

THE GEOMETRIC DESIGN OF CONVENTIONAL SINGLE LANE TRAFFIC CIRCLES

P G PURCHASE, L de V Roodt* and S C van As*

ARCUS GIBB, P O Box 35007, Menlo Park, 0102

*University of Pretoria

1. INTRODUCTION

At-grade intersections are invariably the critical capacity and safety element in the urban road transportation network. Large numbers of traffic interactions take place daily at intersections, sometimes resulting in high levels of congestion and severe accidents.

According to AASHTO, 1994 the design objective of an intersection is:

- *“to reduce the severity of potential conflicts between operational units and facilities*
- *facilitating convenience, ease and comfort of the people traversing the intersection.*

The design should be fitted closely to the natural paths and operating characteristics of the users”.

There are various forms of control that can be employed at intersections. These include:

- no control,
- yield and stop control,
- grade separation,
- traffic signal control
- traffic circle control

The traffic circle is a relatively efficient and safe method of control.

During recent years there has been resurgence in the interest in traffic circles around the world. However, this trend has not manifested in South Africa to any significant extent, except mini-circles, used in conjunction with traffic calming on low order roads.

A research project was commissioned by Gauteng Province to investigate the acceptability of traffic circles on arterial routes (PWV Consortium, 1999). During this study the lack of adequate South African traffic circle design guidelines became apparent. This study was prompted by this lack of guidelines.

1.1 OBJECTIVES OF THE STUDY

The purpose of the study was to develop geometric design guidelines for one particular type of traffic circle, namely the conventional single lane circle. This type of circle has the advantage that it does not require merging or weaving maneuvers in the circle. This allows for a significant reduction in the size of the circle.

1.2 SCOPE & METHODOLOGY OF THE STUDY

The study was restricted to single lane conventional traffic circles with single lane approaches. Multi-lane traffic circles and mini-circles are excluded from the study.

Furthermore, the study was restricted to the geometric design elements of a traffic circle. Elements, such as the following, were specifically excluded from the scope of the study:

- Operational (capacity) analysis,
- Sight distance requirements,
- Road signs and markings
- Lighting requirements

Available geometric design standards were obtained and critically evaluated (local, British and Australian and any other available).

One-on-one interviews were conducted with traffic engineering professionals and a brain storming session was held in order to gain individual opinions and consensus on various aspects related to traffic circles.

A number of critical field observations at traffic circles were made in order to gain a better understanding on the critical operational issues associated with their geometric design.

Vehicle path tracking software was utilized to determine traffic circle geometric requirements in order to accommodate various design vehicles from the single unit truck through to the eight axle inter-link and large semi-trailer vehicles.

This paper concentrates on the basic elements of a traffic circle, the design criteria, the findings of the field experiments and typical designs.

2. ELEMENTS OF A MODERN TRAFFIC CIRCLE

Figure 2.1 indicates the geometric elements of a traffic circle. These include the entry width, exit width, entry curve, corner kerb radius, exit curve, splitter island, inscribed circle diameter, central island diameter and circulating carriageway width.

A brief explanation of the most important terms follows (*Austroads, 1993*):

- Entry width: width of the entry as measured perpendicularly from the outside kerb-line to the point where the extension of the splitter island meets with the point on the inscribed circle.
- Exit width: width of the exit as measured perpendicularly from the outside kerb-line to the point where the extension of the splitter island meets with the point on the inscribed circle.
- Entry curve: left edge of pavement curve of the entry carriageway which leads vehicles into the circulating carriageway.
- Corner kerb radius: radius of the corner kerb between adjacent entry and exit roadways.
- Exit curve: left edge of pavement curve of the exit carriageway which leads vehicles out of the circulating carriageway.
- Splitter island: island placed within a leg of the traffic circle, separating entering and exiting traffic and designed to deflect entering traffic.
- Inscribed circle diameter: diameter of the circle that may be inscribed within the outer kerb-line of the circulating carriageway.
- Central island diameter: diameter of the circle that forms the central island kerb-line.
- Circulating carriageway: carriageway around the central island on which circulating vehicles travel in a clockwise direction.

