given in Figure A3 of Appendix A.

Development of the Criteria in Table 4

The purpose of the criteria for the maximum entry path radius for cutting across lanes of a two-lane entry (the last column in Table 4) is to discourage most motorists from completely cutting across the entry lanes. The values were derived by limiting the potential difference in side friction (refer Equation 2) on the entry curve to 0.7. Arndt (1998) showed that this will minimise the likelihood of sideswipe accidents on the entry curve.

$$\Delta f_1 = ABS \left(\frac{(S_C + \Delta S_C)^2}{127 \times R} - \frac{(S_C + \Delta S_C)^2}{127 \times R_C} \right) \quad \text{Equation 2}$$

Where:

Δf_1 = difference in potential side friction ((km/h)²/m)

S_C = 85th percentile speed on the horizontal geometric element for the particular movement for vehicles cutting lanes (km/h)

ΔS_C = decrease in 85th percentile speed at the start of the horizontal geometric element for vehicles cutting lanes (km/h)

R = radius of the vehicle path for vehicles not cutting lanes (m)

R_C = radius of the vehicle path for vehicles cutting lanes (m)

The absolute maximum entry path radii for single lane entries and two-lane entries where drivers stay in the correct lane (refer to the third column of Table 4) were generally based on limiting the 85th percentile speed on the entry curve to 60km/h. Arndt (1998) shows that this will achieve the following:

- Minimise Approaching Rear-End vehicle accidents
- Help lower Entering/Circulating vehicle accidents
- Help lower Exiting/Circulating vehicle accidents
- Help lower Single Vehicle accidents on the circulating carriageway.

The absolute maximum entry path radii were limited to 100m (the UK value) with some interpolation used for the approach speeds of 50 and 60km/h. As shown in the third column of Table 4, larger values of absolute maximum entry path radii are associated with lower desired driver speeds prior to the roundabout. To achieve the speed control limits given in QDMR (2006), lower desired driver speeds prior to the approach require less speed reduction by the entry curve than do higher driver desired speed prior to the approach. In other words, when the speed prior to the approach is high, greater speed attenuation is required to achieve an appropriate speed for entry onto the roundabout. When speeds approaching the roundabout are slow, less attenuation is required to achieve an appropriate entry speed.

The desirable maximum entry path radii for single lane entries and two-lane entries where drivers stay in the correct lane (refer to the third column of Table 4) were set by avoiding the use of corner kerb radii and allowing sufficient splitter island size for pedestrians. The smallest practical central island radii and entry curve radii to satisfy all of the speed control limits in QDMR (2006) were then identified. The entry path radii for these layouts were all noted to be in the order of 55m for all approach speeds.

Minimum Central Island Radii

Applying the maximum entry path radii given in the Table 4 will ensure that speeds onto the roundabout will be minimised. As identified in the previous section, this will lower many of the accident types at roundabouts. However, it will not minimise total accident rates unless combined with a sufficient size of central island.

At very small roundabouts (roundabouts that are very small with respect to the approach speed, the number of lanes and width of lanes), the following will occur:

- The entry and exit legs will overlap creating excessively tight corner kerb radii. This increases the relative speed between entering and circulating vehicles, having a negative impact on the entering/circulating vehicle accident rate.
- Large decreases in speed between the entry curve and the circulating carriageway will occur, increasing single vehicle accident rates.
- An increase in sideswipe vehicle accidents will occur on the circulating carriageway due to the additional advantage to drivers in cutting lanes (less speed lost and a lower driver workload).

For the above reasons, criteria for absolute and desirable minimum central island radii were developed for single and two-lane circular roundabouts for various approach speeds and these are shown in Table 5. The values given in this table are based on a number of assumptions regarding the geometry as given in Appendix B1.

If any of the assumptions given in Appendix B1 do not apply at a particular site (which is usual), the values given in Table 5 will need to be changed to suit the specific requirements and to obtain the maximum entry path radii in Table 4. Generally, the central island radii in Table 5 will need to be increased to allow for the conditions shown in Appendix B2.

