REVIEW OF ROUNDABOUT DESIGN PARAMETERS AND DEVELOPMENT OF A ROUNDABOUT DESIGN GUIDELINE FOR SRI LANKA

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Prof. W.K. Mampearachchi

ABSTRACT

Review of Roundabout Design Parameters and Development of a Roundabout Design Guideline for Sri Lanka

Roundabouts are frequently used in urban areas in Sri Lanka. There is no proper guideline to design roundabouts in Sri Lanka. Increasing traffic and use of long vehicles resulted in malfunctioning some of the roundabouts. Geometry of roundabout has great influence on operation of the roundabouts.

Objectives of the study are to review the roundabout design guidelines, identify the issues in existing roundabouts and formulate a roundabout design guideline for Sri Lanka.

Five major design guidelines were considered to compare the design parameters of roundabout geometry. Twenty four roundabouts spread over major cities were selected for study. Main geometric parameters of each roundabout were collected using field measurements and calibrated satellite images. Standards of local roundabouts were compared with the international roundabout guidelines. Swept path analysis was carried out on selected roundabout layout for single unit truck to determine the adequacy of entry width, circulation width, exit width and operational speed. Design parameters that need to be improved on existing roundabout were identified and suitable values for selected design parameters were proposed.

Key Words: Design Parameters, Guidelines, Roundabouts

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E.M.C.B. Ekanayake

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ABBREVIATIONS AND ACRONYMS

AASHTO	-American Association of State Highway and Transportation Officials
AUSTROADS	-Association of Australian and New Zealand Road Transport and Traffic Authorities
CID	-Central Island Diameter
DMRB	-Design Manual for Roads and Bridges
ICD	-Inscribed Circle Diameter
ISTEA	-Intermodal Surface Transportation Efficiency Act
MEW	-Maximum Entry Width
RA	-Roundabout
US DOT	-US Department Of Transportation

CHAPTER ONE

INTRODUCTION

1.1 General

Sri Lanka has been thriving though rapid development process since the 30 year old civil war has ended. Currently people of Sri Lanka have been experiencing a local industrial revolution. Lots of high rises, harbours, air ports, highways are been constructed within a short period of time. The major threat for the Sri Lankans was the civil war which restricted the free life of people. As the war ends people tend to travel more, goods and services are reaching to almost every doorstep without any fear or delay. This has made sudden peaks of accessibility and mobility which is a major component of transportation and highway engineering. With the development of road network, the number of trips generated were increased. This has resulted in increment of vehicle usage and the traffic congestions in urban areas. So the local authorities tend to incorporate traffic controlling measures by introducing junctions, roundabouts, intersections, signal lights etc.

Roundabouts have been used frequently in urban areas with more mobility such as Colombo, Gampaha, Anuradhapura and Galle. Well-designed roundabouts have proven to be safe and efficient forms of intersection control (State of Maryland department of transportation, 1995). The use of roundabout in Sri Lankan transportation does not have long history. It has been a new experience for Sri Lankans. However, the operation of roundabout has seemed to be not followed at all as well as this has led delays and accidents at certain roundabout locations.

1.2 Problem Statement

In Sri Lanka, roundabouts are frequently used in urban areas. Roundabouts provide solutions for intersections having capacity/delay issues, intersections in which traffic signals were requested but not warranted and four way stop intersections etc. Roundabouts are more effective for locations with high accident particularly with right turn or right angle accidents.

However, in Sri Lankan context, there are some problematic locations where roundabouts have been identified as inappropriate traffic control devises. However, following site conditions are generally considered as inappropriate locations for roundabouts where;

1. Satisfactory geometric design cannot be provided
2. Signals interconnected system would provide a better level of service
3. Selection of proper signal timing can solve the existing issues,
4. Reversible lanes may be employed in peak period,
5. The roundabout would be close to existing signals and queuing from the signal could be a problem.

Geometry of roundabout is very important for proper function of the roundabout. Some of constructed roundabouts in Sri Lanka are underperforming causing accidents and delays. Sri Lanka does not have own design guideline to follow at geometric design stage. Hence it is advisable to check the design parameters of selected roundabouts as per with reputed and latest international design guidelines.

So, the authorities can identify the roundabouts, which needed geometric improvements and propose values for design parameters to develop design guideline for Sri Lanka.

1.3 Objectives

The objectives of this study are to;

1. Review the Roundabout Design Guidelines of Selected countries
2. Identify the design issues of important roundabouts located in major cities in Sri Lanka and compare the values of design parameters with international guidelines.
3. Propose factors to be considered in developing a design guideline for Sri Lanka.

1.4 Research Approach

The following research approach was adopted to achieve the above research objectives.

- Identify major roundabouts in Sri Lanka for the study. Three factors were considered selecting the roundabouts as RA located in major cities with high traffic, RA act as a node for multiple major roads and RA in cities with frequent roundabouts with minimal restrictions by surrounding.
- Development of detailed roundabout layout. Collected field data and satellite images were combined to develop the roundabout layout.
- Design parameters extracted from RA layout were compared with the values proposed in international design guidelines.
- Swept path analysis were carried out for SU vehicle to check the adequacy of entry width, circulation width, exit width and operational speed.
- Propose the parameters that need to be improved on existing roundabout and factors to be considered in developing a design guideline for Sri Lanka.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

A roundabout is a type of circular intersection or junction in which road traffic flows almost continuously in one direction around a central island. The single greatest benefit of roundabouts is that they eliminate perpendicular T-bone crashes.

The modern form was standardized in the United Kingdom. And the "modern" roundabouts require entering traffic to yield to traffic already in the circle and optimally observe various design rules to increase safety. Variations on the basic concept include integration with tram and/or train lines, two-way flow, higher speeds and many others.

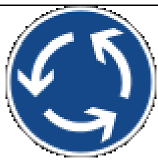
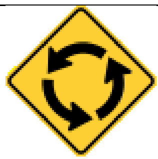
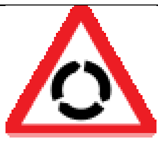
Traffic exiting the roundabout comes from one direction, rather than three, simplifying the pedestrian's visual environment. Traffic moves slowly enough to allow visual engagement with pedestrians, encouraging deference towards them. Other benefits include reduced driver confusion associated with perpendicular junctions and reduced queuing associated with traffic lights. They allow U-turns within the normal flow of traffic, which often are not possible at other forms of junction (Ren at el, 2014). Moreover, since vehicles on average spend less time idling at roundabouts than at signalized intersections, using a roundabout potentially leads to less pollution. Also, when entering vehicles only need to yield, they do not always perform a full stop. As a result, by keeping a part of their momentum, the engine will produce less work to regain the initial speed, resulting in lower emissions. Additionally, slow moving traffic in roundabouts makes less noise than traffic that must stop and start, speed up and brake.

Modern roundabouts are commonplace throughout the world, in particularly Australia, Belgium, People's Republic of China, Costa Rica, Cyprus, Denmark, France, Germany, Hungary, Iceland, Indonesia, Republic of Ireland, Israel, Luxembourg, Malaysia, Morocco, the Netherlands, New Zealand, Poland, Portugal, Qatar, Spain, Trinidad and Tobago, the United Arab Emirates, and the United

Kingdom. Half of the world's roundabouts are in France (more than 30,000 as of 2008) (Douglas, 2011).

Table 2.1 shows the road sign used in several countries for roundabouts.

Table 2.1: Examples of roundabouts in several countries

Roundabout sign	Description
	Germany (right-hand traffic); in the UK a similar sign, with the arrows reversed, is used at mini roundabouts.
	The US and Canada (right-hand traffic); a similar sign is used in Ireland (with directions reversed).
	UK (left-hand traffic)
	Australia (left-hand traffic)

Following locations are identified as suitable locations for roundabouts (State of Maryland department of transportation 1995)

1. High accident locations (with left turn or right angle accidents particularly).
2. Capacity/delay problem intersections.
3. Intersections in which traffic signal were requested but not warranted.
4. Intersection meeting warrants for a traffic signal.
5. 4-way stop intersection.

Following sites can be identified as appropriate sites for roundabouts (State of Maryland department of transportation 1995)

- Heavy delay on minor road.
- Traffic signals that result in greater delay and possibly reduced safety.
- Intersection with heavy left turning traffic.
- Intersection with more than four legs or unusual geometry.

- At rural intersections (including those in high speed areas) at which there are accidents involving crossing traffic.
- Where major roads intersect at "Y or "T" junctions.
- At locations where traffic growth is expected to be high and where future traffic patterns are uncertain or changeable.
- At intersections where U-turns are desirable.
- At Freeway Interchange Ramps.
- High accident intersections where left turn and right angle accidents are prominent.

Following sites can be identified as appropriate sites for roundabouts

- Where a satisfactory geometric design cannot be provided.
- Where signals interconnect system would provide a better level of service.
- Where it is desirable to be able to modify traffic via signal timings.
- Where peak period reversible lanes may be employed.
- Where the roundabout would be close to existing signals and queuing from the signal could be a problem.

2.2 History of Roundabouts

Circular junctions existed before roundabouts, including the Bath Circus world heritage site completed in 1768, the 1907 Place de l'Étoile around the Arc de Triomphe in Paris, the 1904 Columbus Circle in Manhattan, and several circles within Washington, D.C.. The operating and entry characteristic of these circles differs considerably from modern roundabouts. The first British circular junction was built in Letchworth Garden City in 1909. Its centre originally was intended partly as a traffic island for pedestrians. In the early twentieth century, numerous traffic circles were constructed in the United States, particularly in the northeast. Examples include a circle in Atherton, California (Wiki, 2015).

Figure 2.1: Thomas Circle in Washington, D.C., 1922

Widespread use of the modern roundabout began when Transport Research Laboratory engineers re-engineered circular intersections during the 1960s.Frank Blackmore led the development of the offside priority rule and subsequently invented the mini-roundabout to overcome capacity and safety limitations. The design became mandatory in Britain for all new roundabouts in November 1966. This yield requirement has been the law in New York State since the 1920s.

In the United States modern roundabouts emerged in the 1990s. They faced some opposition from a population mostly unaccustomed to them. American confusion at how to enter and how to exit a roundabout was the subject of mockery such as featured in the film European Vacation and the television series, The Simpsons. By 2011, however, some 3,000 roundabouts had been established, with that number growing steadily. The first modern roundabout in the United States was constructed in Summerlin, Nevada in 1990. This roundabout occasioned dismay" from residents, and a local news program said about it, "Even police agree, they (roundabouts) can be confusing at times."

As of the beginning of the twenty-first century, roundabouts were in widespread use in Europe. For instance, in 2010 France had more than 30,000 roundabouts.
In the United States, municipalities introducing new roundabouts often are met with some degree of public resistance, just as in the United Kingdom in the 1960s. Surveys show that negative public opinion reverses as drivers gain experience with them. A 1998 survey of municipalities found public opinion 68% opposed prior to construction; changing thereafter to 73% in favour. A 2007 survey found public

support ranging from 22% to 44% prior to construction, and several years after construction was 57% to 87%.

Figure 2.2: Small roundabout in Barzio, Italy

Figure 2.3: Roundabout in Braşov, Romania

A pedestrian group in Kinston, North Carolina in 2007 proposed roundabouts in place of traffic lights at major intersections.

A "modern roundabout" is a type of looping junction in which road traffic travels in one direction around a central island and priority is given to the circulating flow. Signs usually direct traffic entering the circle to slow and to yield the right of way. Because low speeds are required for traffic entering roundabouts, they usually are not used on controlled-access highways, but may be used on lower grades of highway such as limited-access roads. When such roads are redesigned to take advantage of roundabouts, traffic speeds must be reduced via tricks such as curving the approaches.

2.3 Roundabout Types

2.3.1 Conventional roundabouts

A conventional roundabout is defined as one which is circular in shape and in which all vehicles circulate counter clockwise around a central island. A truck apron maybe used to allow for over tracking of large vehicles. An example of a conventional roundabout is shown in Figure 2.4.

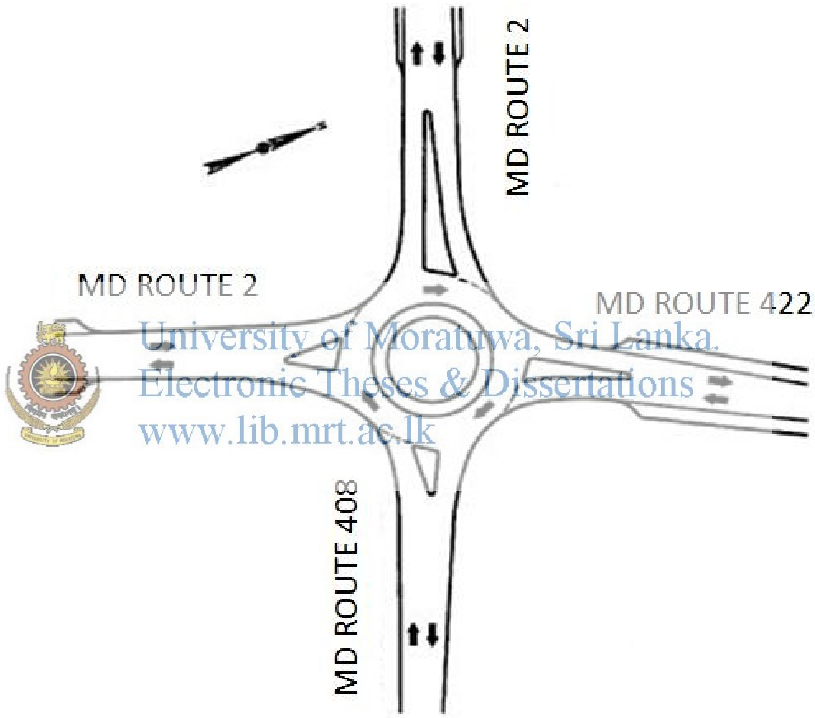


Figure 2.4: Conventional Roundabout

2.3.2 Mini-Roundabout

A mini-roundabout is defined as a roundabout with a fully mountable central island. There are no opportunities for landscaping at a mini-roundabout. The central island would fits within the footprint of the existing intersection. Mini-roundabouts should be restricted to low volume, low speed roadways with prohibited or restricted truck movements. An example of a mini-roundabout is shown in Figure 2.5.

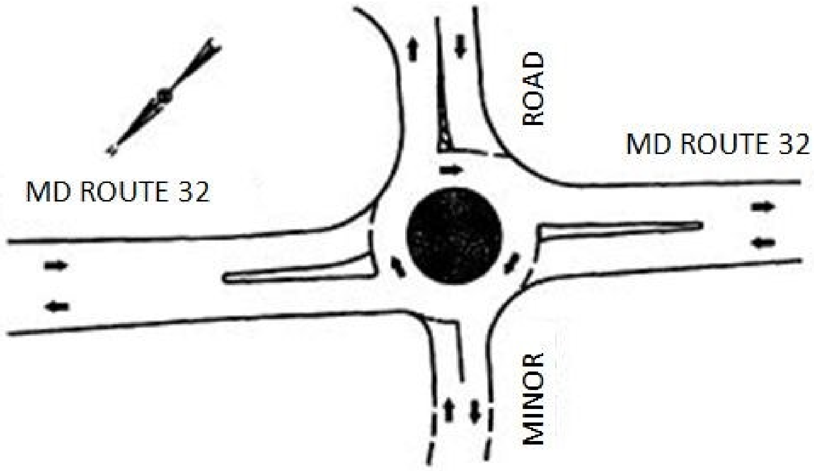


Figure 2.5: Mini-roundabout

2.3.3 Raindrop roundabouts

Raindrop roundabouts do not form a complete circle and have a raindrop or teardrop shape. They appear at U.S. Interstate interchanges to provide a free-flowing left turn to the on-ramps and eliminating the need for turn signals and lanes. Since the entry and exit slip roads are one-way, a complete circle is unnecessary. This means that drivers entering the roundabout from the bridge do not need to give way, and that prevents queuing on narrow, two-lane bridges. These roundabouts have been used at dumbbell roundabout junctions, replacing traffic signals that are inefficient without a turning lane. Several junctions along Interstate 70near Avon, Colorado use teardrop roundabouts.