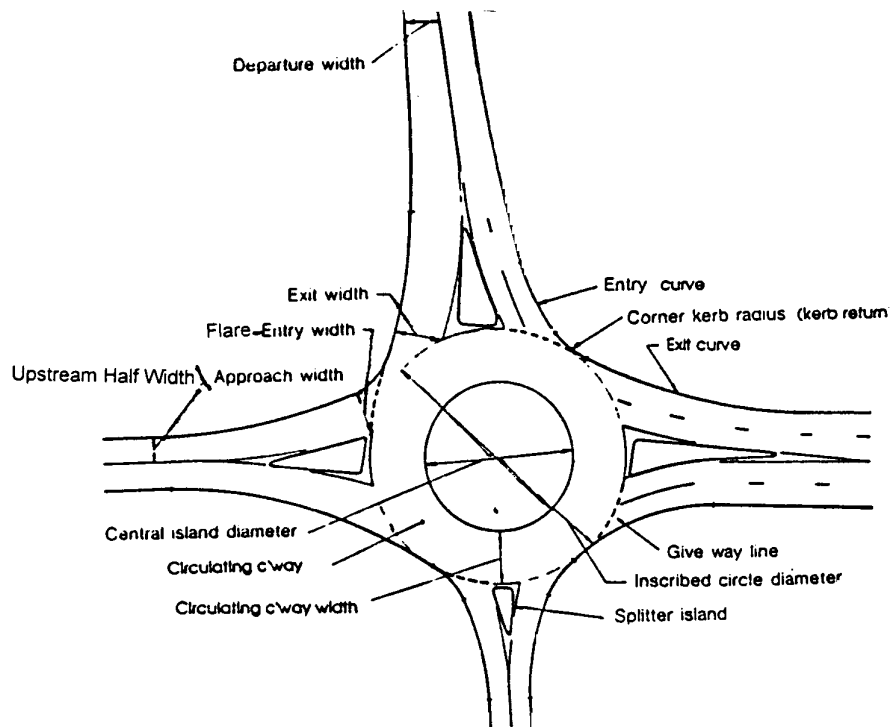


Figure 2.1: Elements of a Traffic Circle (Source: *Austroads, 1993*)

Table 2.1 provides a distinction between old and modern type traffic circles.

Table 2.1 Distinction between “old” and “modern” traffic circles (*McTrans, 1997*).

MODERN TRAFFIC CIRCLE	OLD TRAFFIC CIRCLE
1. Give way control applies and entering vehicles give way to vehicles in the circle	Signalised/stop control sometimes applied else vehicles in the circle are to give way to entering vehicles
2. Allowance for weaving is minimised	Some are designed to allow for weaving i.e. weaving is a design consideration
3. Special attention is given to entrance path of vehicles when determining the relative position of the central island and left entry kerb position	This is not a requirement
4. No parking is allowed in the circle	Parking is sometimes allowed
5. No pedestrian crossing to or activity on the central island	Pedestrian crossing to and activity on the central island is sometimes allowed
6. Designed to accommodate heavy vehicles from all legs	Heavy vehicles can't use all the legs in some cases due to right of way constraints
7. Raised splitter islands are provided	Not all have splitter or raised splitter islands
8. Pedestrians cross approximately one car length from the entry point	Pedestrians often have to cross at the yield/stop position
9. The entry deflection is a result of physical features	Road markings sometimes used to promote deflection

3. FIELD EXPERIMENTS – DETERMINATION OF ACTUAL SPEED VS TRAVEL PATH RADIUS RELATIONSHIPS

The desired design speeds of traffic circles largely determine the geometric design and travel radii through traffic circles for various traffic circle elements. The elements considered are the entry path, circulatory path (both through and around), as well as the exit path. These travel paths combine to form the vehicle travel path through a traffic circle.

In order to ensure adequate safety traffic speeds need to be relatively low and relative entry and circulatory speeds need to be minimized as far as possible.

If inadequate travel path deflection is provided the travel radii are too large and excessive negotiation speeds are possible. This, in turn may compromise safe operation.

A number of references provide speed – travel radii relationships for passenger vehicles at various superelevations and side friction factors. These relationships are based upon simple one direction singular curves and are not sensitive to additional variables that are encountered in a number of reverse curve maneuvers.

Traditionally the shortest possible path with largest possible radius, through a traffic circle, together with this speed – radius relationship, was used to determine likely speeds at various radii.

However, this methodology does not account for the fact that, to a lesser or greater extent, the actual travel path is a set of two reverse curves, that the driver is faced with “active” obstructions and has to react and turn a steering wheel back and forth through the maneuver. This is especially true for smaller circles where these various elements are encountered in close succession. In larger traffic circles the travel radius is dictated, to a larger degree, by the circulatory path width.

The field observations attempted to determine a typical speed-radius relationship for South African conditions in order to assist with the determination of required maximum radii for given design speeds.

Surveys were undertaken in Johannesburg and Durban in June 2001 and at various locations in Pretoria during late July and early August 2001.

Figure 3.1 indicates a typical 85th percentile speed profile of traffic travelling through a traffic circle determined from field data collected during the study.

Various travel radii and traffic circle geometry radii were determined with which travel radii and speeds could be correlated.