Table 5 - Minimum Central Island Radii for a Circular Roundabout ⁽¹⁾

Desired Driver Speed on the Fastest Leg Prior to the Approach (km/h)	Minimum Central Island Radius of a Single Lane Roundabout (m)		Minimum Central Island Radius of a Two Lane Roundabout (m)	
	Absolute	Desirable	Absolute	Desirable
≤40	5 ⁽²⁾	10	8	12
50	8	11	8	12
60	10	12	14	16
70	12	18	18	20
80	14	22	20	24
≥90	14	22	20	24

Notes:

1. The minimum central island radii given in this table are based on a number of assumptions as to the geometry, as given in Appendix B1. If any of these assumptions do not apply then the radius needs to be subjectively increased or decreased. Guidance for this is given in Appendix B2.
2. Minimum central island radius where the design right turn vehicle is a single unit truck is 7m.
3. The desirable minimum central island radii listed for these speeds generally provide sufficient size splitter islands for storage of pedestrians, allow desirable entry curvature to be fitted and avoid the need for corner kerb radii. The absolute minimum central island radii generally do not.

Development of the Criteria in Table 5

The desirable minimum central island radii in Table 5 were the minimum values that met the following criteria when combined with the values of the desirable maximum entry path curvature in Table 4:

- The speed control limits in QDMR (2006), except that the maximum decrease in speed between the entry curve and the circulating carriageway for the right turn was limited to 20km/h, in lieu of the maximum of 30km/h.
- Sufficient size of splitter island exists to accommodate pedestrians.
- No corner kerb radii (or negligible corner kerb radii) being used.

Figure 9 shows an example of a roundabout comprising the desirable minimum central island radius of 16m for a two-lane roundabout where the desired driver speed on the fastest leg prior to the approach is 60km/h. The entry path radius is 55m, the desirable maximum for drivers staying in the correct lane according to Table 4.

The absolute minimum central island radii in Table 5 were the minimum values that met the speed control limits in QDMR (2006) when combined with the values of the absolute maximum entry path curvature in Table 4. Use of the absolute values are associated with the use of corner kerb radii and may not provide sufficient size of splitter island, especially for the central island sizes given for the lower approach speeds. An example of this is shown in Figure 8 for an absolute minimum central island radius of 8m for a two-lane roundabout where the desired driver speed on the fastest leg prior to the approach is 50km/h.

Use of the desirable minimum values of central island radii will yield lower overall accident rates than use of the absolute minimum central island radii. Some rounding of the values of the minimum central island radii in Table 5 were made to provide a more gradual increase in radii from the low approach speeds to the high. Where this occurred, values were only rounded up (achieving a more conservative result).