Figure 2.6: Raindrop roundabout at an Interstate interchange in North Carolina

2.3.4 Turbo roundabouts

In the Netherlands, Poland, Slovenia, Czech, Hungary and Belgium, a relatively new type of roundabout is emerging. It provides a forced spiralling flow of traffic, requiring motorists to choose their direction before entering the roundabout. By eliminating many conflicting paths and choices on the roundabout itself, traffic safety is increased, as well as speed, and capacity. A turbo roundabout only allows a U-turn from two directions.

Several variations of the turbo roundabout exist. The basic shape is designed for the intersection of a major road crossing a road with much less traffic.
Turbo roundabouts were originally built with raised lane separators. Only lane markings increase efficiency (regarding safety, speed, and capacity) by reducing the safety risk and enabling maintenance vehicles such as snow ploughs. Similar roundabouts, with spiralling lane markings, have been used for many years in the UK.

According to simulations, a two-lane roundabout with three right turns should offer 12-20% greater traffic flow than a conventional, three-lane roundabout of the same size. The reason is reduced weaving that makes entering and exiting more predictable. Because there are only ten points of conflict (compared with 8 for a conventional single lane roundabout, or between 32 and 64 with traffic signal control), this design is often safer as well. At least 70 have been built in the Netherlands, while many turbos (or similar, lane splitting designs) can be found in Southeast Asia. Multi-lane roundabouts in the United States of America are typically required to be striped with spiral markings, as most states follow the federal Manual on Uniform Traffic Control Devices.

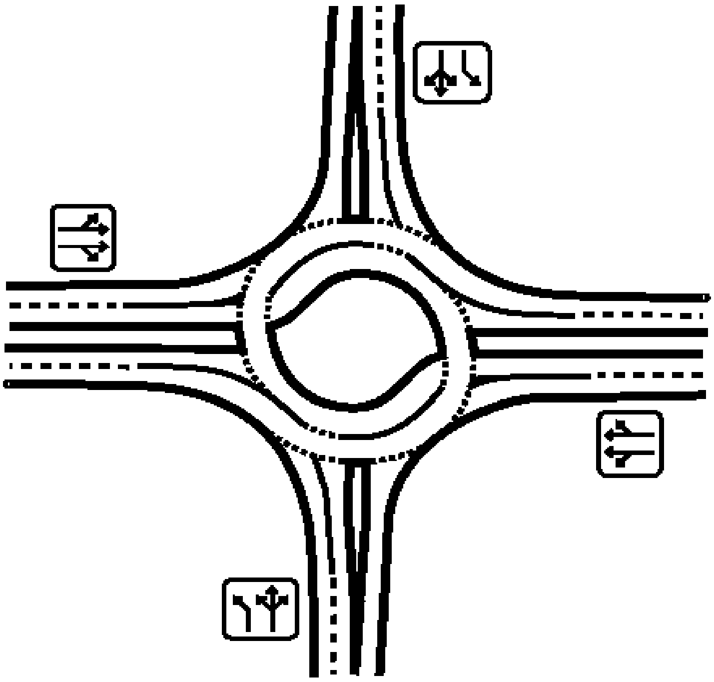


Figure 2.7: The basic shape of the Dutch turbo roundabout

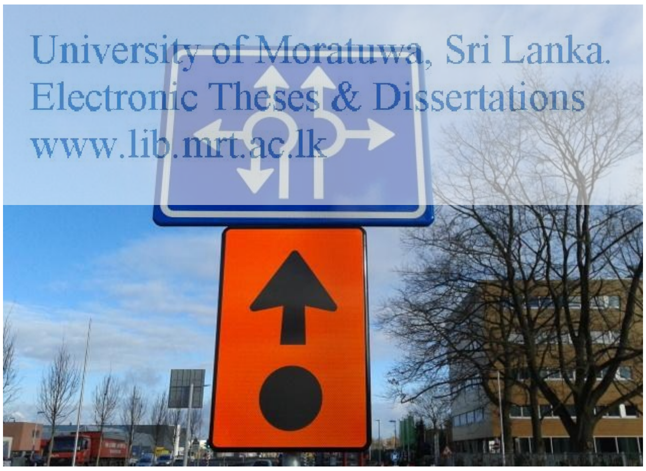


Figure 2.8: Turbo roundabout road sign in the Netherlands

2.3.5 Other types of roundabouts

Roundabouts can be designed in shapes other than circular. For example, an oval shaped roundabout is shown in Figure 2.9. This shape keeps the overall size of the roundabout to a minimum while providing access to all approach legs.

An oval roundabout may also be used where one intersecting street is considerably wider than the other and/or where a wide median exists. This is illustrated in Figure

2.10. Very often in these types of intersections, a roundabout will not be the appropriate treatment. However, where the volume of traffic on the narrower street is greater or equal to that on the wider street and if there are heavy left turn flows, a roundabout could be suitable.

Figure 2.9: Oval Roundabout (Artistic Rendering)

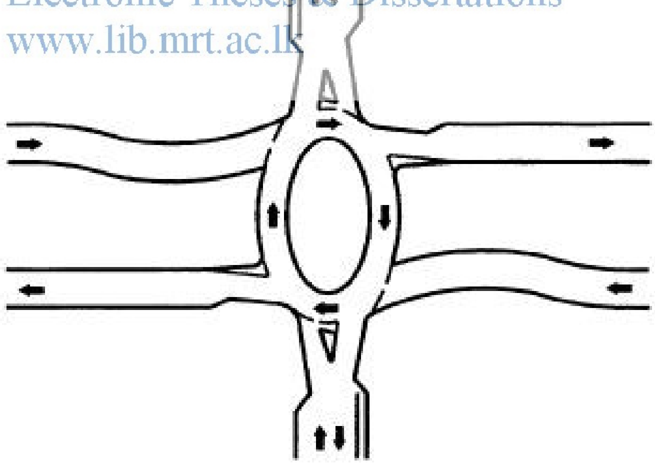


Figure 2.10: Roundabout on a road with a very wide median

Roundabouts should be considered at interchange ramp termini and compared to other conventional interchange designs. The interchange roundabouts may result in less delays and accidents and may be less costly when compared to other interchanges. An example of an interchange roundabout is shown in Figure 2.11.

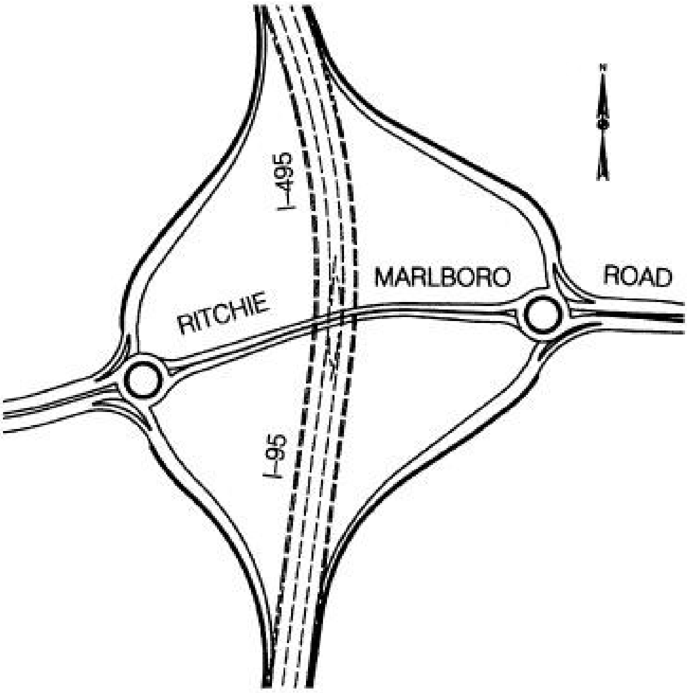


Figure 2.11: I-95/Riichie-Marlboro Road Interchange

Aside from the safety benefits, perhaps one of the more significant features of the roundabout is the reduction in delays which, in turn, reduces auto emissions. With the ever increasing emphasis on air quality (i.e. ISTEA legislation) roundabouts could be a simple solution to solving traffic engineering problems while reducing the pollutants that our automobile-based society imposes on the natural environment.

2.4 Components of a Roundabout

A modern roundabout is a circular intersection that regulates traffic without the signs or lights used in traditional intersections. A roundabout provides a safer driving environment by reducing speeds and conflict points, thus allowing easier decision-making for drivers. Studies have shown that roundabouts have fewer crashes and are more efficient than traditional intersections. It is important to familiarize the features of a roundabout before moving forward in the studies. Figure 2.12 shows a basic sketch of a roundabout with important features that is necessary to operate a roundabout at its best.

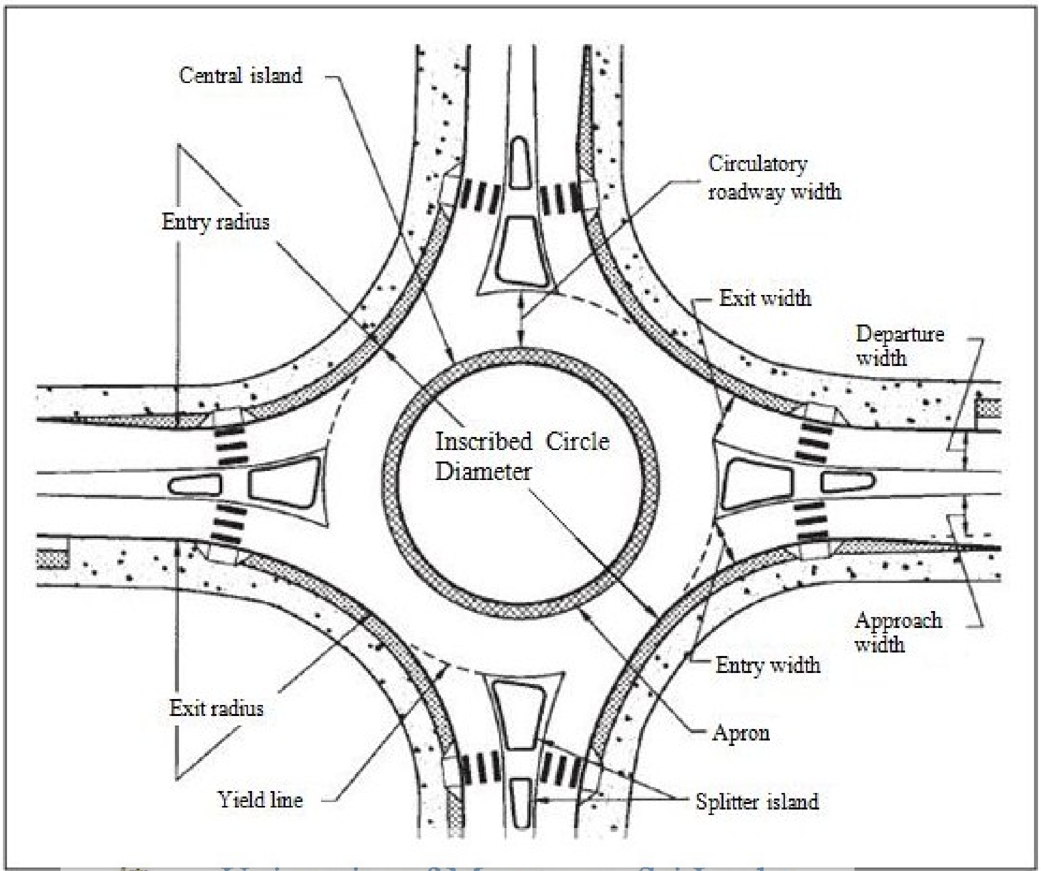


Figure 2.12: Basic geometric elements of a roundabout

2.4.1 Inscribed circle diameter

The inscribed circle diameter is the distance across the circle inscribed by the outer curb (or edge) of the circulatory roadway. It is the sum of the central island diameter (which includes the apron, if present) and twice the circulatory roadway. The inscribed circle diameter is determined by a number of design objectives. The designer often has to experiment with varying diameters before determining the optimal size at a given location (US DOT, 2001).

Larger roundabouts enable better geometry to be designed. Increasing the diameter of a roundabout usually enables provision of better approach geometry which leads to a reduction in vehicle approach speeds. An increase in roundabout diameter will also usually provide a reduction in the angle formed between the entering and circulating vehicle paths thus reducing the relative speed between these vehicles which in turn lowers the entering/circulating vehicle accident rate.

Larger roundabouts also provide greater separation between adjacent conflict areas and make it easier for entering drivers to determine whether vehicles, already on the circulating carriageway, are exiting or continuing on around the circulating carriageway.

In general, roundabouts in areas with high desired speeds need larger diameters to enable better approach geometry to be designed to reduce the high approach speeds. The design of these roundabouts is more critical than that for roundabouts located in areas with low desired speeds.

The roundabout diameter should be limited to maximum of 200m. Larger diameters will encourage high circulating speeds and may encourage wrong way movements if drivers perceive that the time taken to traverse the roundabout is too long (AUSTROADS, 1993).

2.4.2 Entry width

Entry width is the largest determinant of a roundabout's capacity. The capacity of an approach is not dependent merely on the number of entering lanes, but on the total width of the entry. In other words, the entry capacity increases steadily with incremental increases to the entry width. Therefore, the basic sizes of entries and circulatory roadways are generally described in terms of width, not number of lanes. Entry width is measured from the point where the yield line intersects the left edge of the travelled-way to the right edge of the travelled-way, along a line perpendicular to the right curb line. The width of each entry is dictated by the needs of the entering traffic stream. It is based on design traffic volumes and can be determined in terms of the number of entry lanes. The circulatory roadway must be at least as wide as the widest entry and must maintain a constant width throughout(US DOT, 2001).

2.4.3 Circulatory roadway width

The required width of the circulatory roadway is determined from the width of the entries and the turning requirements of the design vehicle. In general, it should always be at least as wide as the maximum entry and should remain constant throughout the roundabout (US DOT, 2001).

2.4.4 Central Island

Figure 2.13: Central Island

The central island of a roundabout is the raised, non-traversable area encompassed by the circulatory roadway; this area may also include a traversable apron. The island is typically landscaped for aesthetic reasons and to enhance driver recognition of the roundabout upon approach. Central islands should always be raised, not depressed, as depressed islands are difficult for approaching drivers to recognize.

In general, the central island should be circular in shape. A circular-shaped central island with a constant-radius circulatory roadway helps promote constant speeds around the central island. Oval or irregular shapes, on the other hand, are more difficult to drive and can promote higher speeds on the straight sections and reduced speeds on the arcs of the oval. This speed differential may make it harder for entering vehicles to judge the speed and acceptability of gaps in the circulatory traffic stream.

It can also be deceptive to circulating drivers, leading to more loss-of-control crashes. Noncircular central islands have the above disadvantages to a rapidly increasing degree as they get larger because circulating speeds are higher. Oval shapes are generally not such a problem if they are relatively small and speeds are low. Raindrop-shaped islands may be used in areas where certain movements do not exist, such as interchanges (see Chapter 8), or at locations where certain turning movements cannot be safely accommodated, such as roundabouts with one approach on a relatively steep grade (US DOT, 2001).