Data collected was used to plot a speed – travel radius relationship for actual travel radii and the shortest path travel radius (maximum possible travel radius) which is generally used for traffic circle design purposes. The data is presented in Figure 3.2

It is apparent from Figure 3.2 that the through movement speed – travel radius does not allow for high speeds at the maximum travel radius when compared to the simple speed-radius relationship.

It is thus concluded that the “chicane” type maneuver when traveling through traffic circles is a complex one in terms of the combination of reverse curves and travel speeds.

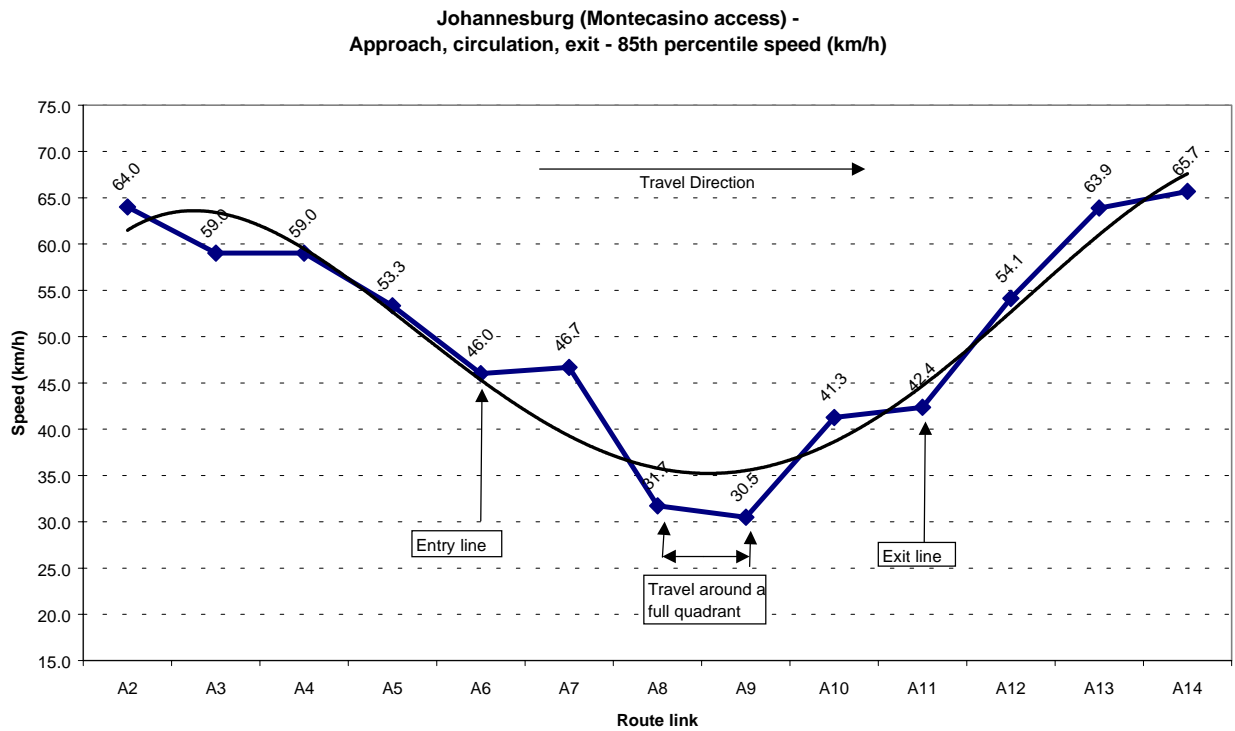


Figure 3.1: Speed profile for cars traveling straight through traffic circle - Jhb