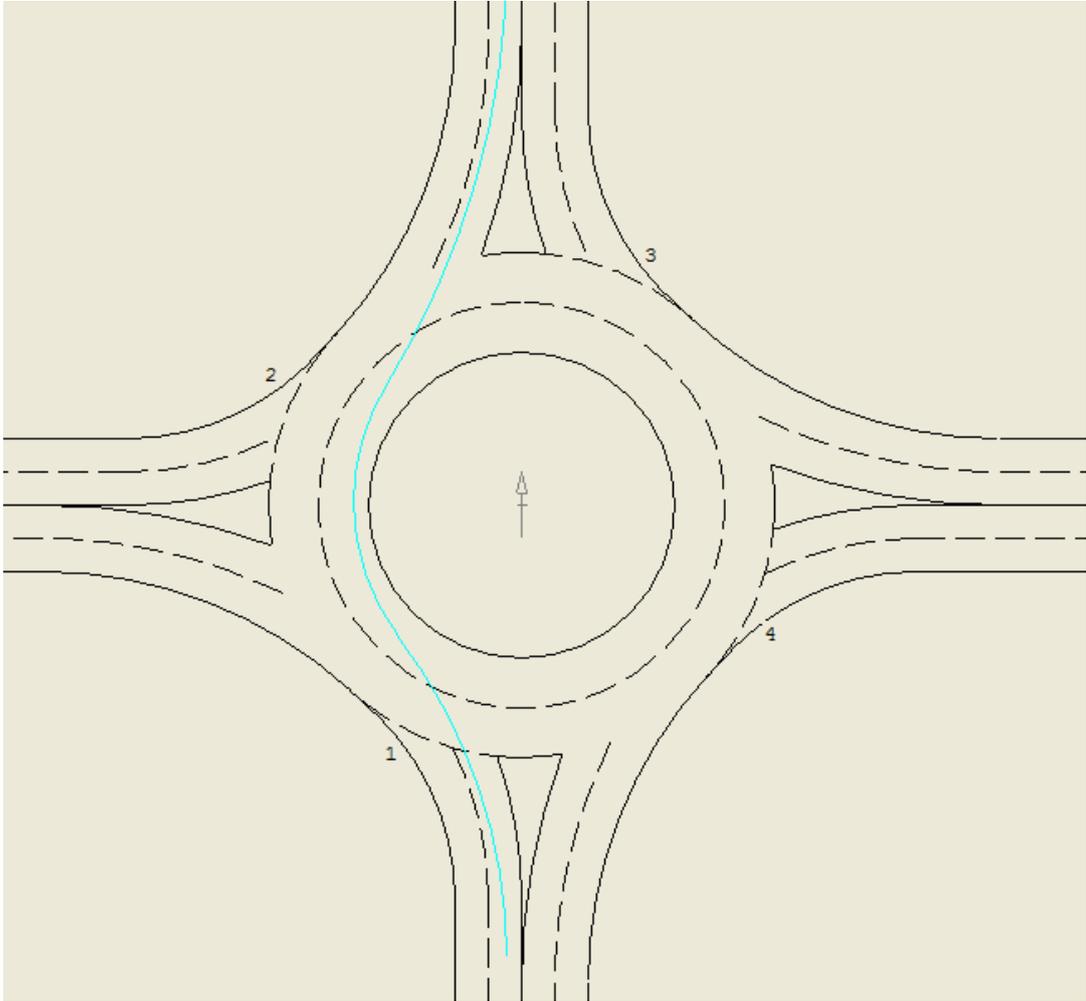


Figure 9 – Example Showing the Desirable Minimum Central Island Radius of 16m for a Two Lane Roundabout where the Desired Driver Speed on the Fastest Leg Prior to the Approach is 60km/h (Vehicle Path Staying in the Correct lane Shown for the Through Movement from Leg 1)

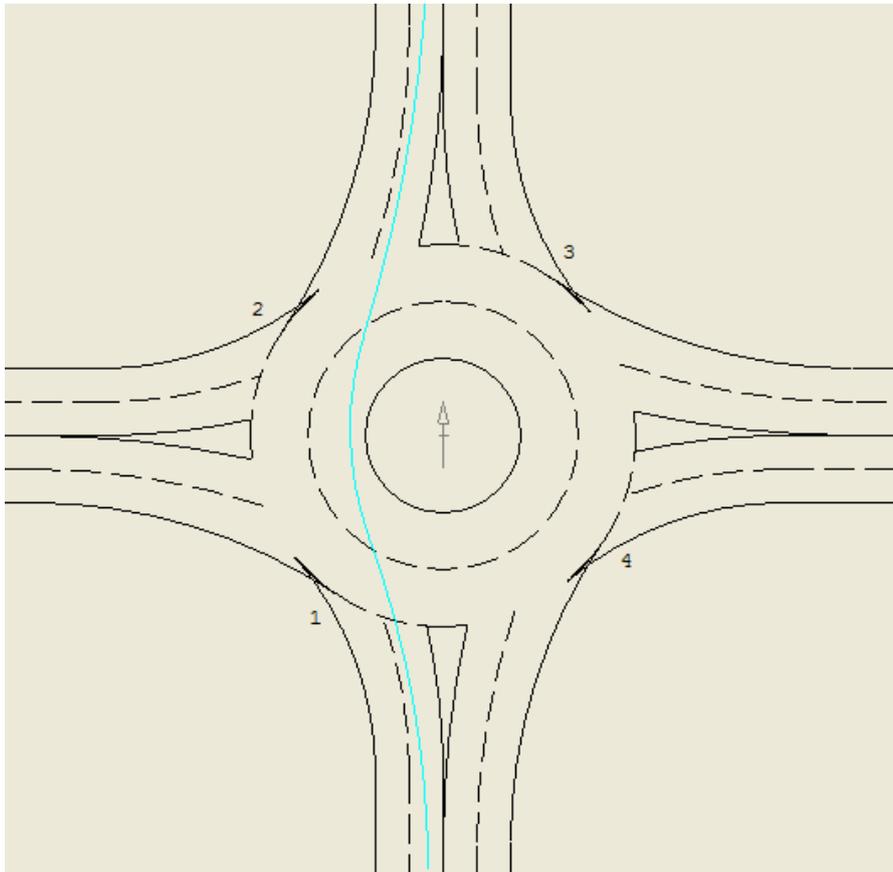


Figure 10 – Example Showing the Absolute Minimum Central Island Radius of 8m for a Two Lane Roundabout where the Desired Driver Speed on the Fastest Leg Prior to the Approach is 50km/h (Vehicle Path Staying in the Correct lane Shown for the Through Movement from Leg 1)