2.4.5 Entry curves

The entry curves are the set of one or more curves along the right curb (or edge of pavement) of the entry roadway leading into the circulatory roadway. It should not be confused with the entry path curve, defined by the radius of the fastest vehicular travel path through the entry geometry.

The entry radius is an important factor in determining the operation of a roundabout as it has significant impacts on both capacity and safety. The entry radius, in conjunction with the entry width, the circulatory roadway width, and the central island geometry, controls the amount of deflection imposed on a vehicle's entry path. Larger entry radii produce faster entry speeds and generally result in higher crash rates between entering and circulating vehicles. In contrast, the operational performance of roundabouts benefits from larger entry radius. The entry curve is designed curvilinear tangential to the outside edge of the circulatory roadway. Likewise, the projection of the inside (left) edge of the entry roadway should be curvilinear tangential to the central island. Figure 2.14 shows typical roundabout entrance geometry.

The primary objective in selecting a radius for the entry curve is to achieve the speed objectives. The entry radius should first produce an appropriate design speed on the fastest vehicular path. Second, it should desirably result in an entry path radius equal to or less than the circulating path radius (US DOT, 2001).

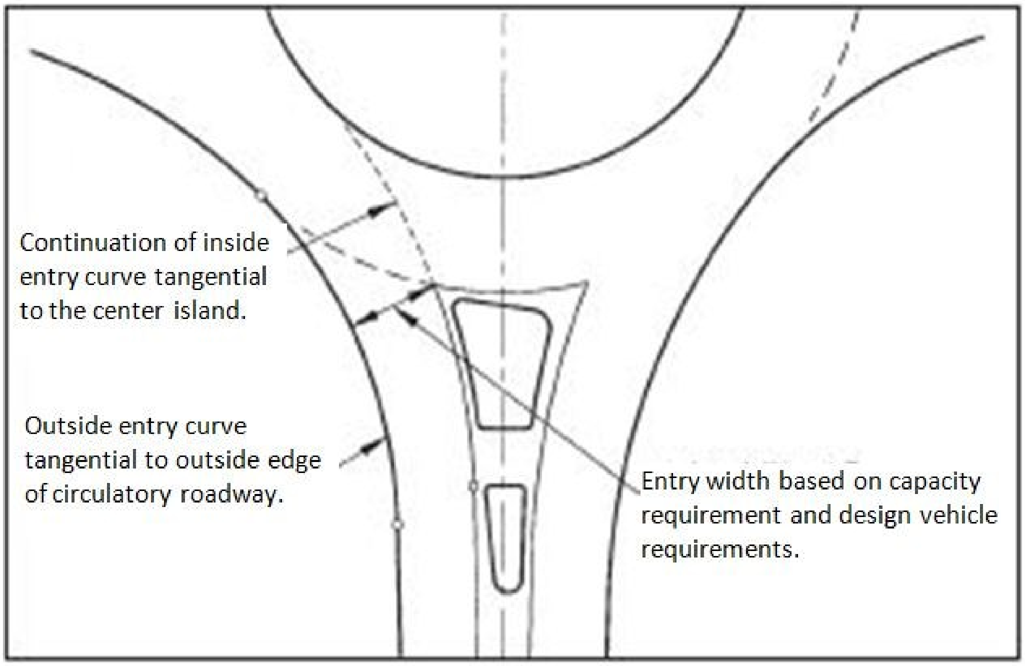


Figure 2.14: Entry Curve at Single Lane Roundabout

Adopted from USDOT, 2001

2.4.6 Exit curves

Exit curves usually have larger radii than entry curves to minimize the likelihood of congestion at the exits. This, however, is balanced by the need to maintain low speeds at the pedestrian crossing on exit. The exit curve should produce an exit path radius (R_3 in Figure 2.15) no smaller than the circulating path radius (R_2). If the exit path radius is smaller than the circulating path radius, vehicles will be travelling too fast to negotiate the exit geometry and may crash into the splitter island or into oncoming traffic in the adjacent approach lane. Likewise, the exit path radius should not be significantly greater than the circulating path radius to ensure low speeds at the downstream pedestrian crossing.

The exit curve is designed to be curvilinear tangential to the outside edge of the circulatory roadway. Likewise, the projection of the inside (left) edge of the exit roadway should be curvilinear tangential to the central island. Figure 2.16 shows a typical exit layout for a single-lane roundabout (US DOT, 2001).

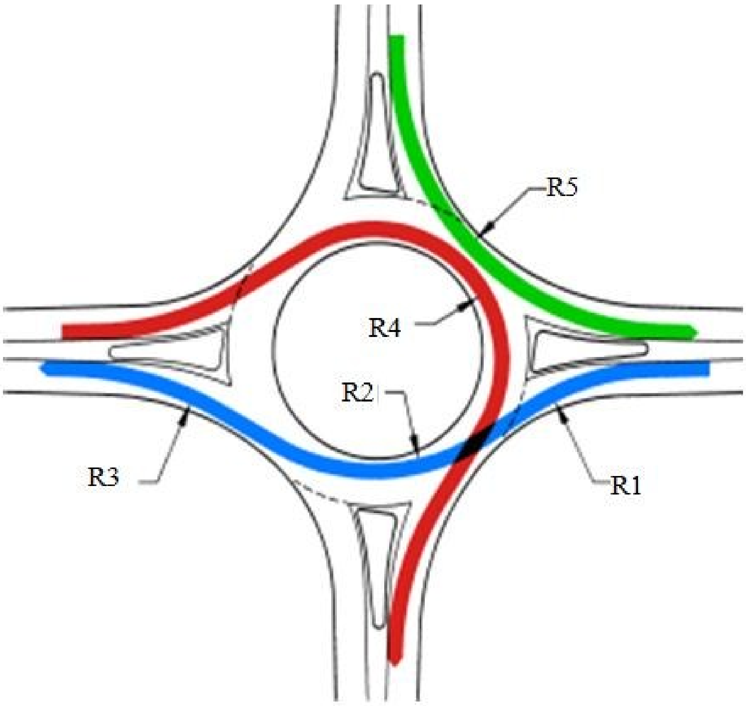


Figure 2.15: Vehicle path radii.

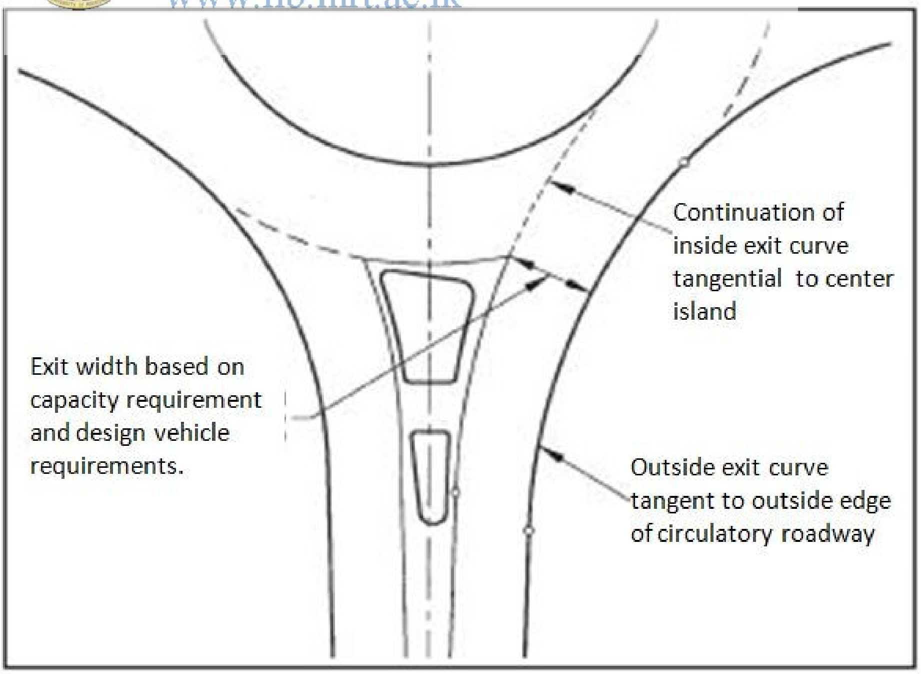


Figure 2.16: Single lane roundabout exit design

Adopted from USDOT, 2001

In areas where there are no pedestrians, the exit from a roundabout should be as easy to negotiate as practicable. After having been slowed down by the entry and circulating curves, vehicles should be able to accelerate on the exit. Therefore, the radius of the exit curve should generally be greater than the circulating radius. Ideally, a straight path tangential to the central island, as shown in Figure 14.17, is preferable for vehicles (where there is negligible pedestrian activity), in contrast to the curved entering path. In areas where there are pedestrians, the exit speed should be minimized. The best solution to minimize the exit speed is to provide a small radius exit curve. Figure 2.17 shows a desirable roundabout treatment where pedestrian crossings are required (AUSTROADS, 1993).

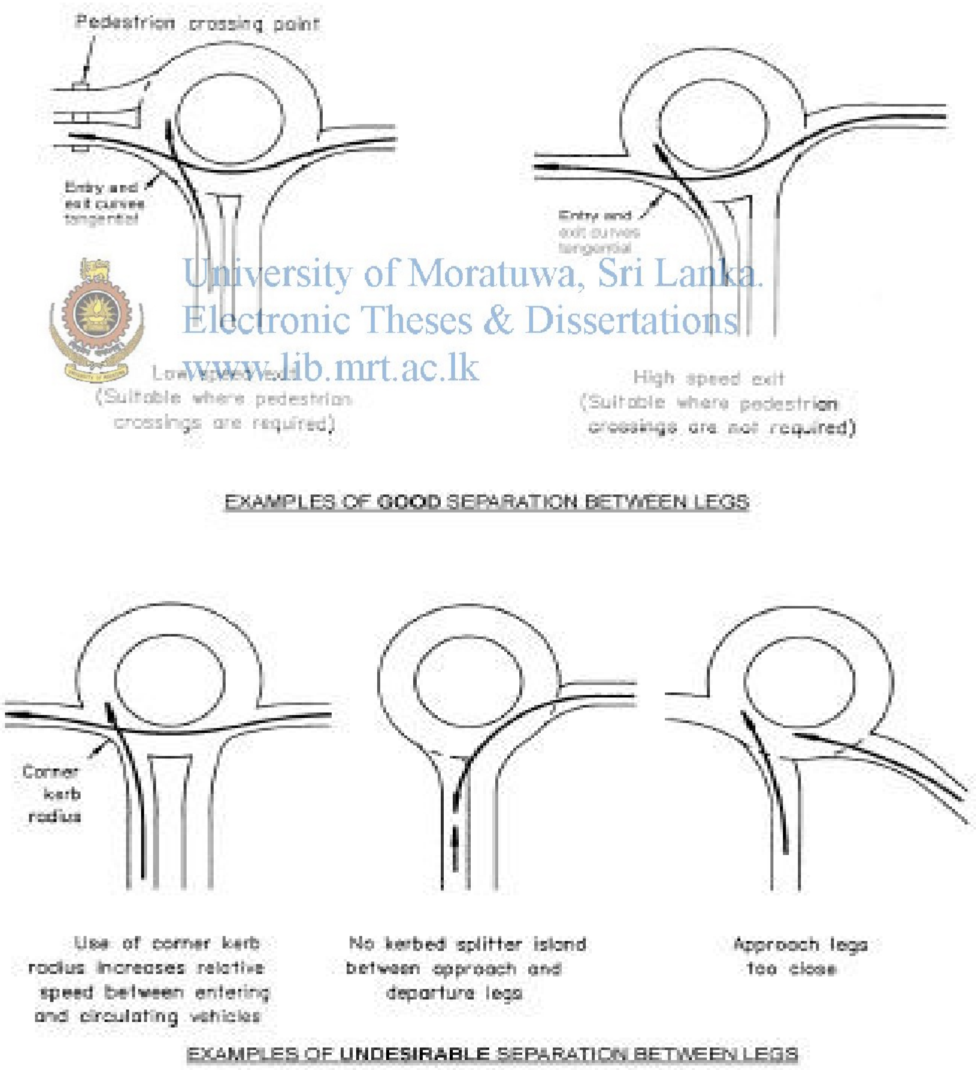


Figure 2.17: Desirable Roundabout Treatment

Adapted from Roundabouts', in Road planning and design manual, Queensland Department of Main Roads, 2006.

2.4.7 Flare length

The theoretical capacity is very sensitive to changes in the flare length. Flare should be developed uniformly, without any sharp changes in angle, if it is to be used effectively in practice. Figure 2.18shows the average flare length (ℓ'). This is obtained by constructing a line parallel to curb, from point C, which is at a distance of [(e-v)/2] from point B. Point F' is where this line intersects with the line GD(which is parallel to the line HA). The average flare length ℓ' is measured along the curved line CF'.

The minimum value of flare ℓ' should be 5m in an urban area, and 15m in a rural area. The upper limit should be 40m. The sharpness of flare is a measure of the rate at which extra width is developed and calculated from the relationship S= 1.6(e-v)/ℓ'. The sharpness of flare should not exceed 1.0 in urban areas or 0.3 in rural areas(Geometric design for Dubai roads, 2002).

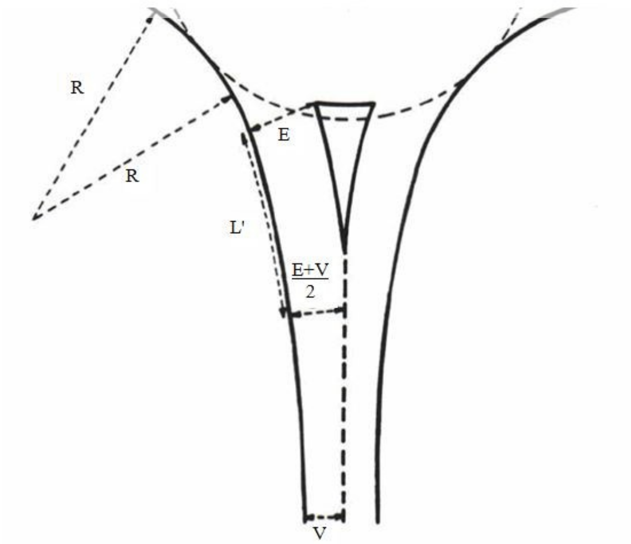


Figure 2.18 Average Flare Lengths (L')

2.4.8 Entry path deflection

One of the most important safety checks at a roundabout is vehicle path deflection on entry to a roundabout. It is necessary in order to ensure that excessive speeds through the roundabout cannot occur. For design purposes, the vehicle entry path should be such that the radius of the tightest curve on the entry path does not exceed 100 meters. This is shown in Figure 2.19 and 2.20 (Geometric design for Dubai roads, 2002).