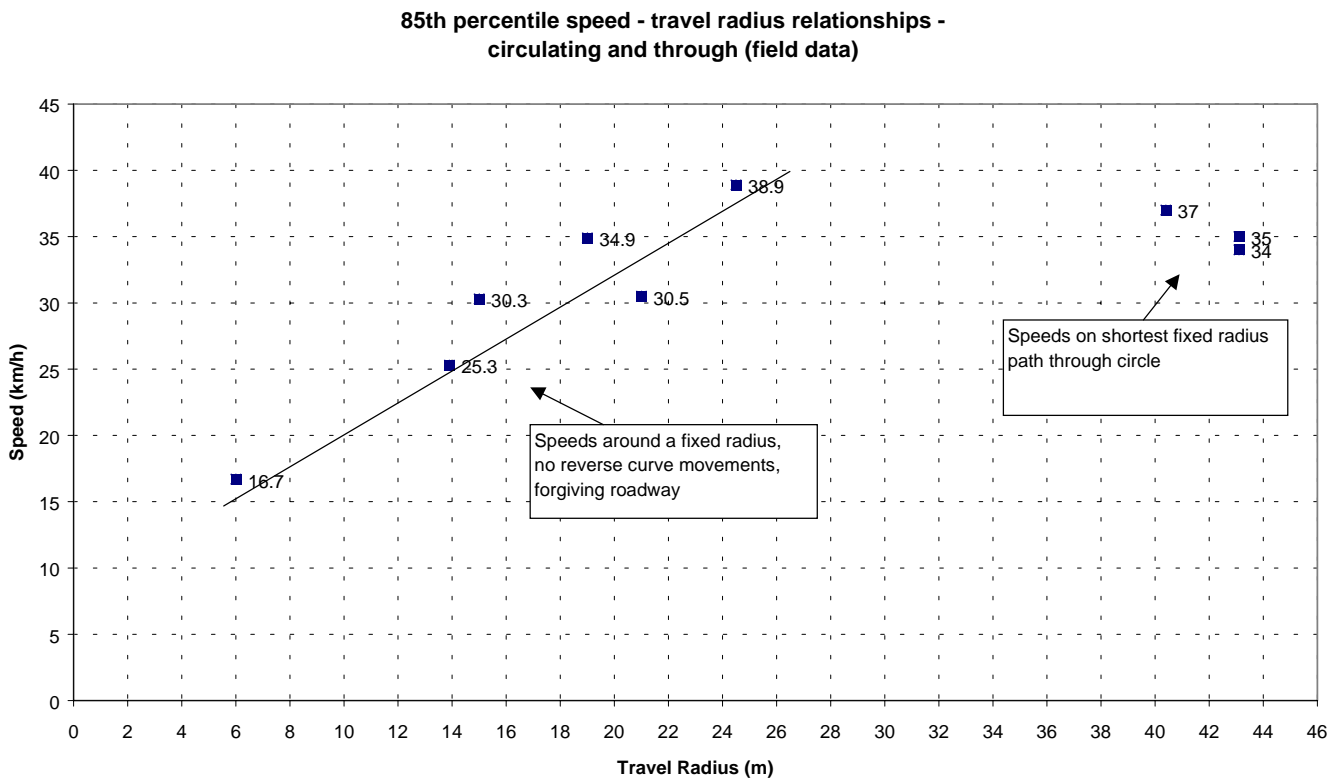


Figure 3.2: Field study speed- travel radius results

It is also concluded that merely determining a maximum radius, shortest through path and applying any particular documented speed – travel radius relationship to the radius determined to estimate a travel speed is not correct due to the actual observed change in speeds from the entry to exit line of a circle.

4. TRAVEL SPEED – RADIUS RELATIONSHIPS FROM AVAILABLE LITERATURE

A number of sources were consulted in order to compare the field study findings to recommended practice. These include studies carried out by *Pretorius (1994)* and *Van As* and standards contained in *AASHTO (1994)*.

The various refined speed – travel radius relationships for simple travel paths are presented in Figure 4.1 below.