CONCLUSIONS

The current national method of controlling speeds through roundabouts in Australia is achieved by the provision of 'deflection' through the circulating carriageway, as outlined in Austroads (1993). This method of speed control is based on 1975 design recommendations by the UK Department of the Environment (UKDOE, 1975).

The method of applying deflection is no longer used in the United Kingdom. The current method for controlling speeds at roundabouts is to limit the maximum radius of the entry path curve to 100m, instead of the vehicle path on the circulating carriageway (UKDOT, 1993).

Criteria used in the United States of America for the control of speeds through roundabouts (FHWA, 2000) involves the use of maximum entry design speeds and a speed consistency model which limits the decrease in speed between successive horizontal elements to 20km/h. No criteria for deflection through the circulating carriageway are given.

The Queensland Department of Main Roads has maximum limits for entry speed, various relative speeds and decrease in speeds between successive horizontal elements to control speeds through roundabouts (QDMR, 2006). No criteria for deflection through the circulating carriageway are given.

The Australian method of using deflection (Austroads, 1993) is least likely to be effective in minimising total accident rates at roundabouts, relative to the other speed models listed above. Maycock and Hall (1984) and Arndt (1998) both show the importance of using appropriate entry path radii to control speeds at roundabouts. For this reason, it is recommended that Austroads give consideration to incorporating speed control through roundabouts by the use of maximum entry path radii, instead of the current method of deflection.

The UK method for the control of speed through roundabouts is the simplest to apply but is the least comprehensive in dealing with the various accident types that occur at roundabouts (at least based on Queensland experience and studies). The USA method is more comprehensive in dealing with the various accident types than the UK method, but also requires a greater design effort.

The Queensland method is the most comprehensive in dealing with the various accident types. It will potentially produce the safest design, especially for smaller to moderate sized roundabouts. The amount of design effort required under the Queensland method, however, is extremely high when calculating manually.

To overcome the particular limitations of each method discussed above, a new method for the control of speeds through roundabouts has been developed in this paper. The method uses the Queensland accident equations, vehicle path and speed prediction models in Arndt (1998) whilst retaining the simplicity of design effort similar to the UK method.

The proposed method for the control of speeds at roundabouts comprises design criteria for the following parameters:

- Maximum entry path radii for various approach speeds and number of lanes based on Queensland vehicle path models. This is given in Table 4.
- Minimum central island radii for various approach speeds and number of lanes. This is given in Table 5.

It is recommended that Austroads consider incorporating the proposed method of speed control at roundabouts into the new Austroads Guide to Road Design (Austroads 2007).

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APPENDIX A – VEHICLE PATH MODELS APPLICABLE TO THE MAXIMUM ENTRY PATH RADII IN TABLE 4

Single Lane Entries

The method of construction of the entry path for single lane entries is given in Figure A1. Use this figure for roundabouts comprising one or two lanes. Steps to construct the entry path are given below.

Step 1 - Where no approach curve/s are used, draw a line parallel to the right approach edge at an offset 'D'. This line is the approach path. Where an approach curve/s is used, draw this line on the last approach curve in the direction of travel at an offset of 'M₁'.

Step 2 - Draw a curved line parallel to the edge of the central island at an offset 'M₂'. For an elliptical/oval/oblong roundabout, the line may comprise multiple radii.

Step 3 - Draw the entry path. This is a circular curve drawn tangentially to the lines constructed in Steps 1 and 2 located at an offset 'D' from the closest point on the left entry edge.

The radius of the entry path drawn in Step 3 must be no greater than the values for single lane entries given in Table 4. If the radius is exceeded, tighten the entry curve, relocate the approach leg and/or increase the roundabout size to achieve the maximum value. If a circular curve cannot be drawn according to the criterion in Step 3, appropriate entry curvature has not been provided.