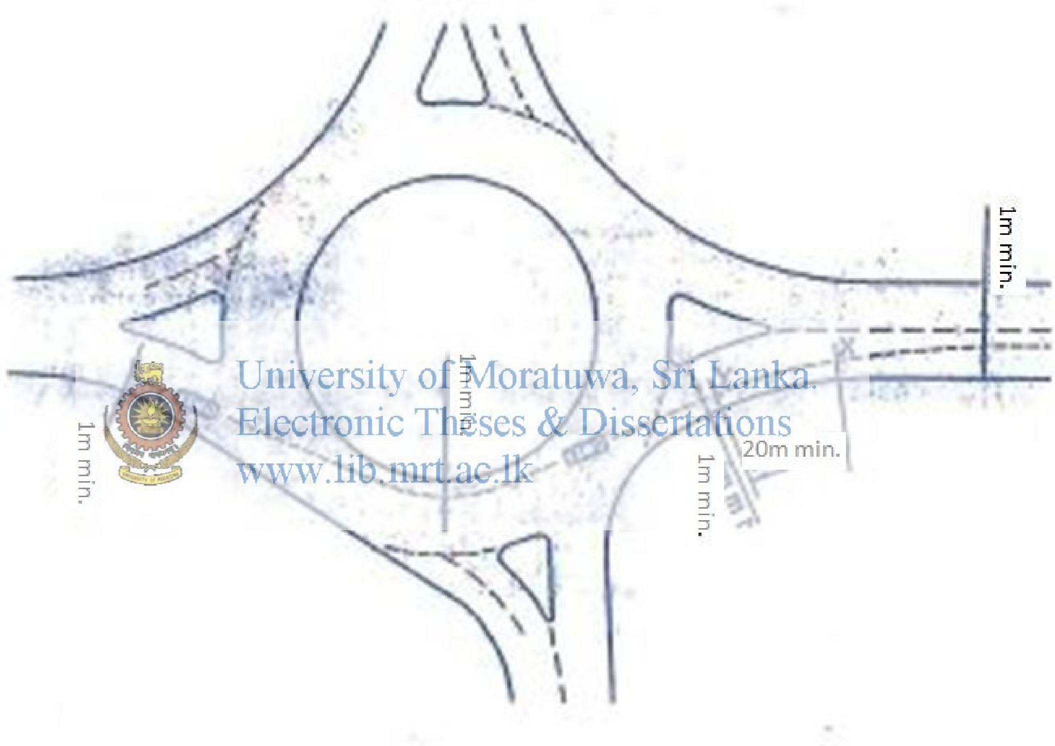


Figure 2.19: Entry Path Curvature

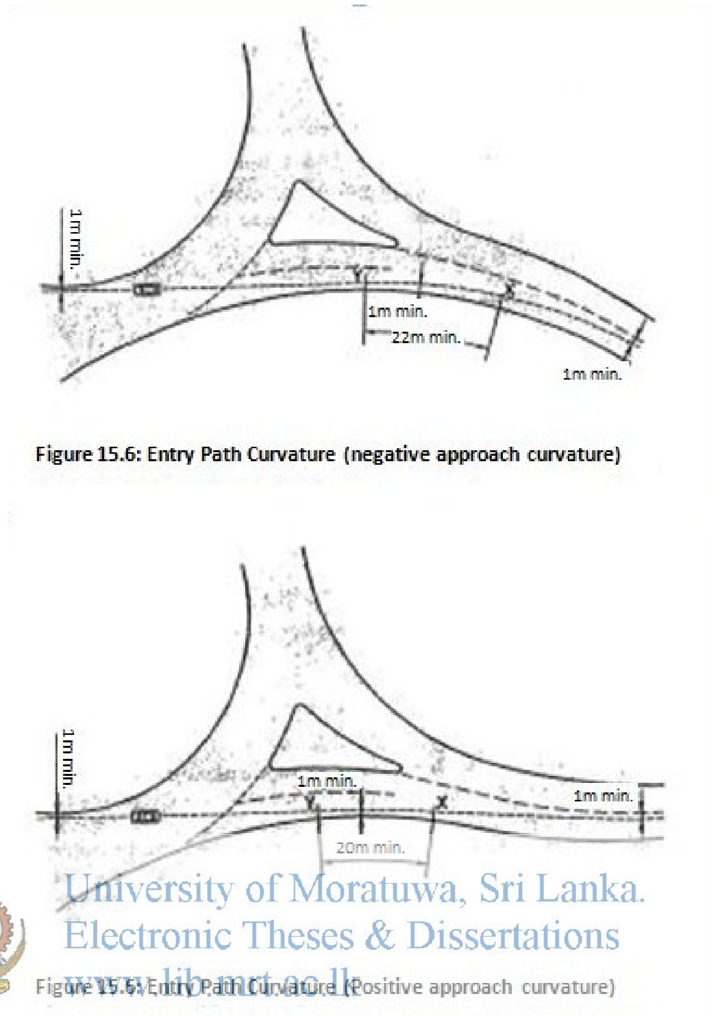


Figure 2.20: Entry Path Curvature (Positive and Negative Approach Curvatures)

The entry curve is one of the most important geometric parameters to be designed at roundabouts. A left hand entry curve must be used. The provision of an appropriate radius on the entry curve encourages drivers to slow down before reaching the roundabout. This is similar to the use of horizontal curves to transition from a horizontal element with a high operating speed to a substandard curve. Care should be taken to ensure that the entry curve radius is not so large as to result in an unacceptably high speed entry onto the circulating carriageway. Figure 2.21 shows desirable and undesirable approach geometry (AUSTROADS, 1993).

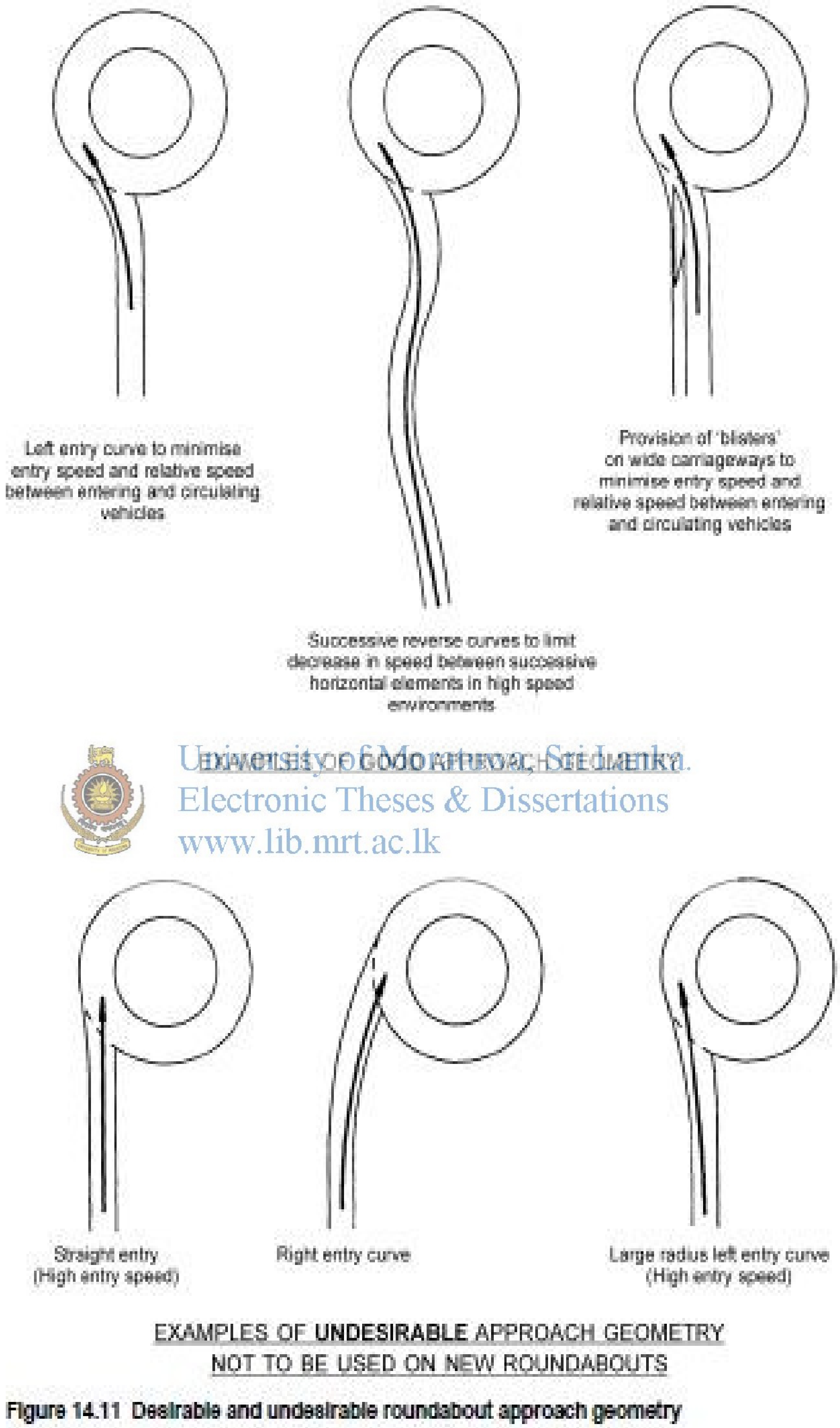


Figure 2.21: Desirable and Undesirable Approach Geometry

2.4.9 Entry angle

The Entry Angle ($) serves as a geometric property for the conflict angle between entering and Circulating streams. The method of measuring the Entry Angle is set out in Figure 2.22.

The line EF is midway between the outer curb and the median line or the edge of any median island. Where this curved line intersects the "Give Way" line, the tangent BC is drawn. A'D' is the centre line of the circulating pavement. The entry angle Φ is measured as the acute angle between the line BC and the tangent to A'O' at the point of intersection between BC and A'O'.

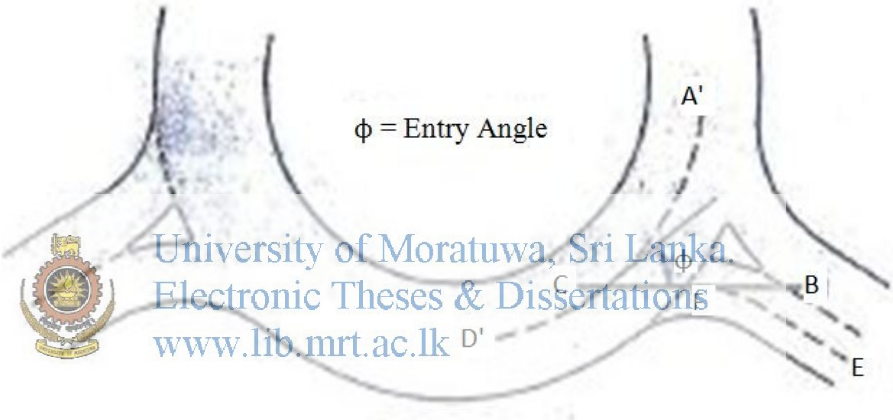


Figure 2.22: Measurement of Entry Angle

Tile relationship between entry angle and entry capacity is a weak inverse one; as the angle increases, so capacity decreases slightly. However, care should be taken in the choice of entry angle, because angles which are too high and angles which are too low may both result in increased accident potential. A small entry angle such as that depicted in Figure 2.23 forces drivers into a position where they must either look over their left shoulders or attempt a true merge using their mirrors (with the attendant problems of disregarding the "Give Way" line and the encouragement of high entry speeds).

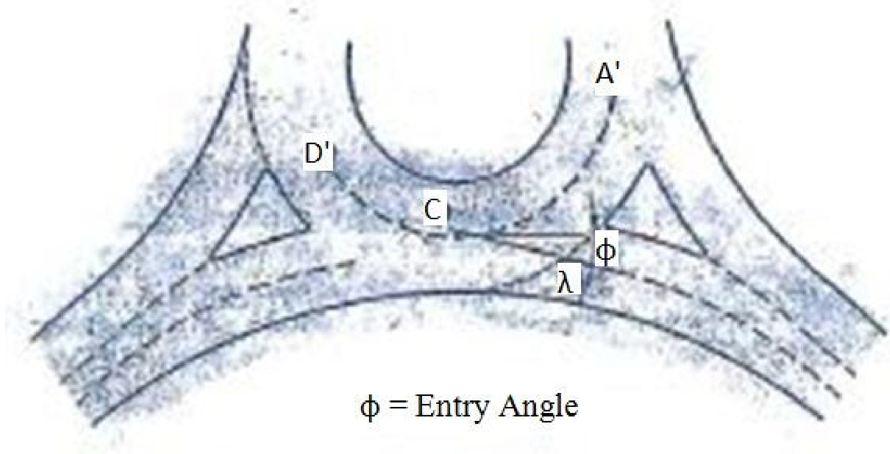


Figure 2.23: Too Small Entry Angle

Large entry angles produce excessive entry deflection and can lead to sharp braking at entries accompanied by "nose to tail" accidents, especially in rural areas. Figure 2.24 shows an extreme case (Geometric design for Dubai roads, 2002).

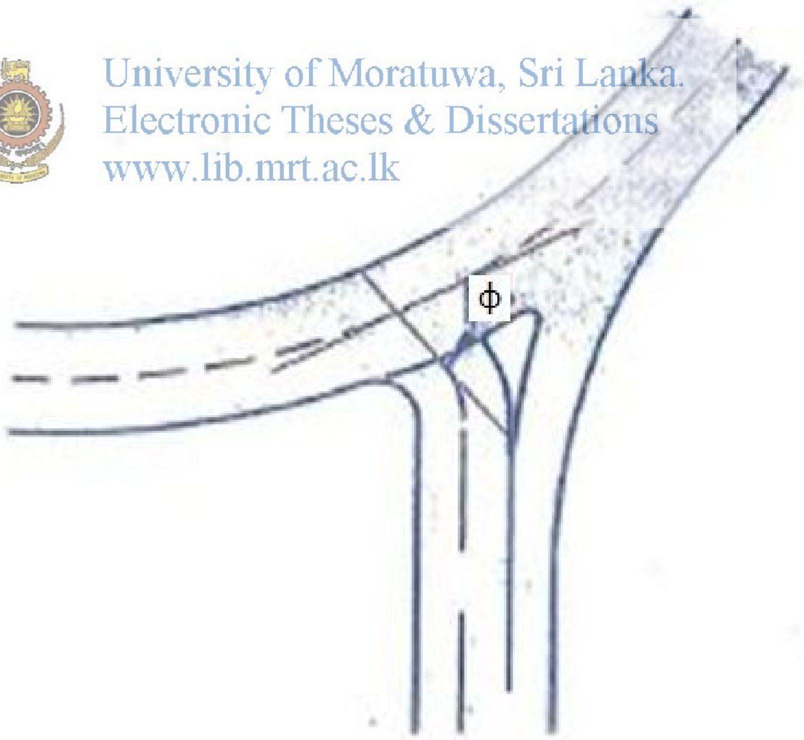


Figure 2.24: Too Large Entry Angle

2.4.10 Cross fall and drainage

Steep grades should be avoided on roundabout approaches. Where this cannot be accomplished, they should be flattened to a maximum of 2% before entry.

Cross fall and longitudinal grade combine to provide the slope necessary to drain surface water from the pavement. Thus, although the following clauses are for simplicity written in terms of cross fall, the value and direction of the greatest slope (resulting from the combination of cross fall and grade) should always be taken into account when considering drainage.

Generally speaking, super elevation is provided in order to assist vehicles when traveling round a curve. Its values, when used, are equal to or greater than those necessary for surface water drainage. Super elevation is not required on the circulating pavement of roundabouts irrespective of their size, whereas cross fall is required so that surface water can drain effectively.

Cross fall on the circulating pavement can be either inwards (towards the central island), or a normal crown profile, or outwards. Inward cross fall may be appropriate on very large roundabouts, where circulating speeds are high, but elsewhere the fall should normally be normal crown or outwards.

To provide comfort and to enable drivers to remain in control, the maximum algebraic sum of opposing cross fall grades at a crown line should not be greater than 5%.

Normal cross fall for drainage on roundabouts should not exceed 2%. To avoid ponding, longitudinal edge profiles should be graded at not less than 0.5%.

Application of proper grades and cross falls may not necessarily ensure satisfactory drainage, and therefore the correct siting and spacing of gullies is critical to efficient drainage (Geometric design for Dubai roads, 2002).