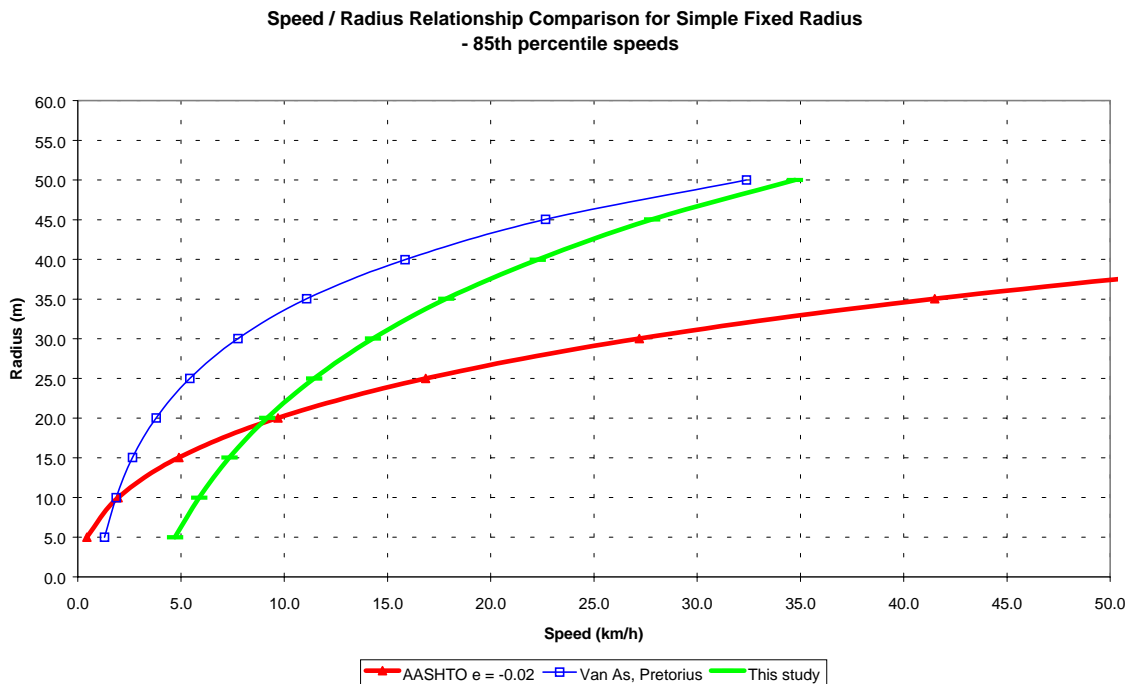


Figure 4.1: Speed – travel radius relationships for simple travel paths

It is noted that above radii of 10m and speeds of 20km/h the AASHTO curve appears to be somewhat conservative. This is due mainly to the fact that the curve has been generated for wet road conditions. The super-elevation of -2% throughout has a negligible effect of the curve up to about 40km/h when compared to favourable super-elevations.

However, apart from the factors mentioned it is apparent that the relationship between travel radius and speed varies somewhat due to the variables involved.

5. DISCUSSION ON SPEED-RADIUS CURVES FROM LITERATURE VERSUS FIELD EXPERIMENTS

The relationship derived from the *Pretorius*, *Van As* data, as well as that derived in this study are applicable to simple radii and minimal driver demands. The *AASHTO* curve appears somewhat more conservative than the others considered and the three points for through traffic correlate relatively well with this curve. However, this appears to be a coincidence.

All the relationships under consideration can be questioned with regard to their applicability to traffic circle design because:

- They consider a simple travel radius – speed curve relationship not accounting for reverse curve negotiation, passive as well as active obstructions, general increased demands on driver,
- The variation in possible travel radii through a smaller circle with a wide circulatory carriageway is too large to merely approximate and equate to a fixed maximum radius, travel speed and distance, hence a vast amount of data is required in order to determine actual travel paths, distances and speeds of through traffic.
- Approximating a likely through path, determining a travel radius and comparing to other curves found that these points differ greatly from any of the curves suggesting
- Data collected in Johannesburg provides a typical speed profile for that particular traffic circle and indicates that speeds change between the entry and exit,
- The variation in how drivers approach and negotiate traffic circles, inter alia, necessitates the re-evaluation of clearances allowed for, particularly on the outside where an unforgiving roadway is encountered.

The *Code of Practice for the Installation of Traffic Control Devices in South Australia (July 1996)* methodology of using a fixed design envelope with a fixed radius also assumes a fixed radius travel path and hence fixed speed which is, in fact, not encountered in reality.

Furthermore, as the circle size increases the relative angle between the envelope and approach (and departure) increases to the extent that it becomes a very unlikely, if not impossible, travel path option. However, the envelope may work as an approximation for smaller circles where the angle between the approach and envelope are realistic. The problem of varying speeds between the entry and exit remain a concern nevertheless.

It is concluded that due to the “chicane” type maneuver that creates a situation whereby drivers are faced with:

- both “active” and “passive” obstructions, and
- the necessity to react and turn a steering wheel through consecutive reverse curves

a simple speed – radius relationship such as those reported in literature does not appear to be relevant.

The complexity of the maneuver causes drivers to react differently than they would given a simple curve being negotiated in one direction together with an unforgiving roadway.

Due to a lack of adequate resources and traffic circles to study, it was not possible to determine the behavior of traffic adequately to provide a confident speed – travel radius relationship for traffic circles at present.

6. GEOMETRIC DESIGN

6.1 GEOMETRIC DESIGN CONSIDERATIONS

One primary consideration for the design and safe operation of intersections is the operational and relative traffic speeds in and directly around an intersection.

In the case of traffic circles, the passive regulatory nature requires that operational speeds are low and do not vary greatly. The speeds considered include the entry, circulatory and exit speeds of various classes of traffic at different demand scenarios.

In addition to slowing traffic down adequately to negotiate traffic circles, consideration should be given to the accommodation of the chosen design vehicle. The geometric design of traffic circles is thus largely a trade-off between the accommodation of large design vehicles and the achievement of design speeds of motor cars.

It was concluded from field work carried out for this project, that the estimation of speed – travel radius relationships for traffic circles is not a simple one and could not be satisfactorily studied given the resource constraints, as well as the limited number of circles to study.