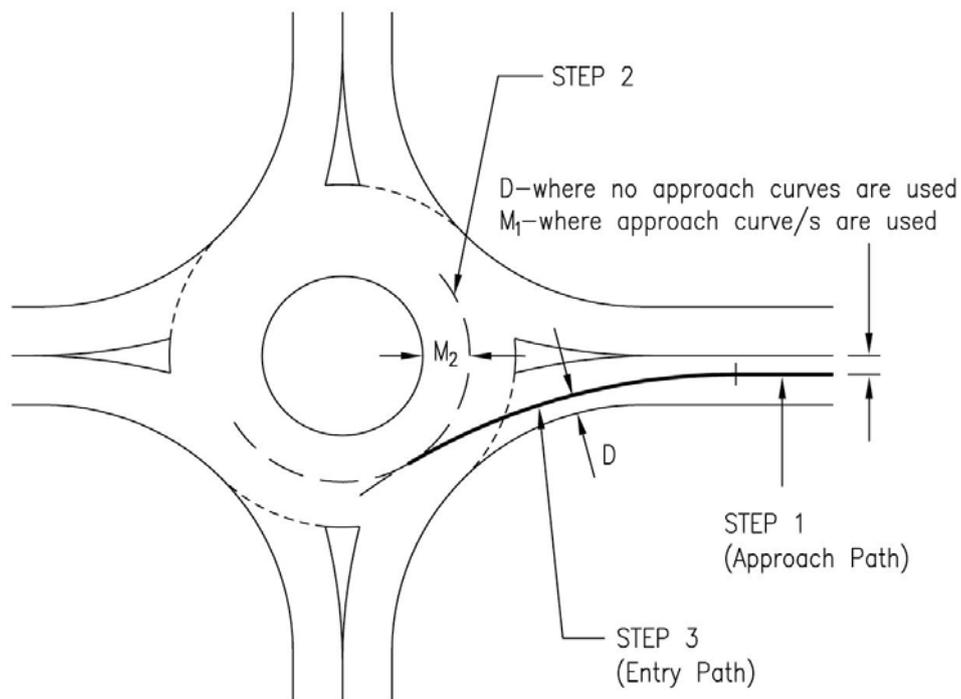


Figure A1 - Construction of the Entry Path of a Single Lane Entry

Notes:

1. D = 1.5m when measuring from a road centre-line or kerb face, 1.0m when measuring from a lane edge line.
2. M₁ = Half the width of the approach lane
3. M₂ = Half of the width of the circulating carriageway (for two-lane roundabouts, the width of the inner circulating lane may be used)

Two-lane Entries – Staying in Correct Lane

The method of construction of the entry path for two-lane entries for drivers staying in the correct lane is given in Figure A2. The vehicle path is drawn in the right entry lane and the inner circulating lane. Steps to construct the entry path for drivers staying in the correct lane are given below.

Step 1 - Where no approach curve/s are used, draw a line parallel to the right approach edge at an offset 'D'. This line is the approach path. Where an approach curve/s is used, draw this line on the last approach curve in the direction of travel at an offset of 'M₁'.

Step 2 - Draw a curved line parallel to the edge of the central island at an offset 'M₂'. For an elliptical/oval/oblong roundabout, the line may comprise multiple radii.

Step 3 - Draw the entry path for drivers staying in the correct lane. This is a circular curve drawn tangentially to the lines constructed in Steps 1 and 2 located at an offset 'D' from the closest point on the left edge of the right most lane.

The radius of the entry path for drivers staying in the correct lane drawn in Step 3 must be no greater than the values for 'two lane entries – staying in correct lane' given in Table 4. If the radius is exceeded, tighten the entry curve, relocate the approach leg and/or increase the roundabout size to achieve the maximum value. If a circular curve cannot be drawn according to the criterion in Step 3, appropriate entry curvature has not been provided.