2.4.11 Vertical consideration

Elements of vertical alignment design for roundabouts include profiles, super elevation, approach and grades.

2.4.11.1 Profiles

The vertical design of a roundabout begins with the development of approach roadway and central island profiles. The development of each profile is an iterative process that involves tying the elevations of the approach roadway profiles into a smooth profile around the central island.

Generally, each approach profile should be designed to the point where the approach baseline intersects with the central island. A profile for the central island is then developed which passes through these four points (in the case of a four legged roundabout). The approach roadway profiles are then readjusted as necessary to meet the central island profile. The shape of the central island profile is generally in the form of a sine curve. Examples of how the profile is developed can be found in Figure 2.25 and 2.26, which consist of a sample plan, profiles on each approach, and a profile along the central island, respectively. Note that the four points where the approach roadway baseline intersects the central island baseline are identified on the central island profile (US DOT, 2001).

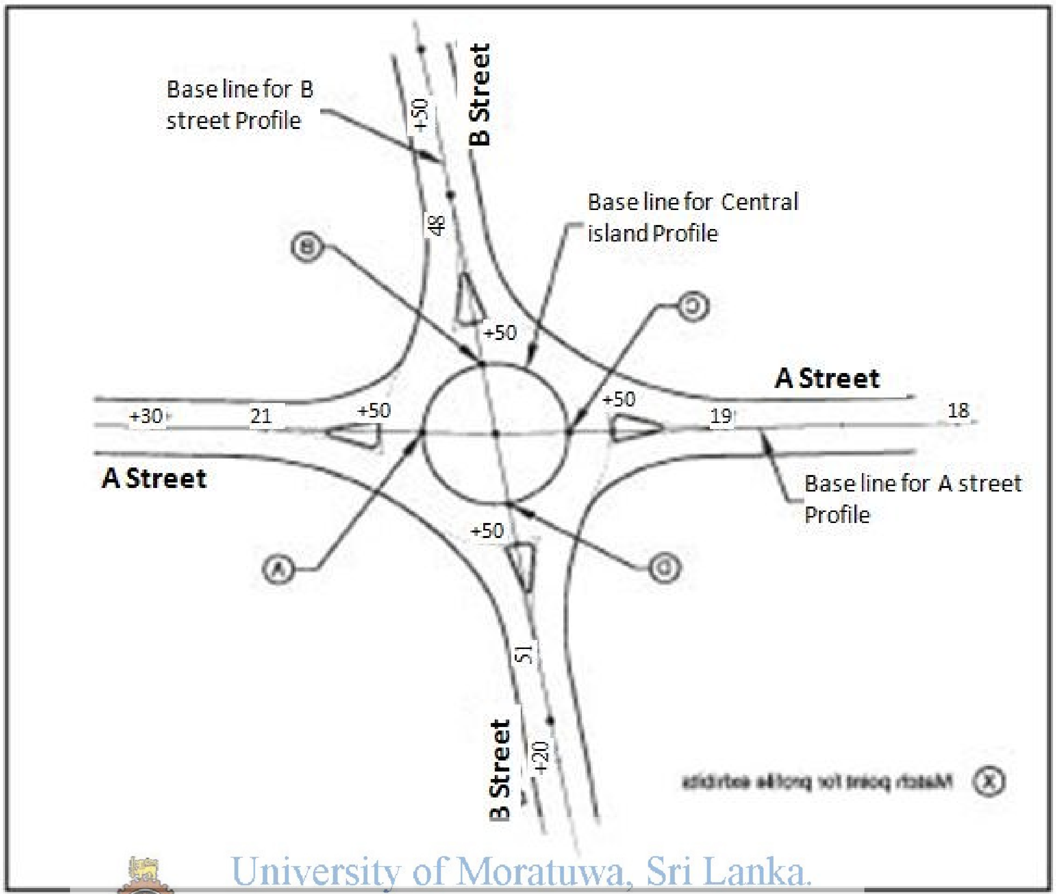


Figure 2.25: Sample Plan

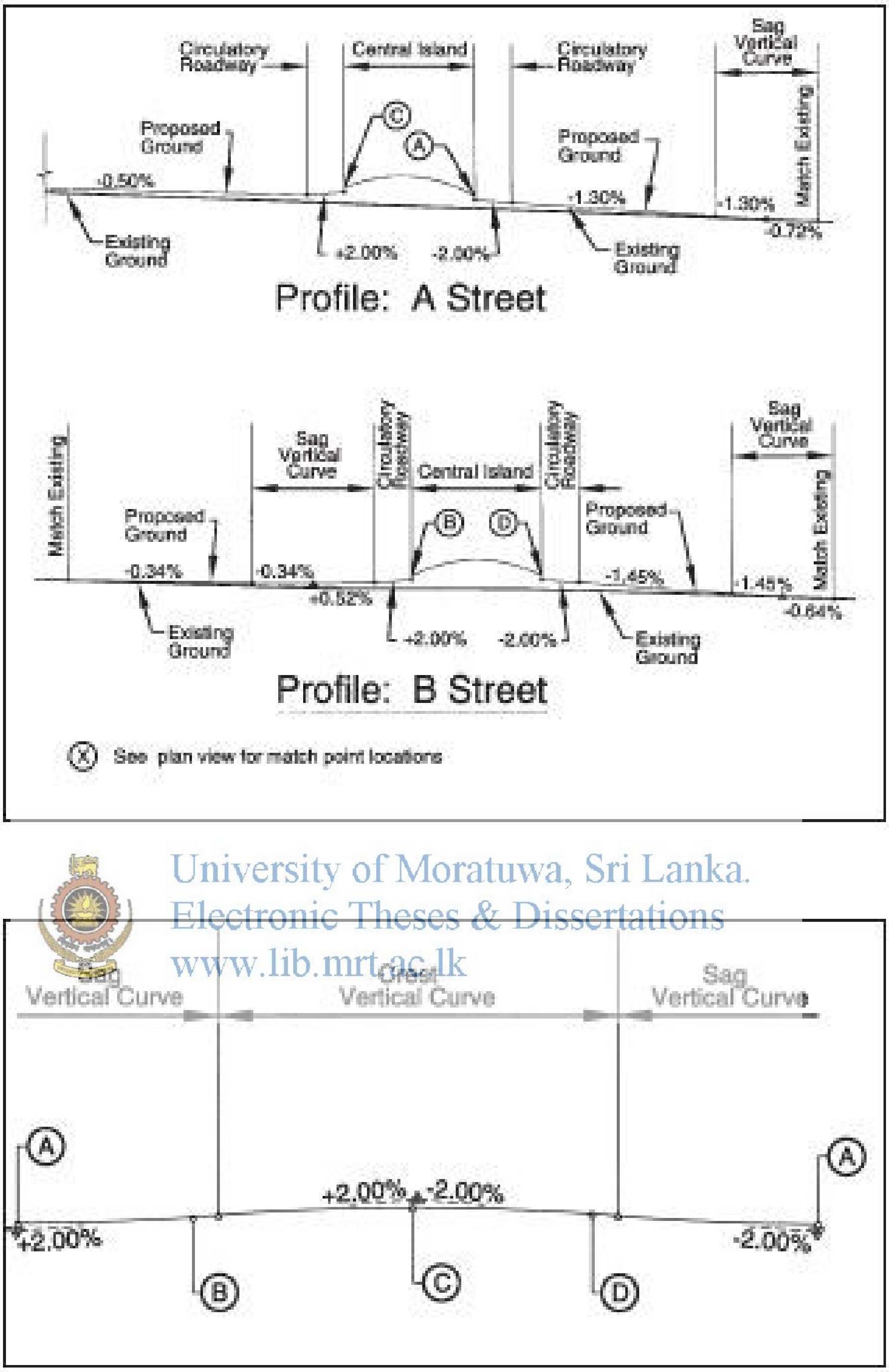


Figure 2.26: Sample Approach Profile and Simple Central Island Profile

2.4.11.2 Super Elevation

As a general practice, a cross slope of 2% away from the central island should be used for the circulatory roadway. This technique of sloping outward is recommended for four main reasons:

- It promotes safety by raising the elevation of the central island and improving its visibility;
- It promotes lower circulating speeds;
- It minimizes breaks in the cross slopes of the entrance and exit lanes; and
- It helps drain surface water to the outside of the roundabout

2.5 Roundabout Guidelines

2.5.1 Introduction

This chapter provides comprehensive description of different Roundabout design approaches available in the world. It is in detail discussed in,

- US DOT guidelines
- Austroads guidelines
- UK guidelines
- Dubai guidelines
- Oman guidelines

2.5.2 US DOT guidelines

This guide provides information and guidance on roundabouts, resulting in designs that are suitable for a variety of typical conditions in the United States. The scope of this guide is to provide general information, planning techniques, evaluation procedures for assessing operational and safety performance, and design guidelines for roundabouts. While the basic form and features of roundabouts are uniform regardless of their location, many of the design techniques and parameters are different, depending on the speed environment and desired capacity at individual sites.

Before the details of the geometry are defined, three fundamental elements must be determined in the preliminary design stage:

1. The optimal roundabout size;
2. The optimal position; and
3. The optimal alignment and arrangement of approach legs.

The process of design in US-DOT roundabout manual is shown in Figure 2.26.

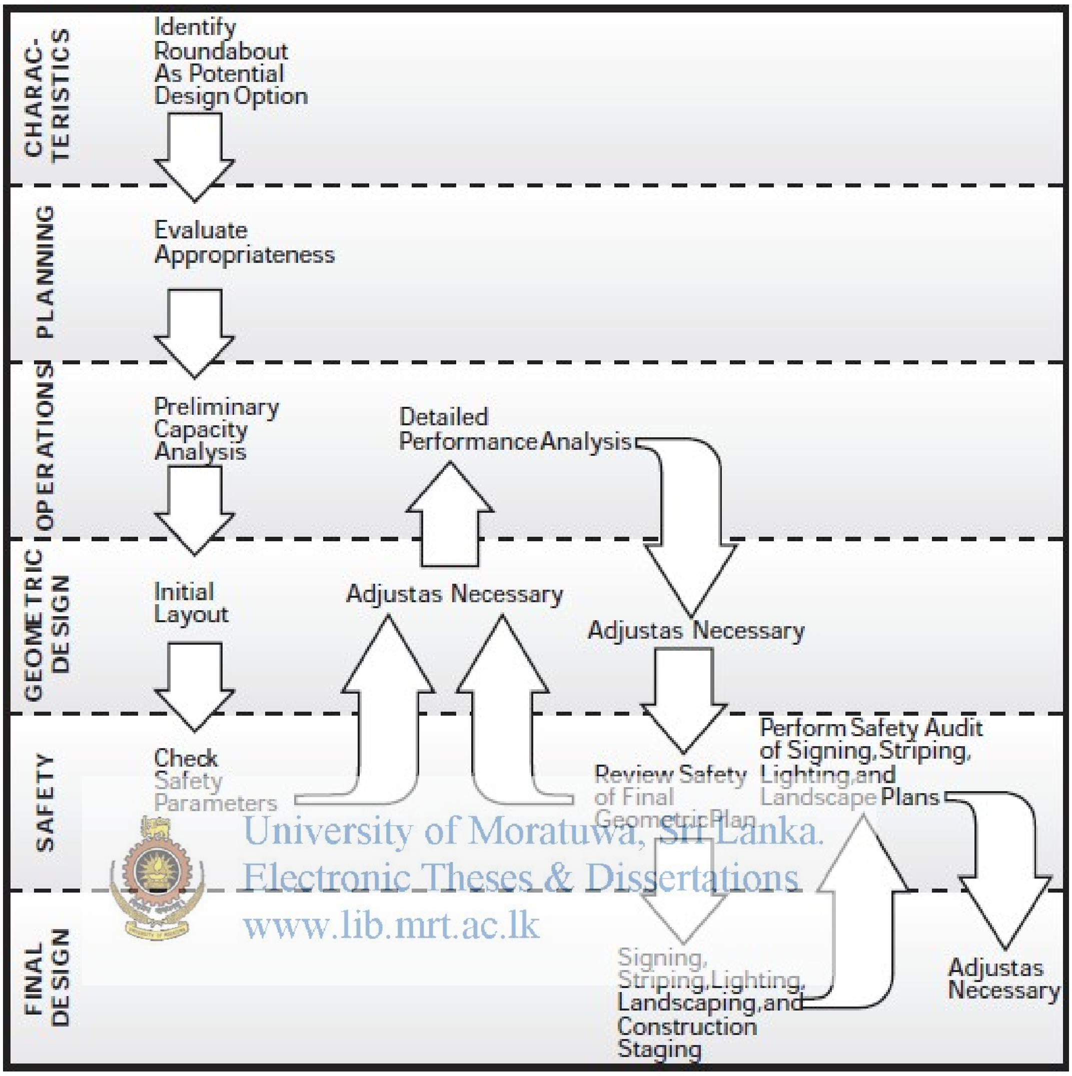


Figure 2.27: Roundabout Design Processing US-DOT Roundabout Manual

Design speed

International studies have shown that increasing the vehicle path curvature decreases the relative speed between entering and circulating vehicles and thus usually results in decreases in the entering-circulating and exiting-circulating vehicle crash rates.
The typical design entry speed is shown in the table below with category of roundabout.

Table 2.2: Recommended Design Speeds For Roundabouts According To Site Category (USDOT)

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)

Vehicle paths

To determine the speed of a roundabout, the fastest path allowed by the geometry is drawn. A vehicle is assumed to be 2 m (6 ft.) wide and to maintain a minimum clearance of 0.5 m (2 ft.) from a roadway centre line or concrete curb and flush with a painted edge line.

The centre line of the vehicle path is drawn with the following distances to the particular geometric features:

- 1.5 m (5 ft.) from a concrete curb,
- 1.5 m (5 ft.) from a roadway centre line, and
- 0.9m (3 ft.) from a painted edge line.

This is shown in Figure 2.28 and 2.29.