In the absence of more reliable information, and despite the identified shortcomings of the speed – radius relationship for the purpose of traffic circle design, the relationship as reported in “*Roundabouts – An Informational Guide, FHWA, (2000)*” is considered as the lower boundary relationship forthwith for the purpose of this study. In addition, the relationship as determined by this study is considered as the upper boundary.

This approach should provide a range within which actual car speeds should fall. The primary focus of this section is thus the accommodation of large design vehicles.

6.2 GEOMETRIC DESIGN PROCEDURE AND CRITERIA

The design procedure set out below is the result of the consideration of all the important factors during the design of single lane traffic circles. The procedure is set up in a sequential manner. A certain amount of iteration was necessary in order to achieve a well-balanced design in terms of entry, circulatory and exit radii.

The traffic circle design procedure for a single lane circle that was followed during this study is summarized as follows:

- a. Decide on the design vehicle to be used
- b. Decide on a design speed (further work required in order to establish guidelines)
- c. Choose an inscribed circle diameter (ICD) for a full conventional circle considering the minimum and maximum roadway width requirements for a single lane circle as well as approach road angles
- d. Carry out a preliminary test to determine whether the chosen ICD can accommodate the design vehicle proving for the necessary clearance. Take note of the circulatory carriageway width requirements. Adjust if necessary
- e. Check whether the ICD can fit into the road reserve with enough verge clearance, if not consider a smaller circle with the use of truck aprons
- f. Establish the desirability of a truck apron in any particular instance
- g. Design the circulatory carriageway area with a central island
- h. Determine whether the likely largest radius passenger vehicle travel path exceeds the maximum in order to achieve deflection, if not consider the use of a truck apron to reduce car speeds
- i. As before, establish the desirability of a truck apron in any particular instance
- j. Design the entry splitter island such that the design speeds can be achieved
- k. Design the vehicle entry clearance for the design vehicle bearing in mind the deflection requirements for smaller vehicles
- l. Check the design vehicle tracking and outside clearance – attempt to minimize the outside kerb radius as per the guidelines presented further along in this report, make use of compound radii if necessary
- m. Attend to the approach roadway and tapers in order to tie in to the entry design

- n. Consider both through movement and left turning movement of the design vehicle during the design of both the entry and exit – the left turning movement is more critical using the entry and exit design method proposed
- o. Design the exit splitter island with a large enough radius to allow for easy exit and return to operational speeds – take note of pedestrian traffic and adjust the exit width in order to accommodate pedestrians if necessary
- p. Exit – check the design vehicle inside clearance (at the splitter island)
- q. Exit – check the design vehicle tracking and outside clearance and minimum kerb line requirements – the minimum design is not necessary unless a large number of pedestrians are present
- r. Assess the departure roadway and tapers in order to tie into the exit design and accommodate the design vehicle

The following did not form part of the scope of this study but are mentioned in order to ensure a more holistic view on the design process:

- a. The splitter island and pedestrian accommodation and refuge on the island if necessary (narrow exit – less crossing distance, slower exit speeds)
- b. Ensure adequate sight distances
- c. Design road markings, signage and lighting
- d. Drainage and super-elevation considerations

6.2.1 Design speeds

Suggested design speeds vary somewhat in available literature. The general range on entry design speeds recommended in literature varies between 25km/h and 50km/h depending on the site category (*FHWA, 2000*).

a) Entry design speed

The entry design speed is related to the circulatory design speed in the sense that it is preferable to achieve minimal relative speed differences between the entry and circulatory speeds. Entry design speeds of around 25km/h to 35km/h are desirable. .

b) Circulatory speed

Circulatory speeds are limited by the deflection and radius around which traffic must travel and thus largely dictate the range of required entry speeds, particularly on larger circles. Circulatory design speeds of between 30km/h to 40km/h are desirable.

6.2.2 Design speed - travel radius considerations

The travel radius is defined as the radius of travel measured from the longitudinal centre line of the vehicle.

A typical travel radius range associated with certain travel speeds was considered instead of a fixed radius for a given speed. The lower boundary of the radius range is based upon the field-experiments carried out in this study and the upper boundary by the AASHTO curve. These values do not account for the complexities of the travel through traffic circles as mentioned.

The speed – travel radius data used during the geometric design process is summarized in Table 6.1.

Table 6.1: Speed – travel radius data from AASHTO and field experiments during this study

Design speed (km/h)	Travel Radius data obtained from field work (m)	AASHTO travel radius data (m)	
		Fixed super-elevation of -2%	Varying super-elevation
20-30	14,3	27,2	27,5
40	22,3	60,5	54,6
60	54,1	206,0	114,5

It is evident that there is a large variation in radii, as determined with the various curves, particularly at higher speeds. However, for the most critical element, namely the entry radius the variation is the lowest.