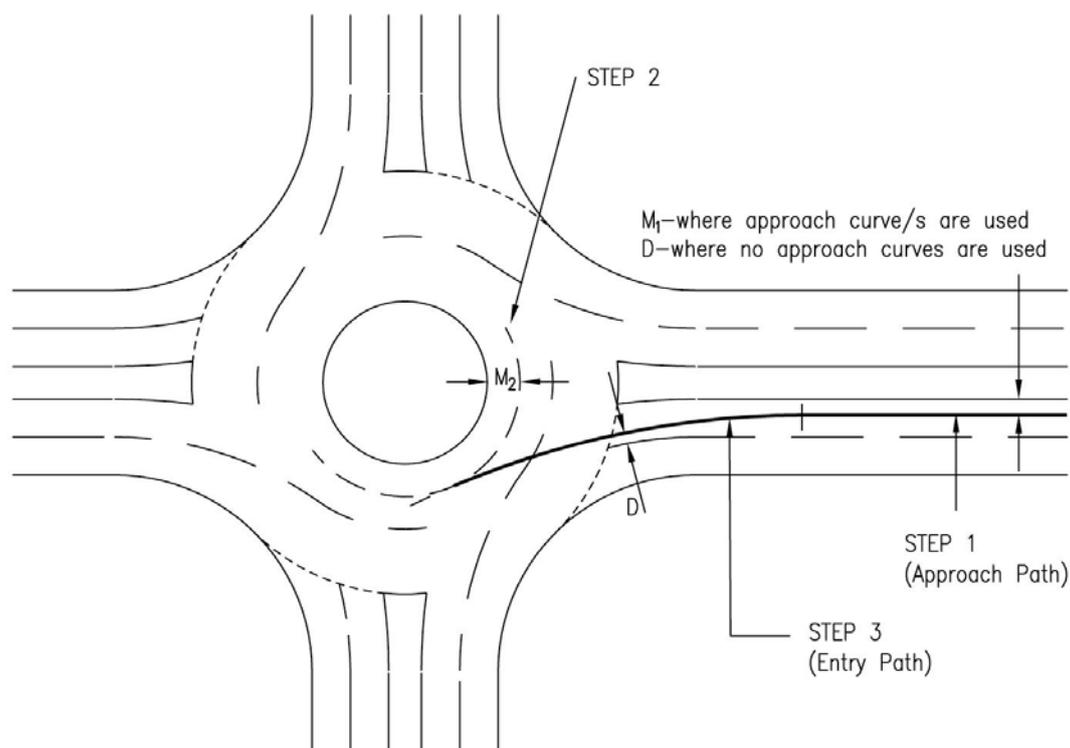


Figure A2 - Construction of the Entry Path of a Two-Lane Entry – Staying in the Correct Lane

Notes:

1. D = 1.5m when measuring from a road centre-line or kerb face, 1.0m when measuring from a lane edge line.
2. M₁ = Half the width of the right approach lane
3. M₂ = Half of the width of the inner circulating lane

Two-lane Entries – Cutting Across Lanes

The method of construction of the entry path for two-lane entries for drivers cutting across lanes is given in Figure A3. Steps to construct the entry path for drivers cutting across lanes are given below.

Step 1 - Where no approach curve/s are used, draw a line parallel to the right approach edge at an offset 'D'. This line is the approach path. Where an approach curve/s is used, draw this line on the last approach curve in the direction of travel at an offset of 'M₁'.

Step 2 - Draw a curved line parallel to the edge of the central island at an offset 'M₂'. For an elliptical/oval/oblong roundabout, the line may comprise multiple radii.

Step 3 - Draw the entry path for drivers cutting across lanes. This is a circular curve drawn tangentially to the lines constructed in Steps 1 and 2 located at an offset 'D' from the closest point on the left edge of the left entry lane.

The radius of the entry path drawn in Step 3 must be no greater than the radius of the entry path for drivers staying in the correct lane (constructed in accordance with Figure A2) multiplied by the factor for 'two lane entries – cutting across lanes' given in Table 4. If the radius is exceeded, lengthen the entry curve, relocate the approach leg and/or increase the roundabout size to achieve the maximum value. If a circular curve cannot be drawn according to the criterion in Step 3, appropriate entry curvature has not been provided.