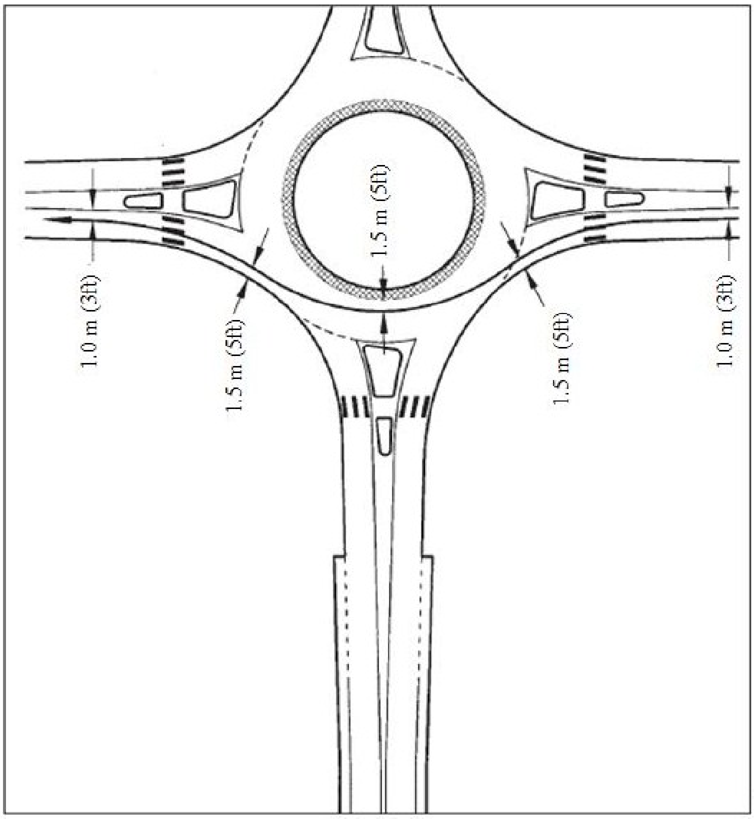


Figure 2.28: Fast Vehicle Path through Single Lane Roundabout

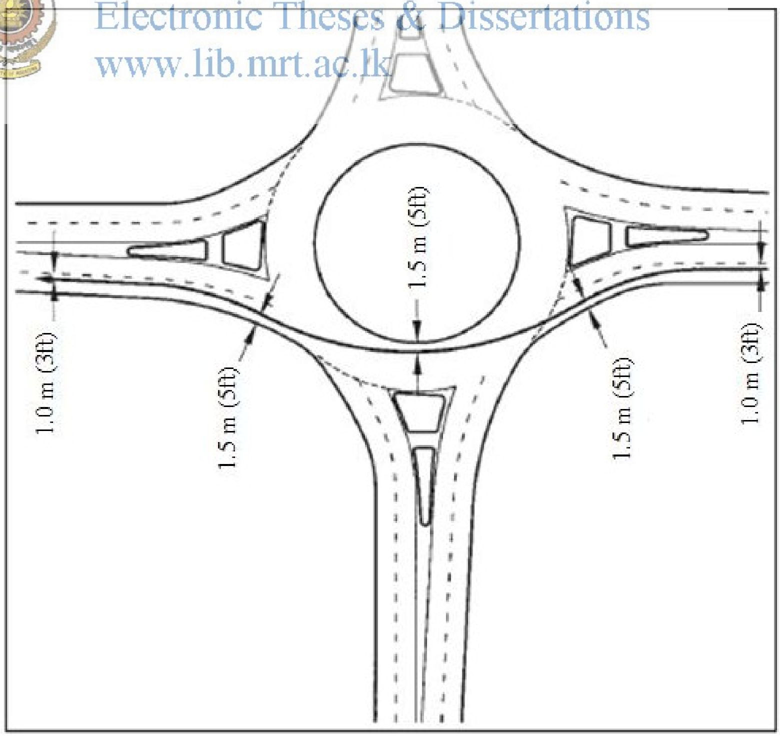


Figure 2.29: Fast Vehicle Path through Double Lane Roundabout

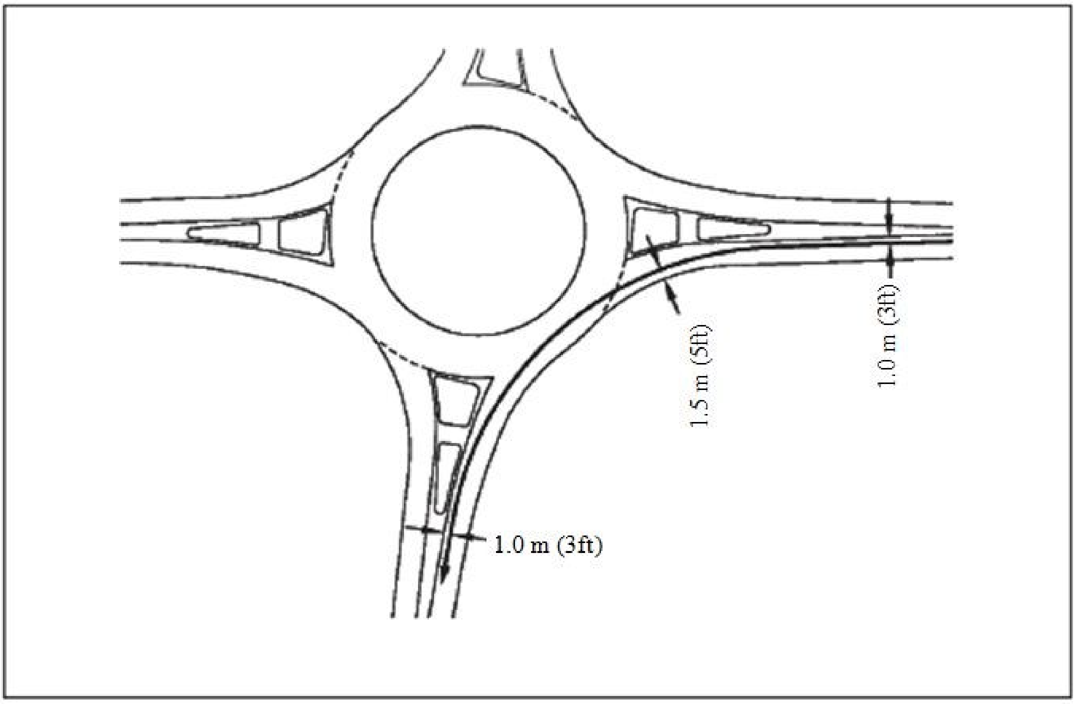


Figure 2.30: Critical Right Turn Movement

Speed Consistency

In addition to achieving an appropriate design speed, achieving consistent speeds for all movements is also essential.

Along with overall reductions in speed, speed consistency can help to minimize the crash rate and severity between conflicting streams of vehicles.
It also simplifies the task of merging into the conflicting traffic stream, minimizing critical gaps, thus optimizing entry capacity. This principle has two implications:

1. The relative speeds between consecutive geometric elements should be minimized
2. The relative speeds between conflicting traffic streams should be minimized.

As shown in Figure 2.31, five critical path radii must be checked for each approach. R_1, the entry path radius, is the minimum radius on the fastest through path prior to the yield line. R_2, the circulating path radius, is the minimum radius on the fastest through path around the central island. R_3, the exit path radius, is the minimum radius on the fastest through path into the exit. R_4, the left-turn path radius, is the minimum radius on the path of the conflicting left-turn movement. R_5, the right-turn path radius, is the minimum radius on the fastest path of a right-turning vehicle. It is important to note that these vehicular path radii are not the same as the curb radii.

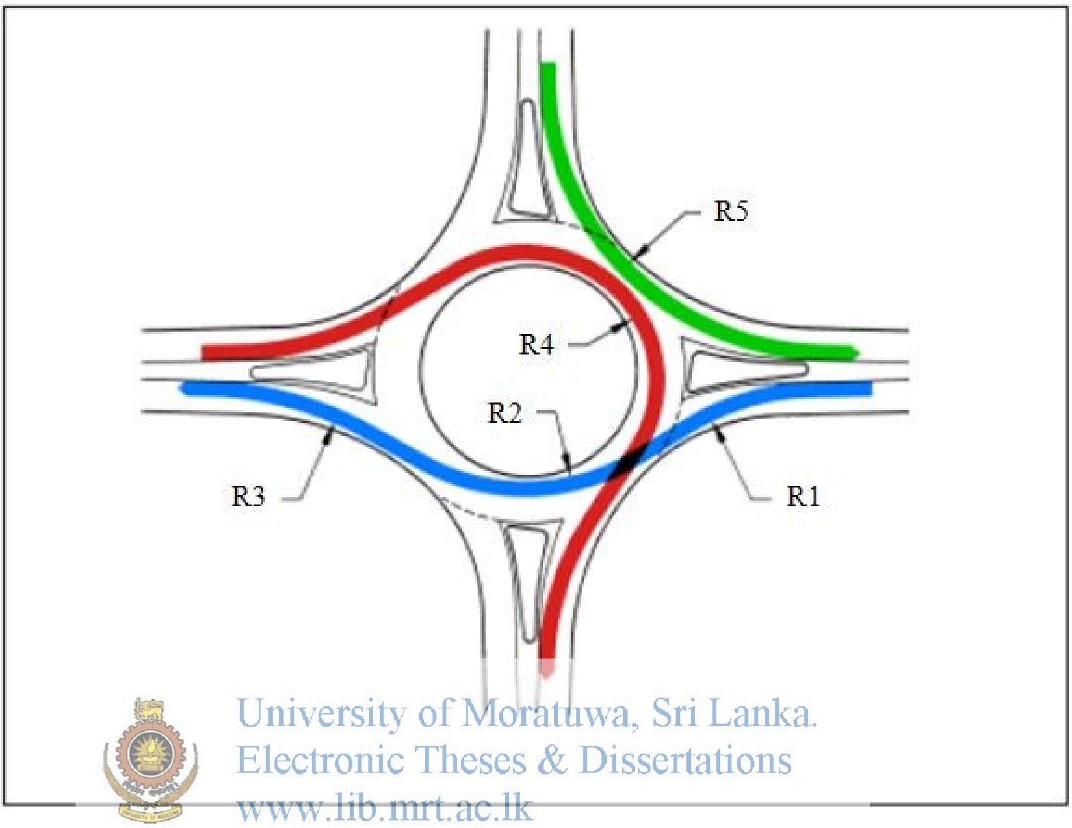


Figure 2.31: Vehicle Path Radii

Design Vehicle

The local or State agency with jurisdiction of the associated roadways should usually be consulted to identify the design vehicle at each site. The AASHTO a policy on Geometric Design of Highways and Streets provides the dimensions and turning path requirements for a variety of common highway vehicles.

Commonly, WB-15 (WB-50) vehicles are the largest vehicles along collectors and arterials. Larger trucks, such as WB-20 (WB-67) vehicles, may need to be addressed at intersections on interstate freeways or State highway systems.

Smaller design vehicles (Bus or single unit truck) may often be chosen for local street intersections.

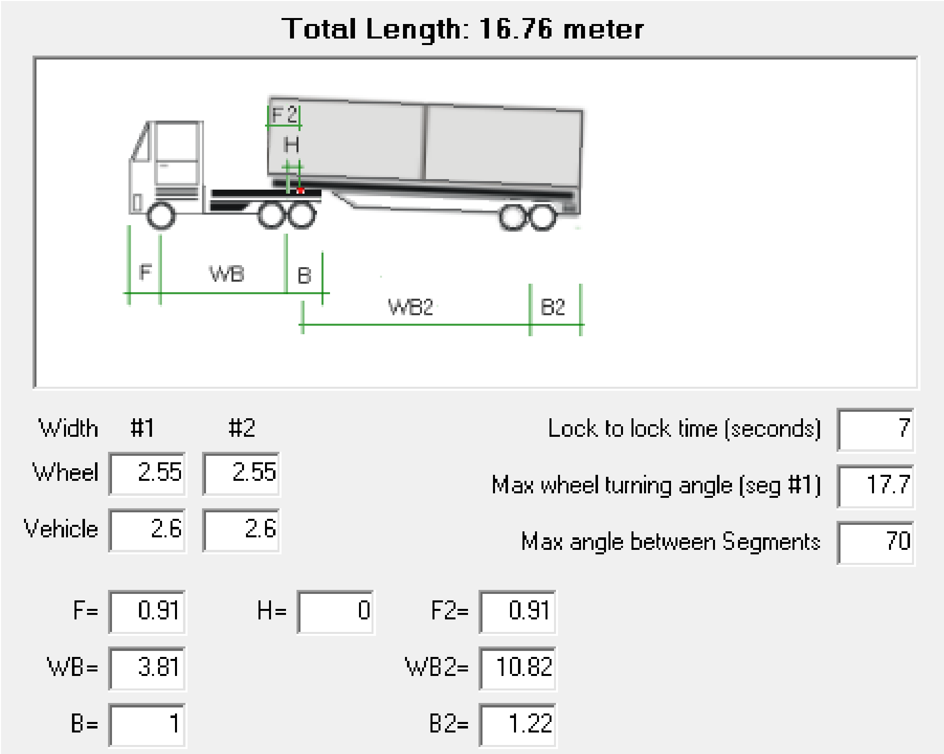


Figure 2.32: AASHTO WB-50 Vehicle

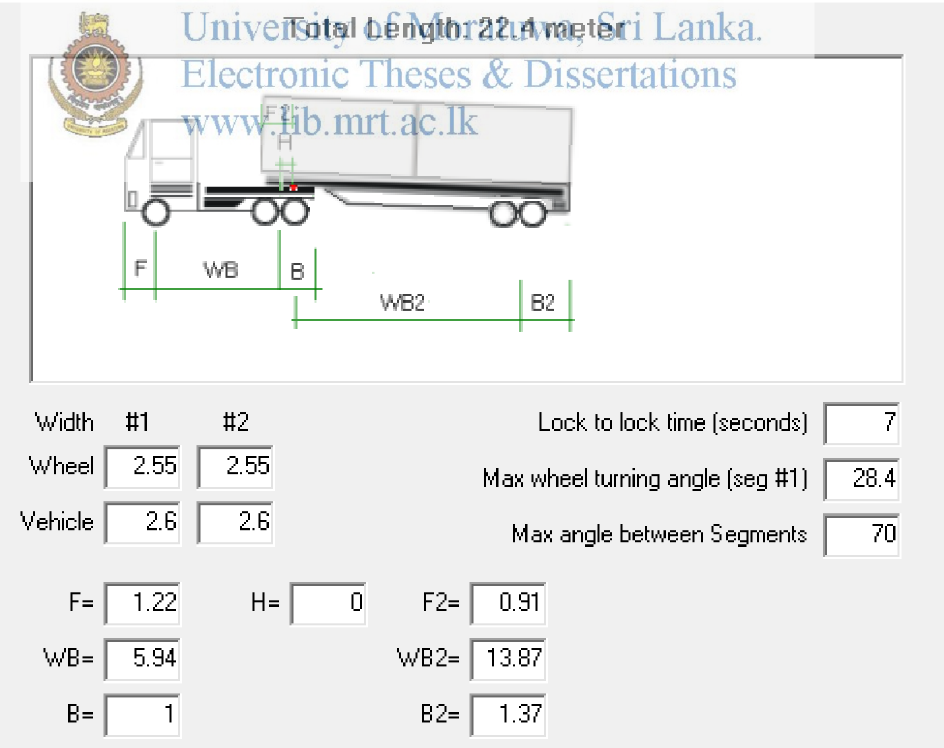


Figure 2.33: AASHTO WB-67 Vehicle

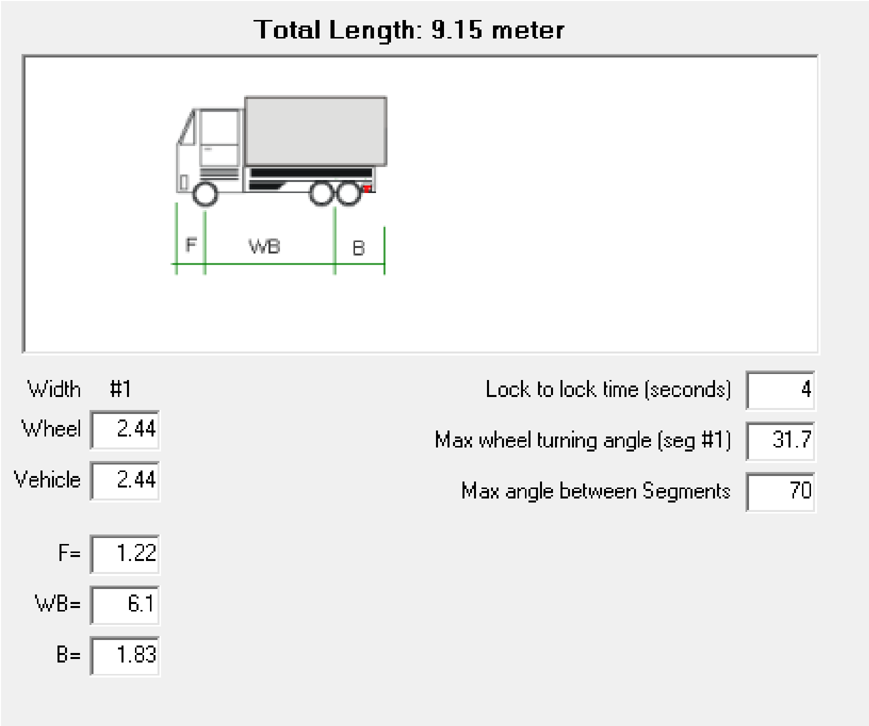


Figure 2.34: AASHTO SU (Single Unit Truck)

Inscribed circle diameter

Generally, the inscribed circle diameter should be a minimum of 30 m (100 ft) to accommodate a WB-15 (WB-50) design vehicle. Smaller roundabouts can be used for some local street or collector street intersections, where the design vehicle may be a bus or single-unit truck. Table 2.3 shows recommended ICD for several site categories.