The lower boundary is considered appropriate due to the fact that this represents the critical situation. Should actual radius data for the design speed under consideration lie between the boundaries, as may be expected, the speeds associated with these lower boundary radii would be lower.

6.2.3 Design vehicles

The freight industry was deregulated during the late 1980's, making it possible to transport goods by road which were generally previously reserved for rail transport. A sharp increase in the heavy vehicle volumes was experienced on South African roads.

For this reason a number of appropriate design vehicles were identified for the geometric design process including vehicles larger than the current South African Design vehicle.

These include:

- WB20 (AASHTO) - ± 22,5m semitrailer
- BDUB / 8 axle inter-link (Austroads) - ± 25m double articulated vehicle
- WB15 (AASHTO) - ± 17m semi trailer
- SUB (AASHTO) - ± 12m single unit bus
- SUT (AASHTO) - ± 9m single unit truck

A set of roadway width versus inscribed circle diameter curves were developed using a spreadsheet based upon tracking paths generated with a CAD based tracking program *Autoturn4*. The curves represent full circle requirements with no provision for truck aprons. These curves are presented in Figure 6.1.

The preferred inscribed circle diameters for various design vehicles given the minimum and maximum circulatory carriageway widths are summarized in Table 6.2 below. These values have been determined given the preferable circulatory carriageway width minimum and maximum limits and the tracking of various design vehicles.

The minimum and maximum circulatory carriageway widths have been set as described below. Although a minimum of less than 6m is theoretically possible a minimum of 6m is recommended to provide enough space within the circulatory carriageway should a vehicle break down and also to compensate for driver variation.

The maximum circulatory carriageway width should be set such that the operational speeds of heavy vehicles are not too low and that the circle is not perceived as a double lane circle by road users. The preferable maximum width should be around 9m with an absolute maximum of 10,5m.

Table 6.2: Recommended ICDs for various design vehicles given the roadway width recommendations

Vehicle	Description	Recommended approximate ICD (m)	Circulatory roadway width (m)
WB20 (AASHTO)	Articulated semi-trailer	55 – 60m	9,5 to 10,1m
BDUB (Austroads)	8 axle interlink – double articulated	45m preferable, 40m min	9,3 to 10,2m
WB15 (AASHTO)	Articulated semi-trailer	40m	8,4m
SUB (AASHTO)	Single Unit Bus	35m	6,7m
SUT (AASHTO)	Single Unit Truck	35m	6,1m