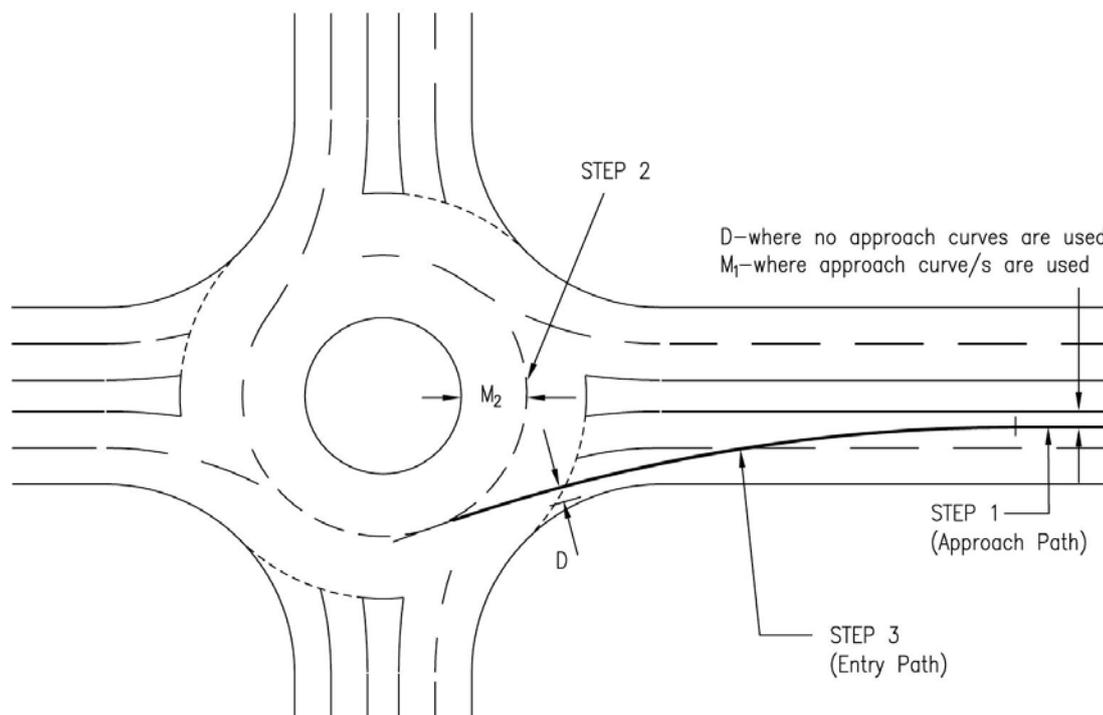


Figure A3 - Construction of the Entry Path of a Two-Lane Entry – Cutting Across Lanes

Notes:

1. D = 1.5m when measuring from a road centre-line or kerb face, 1.0m when measuring from a lane edge line.
2. M₁ = Half the width of the right approach lane
3. M₂ = Half of the width of the circulating carriageway (the width of the inner circulating lane may be used)

APPENDIX B1 – ASSUMPTIONS APPLICABLE TO THE MINIMUM CENTRAL ISLAND RADII IN TABLE 5

In developing the absolute and desirable minimum central island radii in Table 5 of this paper, the following assumptions were made regarding the geometry of each roundabout:

- The roundabout comprises four legs;
- Each leg is at 90° to adjacent legs;
- The centreline of each leg goes through the centre of the roundabout;
- For two-lane roundabouts, each leg comprises two lanes;
- Kerbing exists on both sides of all legs;
- There are no medians on any of the approaches;
- Each leg has the same desired speed prior to the roundabout;
- The largest right turning design vehicle is a semi-trailer; and
- The design vehicle swept path remains on the pavement (does not require an encroachment area).

APPENDIX B2 – MODIFICATION OF THE MINIMUM CENTRAL ISLAND RADII IN TABLE 5

If any of the assumptions given in Appendix B1 do not apply at a particular site (which is usual), the values given in Table 5 will need to be changed to suit the specific requirements and to obtain the maximum entry path radii in Table 4. Generally, the central island radii in Table 5 will need to be increased to allow for the following conditions:

- The roundabout has more than four legs;
- The angle between any adjacent roundabout leg is considerably more or less than 90°;
- The centreline of some or all of the legs in the direction of the central island passes considerably to the left of the centre of the roundabout;
- There are shoulders and no kerbing on some or all of the legs;
- There are medians on some or all of the approaches;
- The design vehicle is larger than a semi-trailer; and/or
- Other considerations apply (e.g. the roundabout will form an overpass or underpass with a highway or motorway).

In constrained areas, the minimum values given in Table 5 can generally be reduced to allow for any of the following conditions (provided the maximum entry path radii in Table 4 are still obtained):

- The roundabout has three legs;
- For two-lane roundabouts, some of the legs comprise one lane;
- The desired speeds on some of the approaches are significantly lower than that of others; and/or
- Encroachment areas are used for the design vehicle.