Table 2.3: Recommended Inscribed Circle Diameter Ranges

Site Category	Typical Design Vehicle	Inscribed Circle Diameter Range*
Mini-Roundabout	Single-Unit Truck	13–25m (45–80 ft)
Urban Compact	Single-Unit Truck/Bus	25–30m (80–100 ft)
Urban Single Lane	WB-15 (WB-50)	30–40m (100–130 ft)
Urban Double Lane	WB-15 (WB-50)	45–55m (150–180 ft)
Rural Single Lane	WB-20 (WB-67)	35–40m (115–130 ft)
Rural Double Lane	WB-20 (WB-67)	55–60m (180–200 ft)

* Assumes 90-degree angles between entries and no more than four legs.

Entry Width

Typical entry widths for single-lane entrances range from 4.3 to 4.9 m (14 to 16 ft.); however, values higher or lower than this range may be required for site-specific design vehicle and speed requirements for critical vehicle paths.

Circulatory Roadway Width

The required width of the circulatory roadway is determined from the width of the entries and the turning requirements of the design vehicle. In general, it should always be at least as wide as the maximum entry width (up to 120% of the maximum entry width) and should remain constant throughout the roundabout (3).

Single-Lane Roundabouts

At single-lane roundabouts, the circulatory roadway should just accommodate the design vehicle. In accordance with AASHTO policy, a minimum clearance of 0.6 m (2 ft.) should be provided between the outside edge of the vehicle's tire track and the curb line. Table 2.4 shows the minimum circulatory lane widths.

Table 2.4: Minimum Circulatory Lane Widths

Inscribed Circle Diameter	Minimum Circulatory Lane Width*	Central Island Diameter
45 m (150 ft)	9.8 m (32 ft)	25.4 m (86 ft)
50 m (165 ft)	9.3 m (31 ft)	31.4 m (103 ft)
55 m (180 ft)	9.1 m (30 ft)	36.8 m (120 ft)
60 m (200 ft)	9.1 m (30 ft)	41.8 m (140 ft)
65 m (215 ft)	8.7 m (29 ft)	47.6 m (157 ft)
70 m (230 ft)	8.7 m (29 ft)	52.6 m (172 ft)

* Based on 1994 AASHTO Table III-20, Case III(A) (4). Assumes infrequent semi-trailer use (typically less than 5 percent of the total traffic). Refer to AASHTO for cases with higher truck percentages.

Central Island

A circular-shaped central island with a constant-radius circulatory roadway helps promote constant speeds around the central island.

Oval or irregular shapes, on the other hand, are more difficult to drive and can promote higher speeds on the straight sections and reduced speeds on the arcs of the oval. This speed differential may make it harder for entering vehicles to judge the speed and acceptability of gaps in the circulatory traffic stream.
It can also be deceptive to circulating drivers, leading to more loss of control crashes. Noncircular central islands have the above disadvantages to a rapidly increasing degree as they get larger because circulating speeds are higher.

Oval shapes are generally not such a problem if they are relatively small and speeds are low. Raindrop-shaped islands may be used in areas where certain movements do not exist, such as interchanges, or at locations where certain turning movements cannot be safely accommodated, such as roundabouts with one approach on a relatively steep grade.

The size of the central island plays a key role in determining the amount of deflection imposed on the through vehicle's path. However, its diameter is entirely dependent upon the inscribed circle diameter and the required circulatory roadway width. Therefore, once the inscribed diameter, circulatory roadway width, and initial entry geometry have been established, the fastest vehicle path must be drawn though the layout to determine if the central island size is adequate. If the fastest path exceeds the design speed, the central island size may need to be increased, thus increasing the overall inscribed circle diameter.

There may be other methods for increasing deflection without increasing the inscribed diameter, such as offsetting the approach alignment to the left, reducing the entry width, or reducing the entry radius. These treatments, however, may preclude the ability to accommodate the design vehicle.

Entry curves at single-lane roundabouts

Entry radii at urban single-lane roundabouts typically range from 10 to 30 m (33 to 98 ft.). Larger radii may be used, but it is important that the radii not be so large as to result in excessive entry speeds.

At local street roundabouts, entry radii may be below 10 m (33 ft.) if the design vehicle is small. At rural and suburban locations, consideration should be given to the speed differential between the approaches and entries.
If the difference is greater than 20 km/h (12 mph), it is desirable to introduce approach curves or some other speed reduction measures to reduce the speed of approaching traffic prior to the entry curvature.

Entry curves at double-lane roundabouts

At double-lane entries, the designer needs to balance the need to control entry speed with the need to minimize path overlap. One method to avoid path overlap on entry is to start with an inner entry curve that is curvilinear tangential to the central island and then draw parallel alignments to determine the position of the outside edge of each entry lane.

These curves can range from 30 to 60 m (100 to 200 ft.) in urban environments and 40 to 80 m (130 to 260 ft.) in rural environments. These curves should extend approximately 30 m (100 ft.) to provide clear indication of the curvature to the driver.

The designer should check the critical vehicle paths to ensure that speeds are sufficiently low and consistent between vehicle streams. The designer should also ensure that the portion of the splitter island in front of the crosswalk meets AASHTO recommendations for minimum size.

Exit curves at single-lane roundabouts

At single-lane roundabouts in urban environments, exits should be designed to enforce a curved exit path with a design speed below 40 km/h (25 mph) in order to maximize safety for pedestrians crossing the exiting traffic stream. Generally, exit radii should be no less than 15 m (50 ft.).

At locations with pedestrian activity and no large semi-trailer traffic, exit radii may be as low as 10 to 12 m (33 to 39 ft.). This produces a very slow design speed to maximize safety and comfort for pedestrians. Such low exit radii should only be used in conjunction with similar or smaller entry radii on urban compact roundabouts with inscribed circle diameters below 35 m (115 ft.).

Exit curves at double-lane roundabouts

To avoid path overlap on the exit, it is important that the exit radius at a double-lane roundabout should not be too small. At double-lane roundabouts in urban environments, the principle for maximizing pedestrian safety is to reduce vehicle speeds prior to the yield and maintain similar (or slightly lower) speeds within the circulatory roadway.

At the exit points, traffic will still be traveling slowly, as there is insufficient distance to accelerate significantly. If the entry and circulating path radii are each 50 m (165 ft.), exit speeds will generally be below 40 km/h (25 mph) regardless of the exit radius.

Flare length

Flare lengths should be at least 25 m in urban areas and 40 m in rural areas.

Super Elevation

As a general practice, a cross slope of 2% away from the central island should be used for the circulatory roadway.

2.5.3 Austroads guidelines

The Australian guide for road planning and design is one of the world's well recognized highway design guides especially in the area of roundabouts. It is also well related to Sri Lankan transport systems since they follow left hand driving rule. Chapter 14 of 'Department of Main Roads Road Planning and Design Manual' describes the roundabouts. This guideline is based on the Guide to Traffic Engineering Practice (GTEP) - Part 6 - Roundabouts (Austroads, 1993), and the results of a roundabout study undertaken by Main Roads (Arndt, 1998).

Appropriate sites for Roundabouts

Roundabouts may be appropriate in the following situations:

- At intersections where traffic volumes on the intersecting roads are such that:
- "Stop" or "Give Way" signs or the "T" junction rule result in unacceptable delays for the minor road traffic. In these situations, roundabouts would decrease delays to minor road traffic, but increase delays to the major road traffic.

- Traffic signals would result in greater delays than a roundabout. It should be noted that in many situations roundabouts provide a similar capacity to signals, but may operate with lower delays and better safety, particularly in off-peak periods.
- At intersections where there are high proportions of right-turning traffic: Unlike most other intersection treatments, roundabouts can operate efficiently with high volumes of right-turning vehicles.
- At rural cross intersections (including those in areas with high desired speeds) at which there is an accident problem involving crossing or right turn (versus opposing) traffic. However if the traffic flow on the lower volume road is less than about 200 vehicles per day, consideration could be given to using a staggered "T" treatment.
- At intersections of arterial roads in outer urban areas where traffic speeds are high and right turning traffic flows are high. A well designed roundabout

could have an advantage over traffic signals in reducing right turn opposed type accidents and overall delays.

- At "T" or cross intersections where the major traffic route turns through a right angle. This often occurs on highways in country towns. In these situations the major movements within the intersection are turning movements.
- At intersections of local roads where it is desirable not to road.

Roundabouts may be inappropriate in the following situations:

- Where a satisfactory geometric design cannot be provided due to insufficient space or unfavourable topography, or there is an unacceptably high cost of construction (which includes the cost of property acquisition, service relocations, etc.).
- Where traffic flows are unbalanced with high volumes on one or more approaches, and some vehicles would experience long delays. This is especially true for roundabouts on high desired speed, high volume rural roads which intersect with a very low volume road. In these cases, the number of single vehicle accidents generated by the roundabout can substantially exceed the number of multiple vehicle accidents generated by an at-grade intersection.
- Where there is considerable pedestrian activity and due to high traffic volumes it would be difficult for pedestrians to cross any leg.
- At an isolated intersection in a network of linked traffic signals. In this situation a signalised intersection linked to the others or simply an at-grade intersection would generally provide a better level of service.
- At an isolated intersection where the treatment is inconsistent with the network/link and the expectations of the driver design.
- Where large multi-combination or over dimensional vehicles frequently use the intersection and insufficient space is available to provide for their swept turning paths.

Number of roundabout legs and angles between legs for single lane roundabouts and double lane roundabouts are as follows.

Single lane roundabouts

Aligning roundabout legs at approximately 90° is preferable because it results in the least amount of driver confusion. This design limits the maximum number of roundabout legs to four.

Provision of a greater number of legs on a single lane roundabout is allowable if economic constraints dictate. It is suggested, however, that more than six legs would lead to driver confusion as to which exit leg is required. Adequate signing would also be difficult to obtain.

Multi-lane roundabouts

Multi-lane roundabouts should be limited to a maximum of four legs with legs aligned at approximately 90°. Three and four leg multi-lane lane roundabouts allow legs to be formed at approximately 90°, which helps motorists determine the appropriate lane choice for their path through the roundabout.

Multi-lane roundabouts with more than four legs have some or all legs aligned at angles other than 90°. On these roundabouts, motorists can experience difficulty in determining which is the appropriate lane choice required for left, through and right turns on some of the approaches, as discussed in the following sections.

Number of roundabout lanes

In general, the number of roundabout lanes (entry, circulating and exit lanes) provided should be limited to the minimum number that achieves the desired capacity and operating requirements for the projected future traffic volumes.

Number of circulating lanes

The number of circulating lanes from any particular approach must be equal to or greater than the number of entry lanes on that approach. It is not essential to provide the same number of circulating lanes for the entire length of the circulating carriageway as long as the appropriate multi-lane exits are provided prior to reducing the number of circulating lanes.

Number of exit lanes

The number of exit lanes must not be greater than the number of circulating lanes. On multi-lane roundabouts, the number of exit lanes is based on the lane usage as determined by the pavement arrows on the approaches. Where no pavement arrows are shown, the number of exit lanes should equal the number of circulating lanes prior to the exit.

Roundabout diameter

Larger roundabouts enable better geometry to be designed. Increasing the diameter of a roundabout usually enables provision of better approach geometry which leads to a reduction in vehicle approach speeds.

In general, roundabouts in areas with high desired speeds need larger diameters to enable better approach geometry to be designed to reduce the high approach speeds. The design of these roundabouts is more critical than that for roundabouts located in areas with low desired speeds. Table 2.5 and Table 2.6 show initial selection of minimum central island diameters of single lane roundabouts and two lane roundabouts.

Table 2.5: Initial Selection of Minimum Central Island Diameters of Single Lane Roundabouts

Desired driver speed prior to approach carriageway (km/h)	Minimum central island diameter (m)	Circulating carriageway width (m)	Treatments required to reduce vehicle speed prior to the entry curve *
40	10	7.6	No
50	10	7.6	No
60	15	7.1	No
70	20	6.7	No
80	25	6.5	Desirably
90	25	6.5	Yes
100	25	6.5	Yes
110	25	6.5	Yes
* Refer to Section 14.8.1, 'Entry Curve'.			

Adapted from Road planning and design manual Australia, 2006

Table 2.6: Initial Selection of Minimum Central Island Diameters of Two Lane Roundabouts

Desired speed prior to the roundabout (km/h)	Minimum central island diameter (m)	Circulating carriageway width (m)	Treatments required to reduce vehicle speed prior to the entry curve *
40	15	11.1	No
50	15	11.1	No
60	25	10.3	No
70	30	10.0	No
80	40	9.6	Desirably
90	40	9.6	Yes
100	40	9.6	Yes
110	40	9.6	Yes
* Refer to Section 14.8.1, 'Entry Curve'			

Adapted from Road planning and design manual Australia, 2006

The roundabout diameter should be limited to maximum of 200m. Larger diameters will encourage high circulating speeds and may encourage wrong way movements if drivers perceive that the time taken to traverse the roundabout is too long.

Design vehicle and vehicle swept paths

The design vehicle and consequently the swept path requirements may be different for the various paths through the roundabout. The width of the circulating carriageway depends on several factors, the most important of which are the number of circulating lanes and the radius of vehicle swept paths within the roundabout. The circulating carriageway width of single lane roundabouts should cater for the movement of the largest vehicle normally expected to use the roundabout. The circulating carriageway width of dual lane roundabouts would normally need to cater for the movement of the largest vehicle normally expected to use the roundabout.

Table 2.7 and Table 2.8 show initial selection of roundabout circulating carriageway widths for single lane and two lane roads.

Table 2.7: Initial Selection of Single Lane Roundabout Circulating Carriageway Widths

[1]Central island radius (m)	[2]Width required for design vehicle (m)				
	12.5m Single Unit Truck	19m Semi-Trailer	25m B-Double	Type 1 Road Train	Type 2 Road Train
5	-	9.4	-	-	-
6	-	9.1	10.1	-	-
8	6.9	8.6	9.6	11.1	-
10	6.5	8.2	9.1	10.6	12.6
12	6.2	7.8	8.7	10.1	12.1
14	6	7.4	8.3	9.7	11.6
16	5.8	7.2	8	9.3	11.1
18	5.6	6.9	7.7	8.9	10.7
20	5.4	6.7	7.4	8.6	10.3
23	5.3	6.4	7	8.2	9.8
26	5.1	6.1	6.8	7.8	9.4
30	5	5.9	6.4	7.4	8.8
35	5	5.6	6	6.9	8.2
40	5	5.4	5.8	6.6	7.8
45	5	5.2	5.5	6.3	7.4
50	5	5.1	5.4	6.1	7.1
60	5	5	5.2	5.7	6.5
70	5	5	5	5.4	6.2
80	5	5	5	5.2	5.9

Notes:
1. Radius used for the purpose of determining vehicle path.
2. The widths given in this table are based on right turning vehicle paths with a 0.6m offset to the central island and a 0.6m offset to the outer edge of the circulating carriageway.