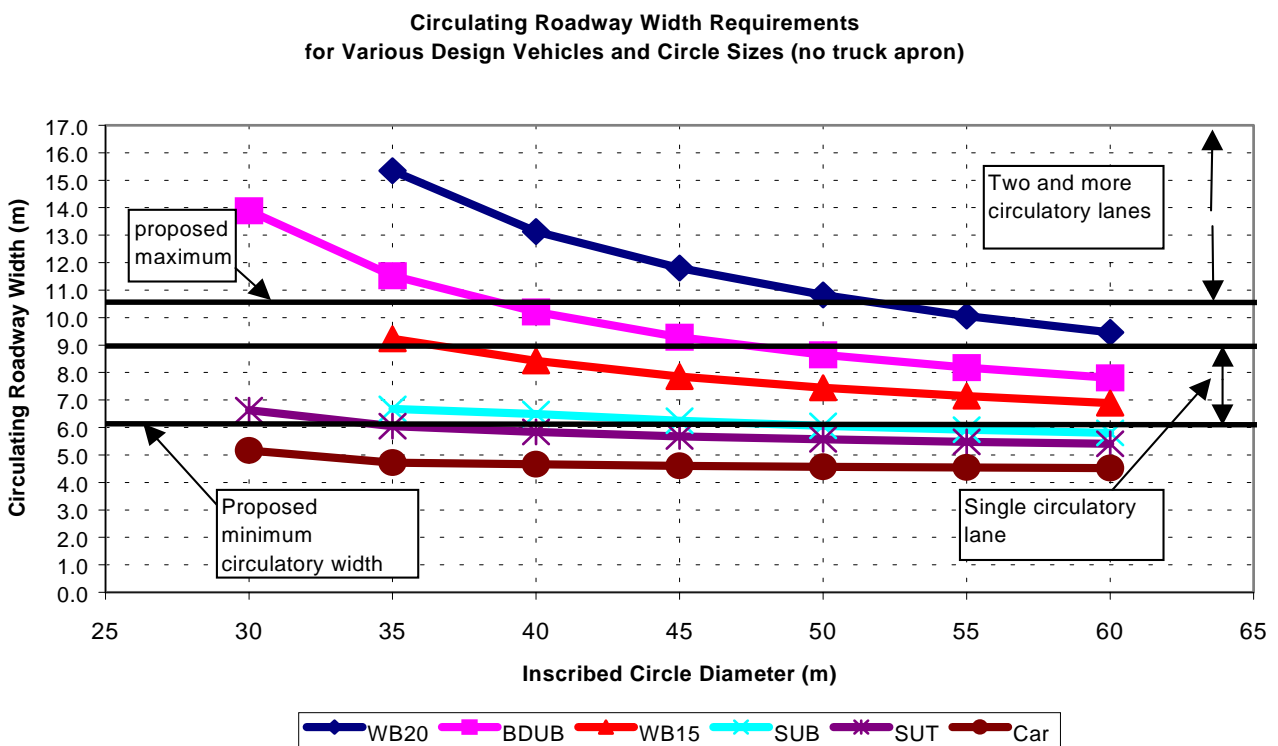


Figure 6.1: Circulatory carriageway requirements for various vehicles and inscribed circle diameters (ICD)

The range of proposed radii for specific design vehicles and ICDs is summarized in Table 6.3 as determined in this study.

Table 6.3: Typical entry and exit kerb radii

Design vehicle	Splitter Radius (m) – inside kerb line		Outside kerb-line radius (m)		
	Entry	Exit	Entry radius A (m)	Entry radius B (m) – minimum	Exit radius (m) – preferable
WB20	20	60	44	25	60
BDUB	20	60	41	20	60
WB15	15	50	37	20	50
SUB	10	40	26	15	40
SUT	10	40	21	15	40

Table 6.4 summarizes proposed entry and exit widths and clearance from the ICD kerb line for left turners associated with the radii reported in Table 6.4.

Table 6.4: Typical entry and exit widths

Design vehicle	Entry width (m)	Exit width (m)	Left turner clearance (LTC) – m #
WB20	6.9	6.8	1.27
BDUB	6.2	6.4	0.51
WB15	5.9	5.8	0.51
SUB	5.0	4.9	0.59
SUT	4.8	4.5	0.43

Note:# - although not the ideal minimum clearance of 0,6m these values are adequate

7. CONCLUSIONS AND RECOMMENDATIONS

With regard to the size requirements of full single lane traffic circles, to accommodate various design vehicles it is concluded that:

- The design vehicle with the largest off-tracking that is likely to use an urban intersection, namely the AASHTO WB20, can be accommodated within an inscribed diameter of 55m,
- The eight axle inter-link, the Austroads B-Double, can be accommodated within an inscribed diameter of 45m,
- The existing South African design vehicle, with a 17m length and equivalent to the AASHTO WB15 design vehicle, can be accommodated within an inscribed diameter of 40m.

In relation to the entry and exit design it is concluded that:

- In order to accommodate the various design vehicles (from the single unit track (SUT) to the large semi-trailer (WB20)) the entry has been designed as a compound curve with two radii in order to accommodate the off-tracking and adequate clearance.
- The first entry radius determined varies between 43,7m and 20,6m while the second radius varies between 25m and 15m.
- The exit radii, which are not as crucial as entry radii for speed control purposes vary between 60m and 40m in order to ensure that vehicles exit from the circle and return to road operating speeds as soon as possible.
- The entry widths vary between 4,8m and 6,9m and the exit widths between 4,5m and 6,8m.

It is concluded, from field data collection exercises and data analysis, that:

- the speed –travel radius relationship for the various elements of traffic circles is complex due to the interaction of each of the elements on one another.
- The load on the driver in terms of having to negotiate a number of reverse curves makes the relationship somewhat more complex than that suggested by literature sources.

This relationship could not be adequately determined due to a lack of resources and suitable traffic circles to study and should be investigated in more depth.

It is recommended that the functional design guidelines relating to:

- the required circle sizes,
- entry and exit designs, and
- central island design

as determined in this study are considered during the design of conventional single lane traffic circles.

8. REFERENCES

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P G PURCHASE, L de V ROODT* and S C van AS*

ARCUS GIBB, P O Box 35007, Menlo Park, 0102

*University of Pretoria

Peter completed a B Eng (Civil) degree at the University of Pretoria in 1993 and commenced employment at Transnet as a bursar. He was primarily involved in risk management, environmental management and permanent way maintenance projects. In 1996 he joined consulting engineers in a contract position as resident engineer on a township development project which included all township infrastructure, bulk infrastructure and low cost housing. During this time he completed the degree B. Eng (Hons) Transportation. Ever since he has been involved in the consulting engineering arena in traffic and transportation engineering projects. Peter completed his M. Eng (Transportation) degree at the University of Pretoria in 2001. He is currently employed by Arcus Gibb in their Pretoria office and is responsible for traffic engineering and transportation projects.