Adapted from Road planning and design manual Australia, 2006

Table 2.8: Initial Selection of Two Lane Roundabout Circulating Carriageway Widths

Central island radius (m) [1]	Width required for design vehicle (m) [2]				
	12.5m Single Unit Truck	19m Semi-Trailer	25m B-Double	Type 1 Road Train	Type 2 Road Train
8	10.1	-	-	-	-
10	9.7	11.4	-	-	-
12	9.4	11	11.9	-	-
14	9.2	10.6	11.5	12.9	
16	9	10.4	11.2	12.5	14.3
18	8.8	10.1	10.9	12.1	13.9
20	8.6	9.9	10.6	11.8	13.5
23	8.5	9.6	10.2	11.4	13
26	8.3	9.3	10	11	12.6
30	8.1	9.1	9.6	10.6	12
35	8	8.8	9.2	10.1	11.4
40	7.9	8.6	9	9.8	11
45	7.8	8.4	8.8	9.5	10.6
50	7.7	8.3	8.6	[illegible]	10.3
60	[illegible]	8.1	8.4	8.9	9.7
70	7.5	7.9	8.2	8.6	9.4
80	7.4	7.8	8	8.4	9.1

Notes:

1. Radius used for the purpose of determining vehicle path.
2. The widths in this table are nominally 3.2m greater than the widths given for single lane roundabouts for the reasons given in the body text.

Adapted from Road planning and design manual Australia, 2006

Generally, lane widths will fall within the range of 3.4m to 4.0m. Exceptions are for kerbed single lane entries and exits where a minimum width of 5.0m between kerbs is usually provided to allow traffic to pass a disabled vehicle.

Entry and exit widths need to be checked for vehicle swept paths to ensure that the design vehicle is properly catered for. Again, a more accurate result is obtained through the use a computer plot of the design vehicle's swept path on an assumed travel path through the critical turning movements.

Entry Curve

The entry curve radius should be chosen such that the 85th percentile entry speed is limited to a maximum of 60km/h. Entry speed is calculated by the vehicle path and speed prediction model. In areas of high desired speeds, it is recommended that the maximum vehicle path radius on the entry curve be limited to 60m to obtain the maximum entry speed.

Deflection through roundabouts

It is recommended that the deflection criteria given in the following sections should be adopted on all roundabouts except those in constrained locations. In these constrained cases, a left hand entry curve is adopted to limit the 85th percentile entry speed to a maximum of 60km/h.

Deflection at roundabouts with one circulating curve

The required vehicle deflection for a single lane roundabout is illustrated in Figure 2.34. In this case, the central island size and location, and the approach geometry, are the controlling factors.

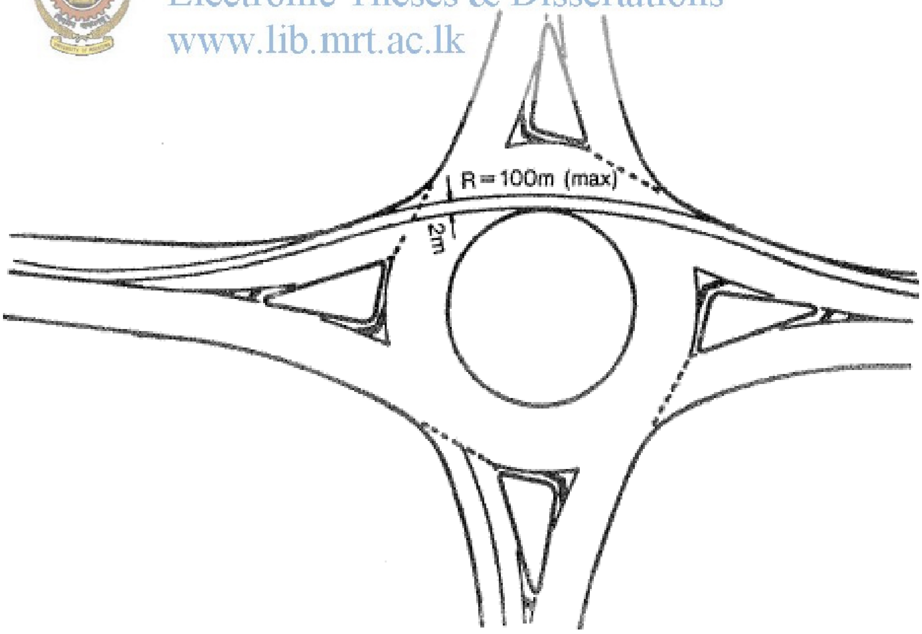


Figure 2.35: Deflection Criteria of Single Lane Roundabout

Deflection at roundabouts with two or three circulating lanes

For multi-lane roundabouts it is generally difficult to achieve the full deflection recommended above for single lane roundabouts. Where this is the case, it is acceptable for the def1ection to be measured using a vehicle path as illustrated in Figure 2.35.

This differs from that used at single lane roundabouts where the fastest (maximum radius) vehicle path is assumed to start in the left entry lane, cut across the circulating lanes and passes no closer than 1.5m to the central island before exiting the roundabout in the left lane.

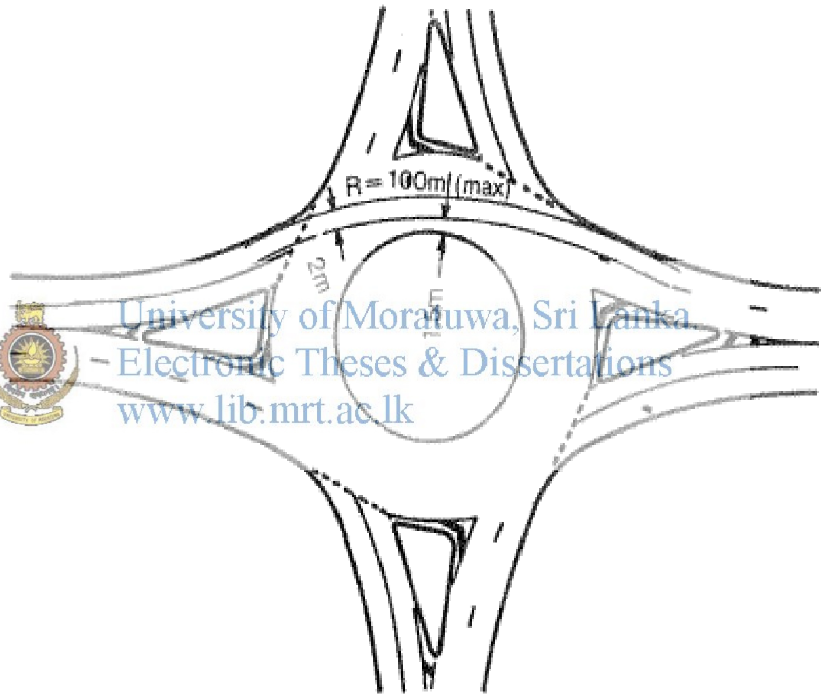


Figure 2.36: Deflection Criteria of Multi Lane Roundabout

Exit curves

In areas where there are no pedestrians, the exit from a roundabout should be as easy to negotiate as practicable. After having been slowed down by the entry and circulating curves, vehicles should be able to accelerate on the exit.

The radius of the exit curve should generally be greater than the circulating radius. Ideally, a straight path tangential to the central island, as shown in Figure 2.36, is preferable for vehicles (where there is negligible pedestrian activity), in contrast to the curved entering path. In areas where there are pedestrians, the exit speed should be minimized.

The best solution to minimize the exit speed is to provide a small radius exit curve. Figure 2.37 shows a desirable roundabout treatment where pedestrian crossings are required.

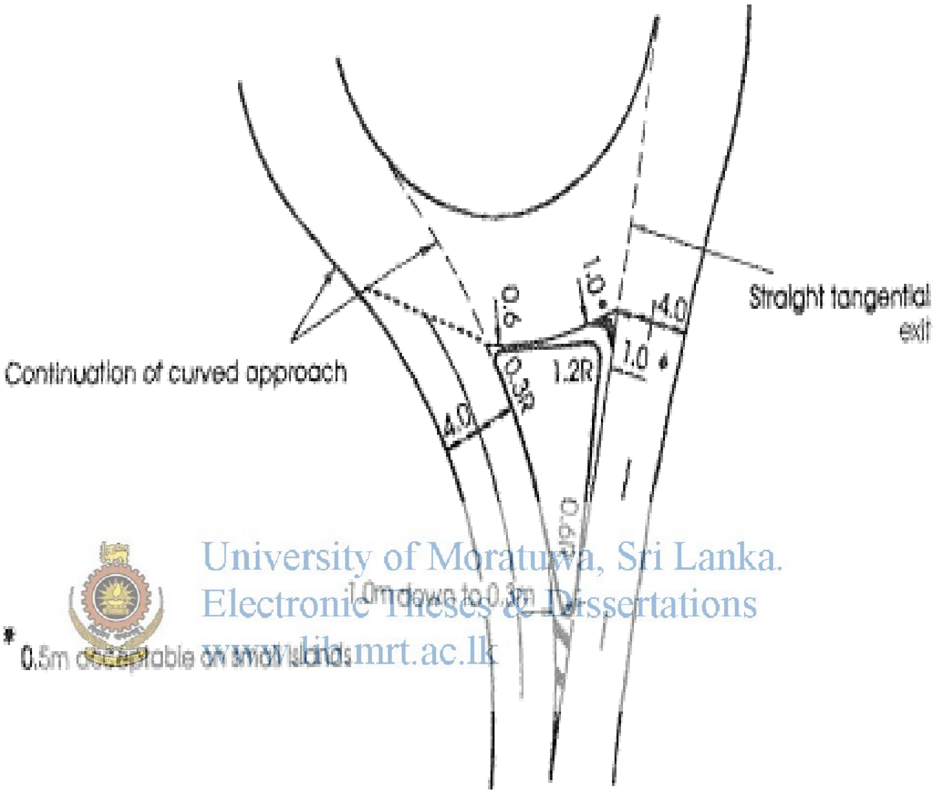


Figure 2.37: Typical Roundabout Entrance/ Exit Conditions for Urban Areas

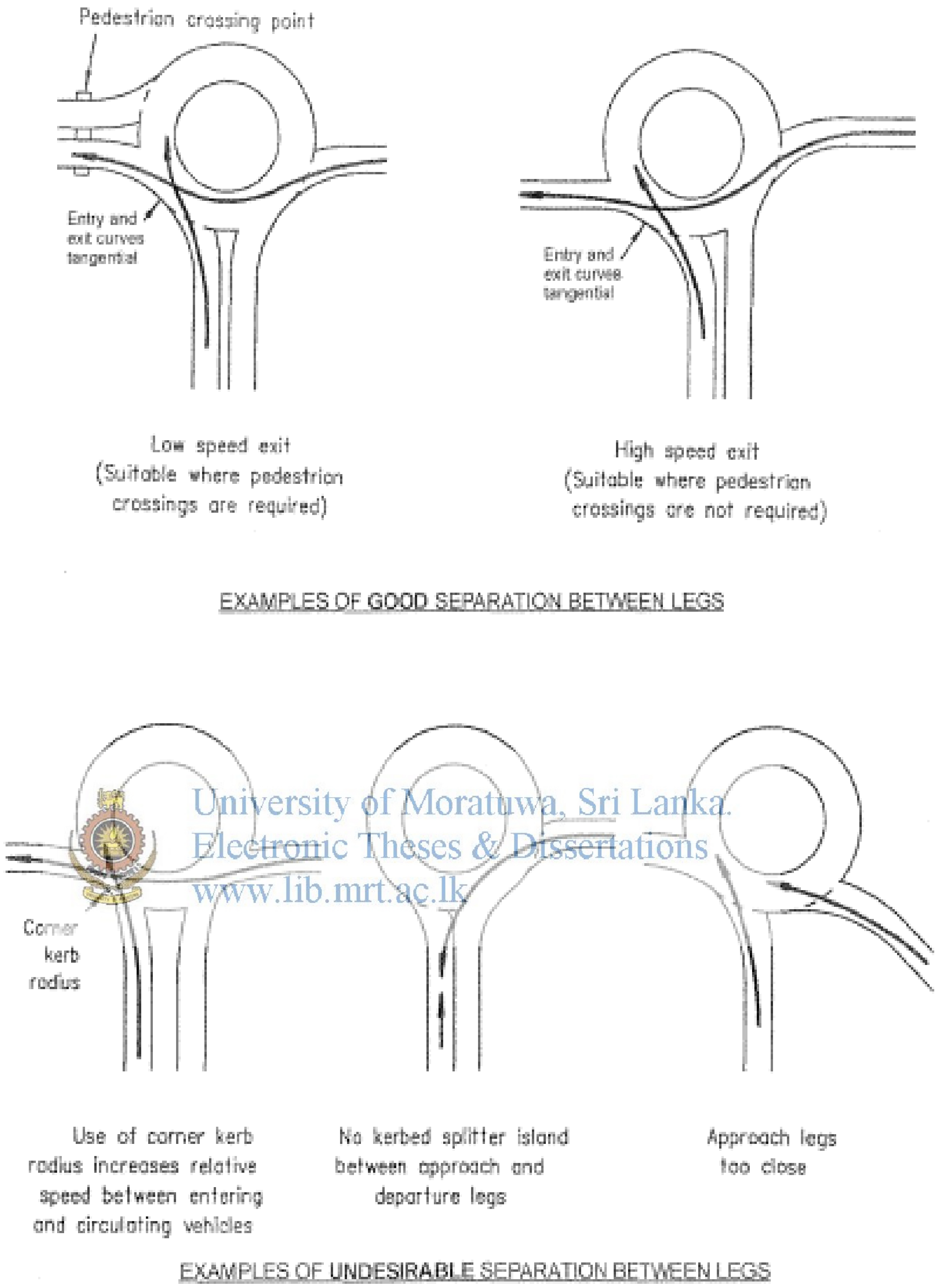


Figure 2.38: Desirable and Undesirable Separation between Lines

Adapted from Road planning and design manual Australia, 2006

2.5.4 UK guideline

Inscribed Circle Diameter (ICD)

The inscribed circle diameter of a Normal Roundabout should not exceed 100m. Large inscribed circle diameters can lead to vehicles exceeding 30mph on the circulatory carriageway.

The minimum value of the inscribed circle diameter for a Normal or Compact Roundabout is 28m. This is the smallest roundabout that can accommodate the swept path of the 'Design Vehicle'.

If the inscribed circle diameter lies between 28m and 36m, a Compact Roundabout should be considered if the traffic flows can be accommodated.

Circulating Pavement

The width of the circulatory carriageway must be between 1.0 and 1.2 times the maximum entry width, excluding any overrun area.

At Normal and Grade Separated Roundabouts, the width of the circulatory carriageway should not exceed 15 meters. At Compact Roundabouts, it should not exceed 6m, although an additional overrun area may be required for small values of inscribed circle diameter, depending on the types of vehicles using the roundabout

Short lengths of reverse curve, where two consecutive tangential circular arcs curve in opposite directions, should be avoided between entry and adjacent exits. This can be achieved by linking the curves with a short straight section. Reducing the size of the inscribed circle diameter or converting to a Double Roundabout can also eliminate the problem. Where there is a considerable distance between the entry and the next exit, such as at three-arm roundabouts, reverse curvature is acceptable

Centre Island

The central island should be circular and at least 4 meters in diameter. (mini-roundabouts have central markings rather than kerbed islands with diameters of up to 4 meters capable of being be driven over where unavoidable.

The inscribed circle diameter, the width of the circulatory carriageway and the central island diameter are interdependent: once any two of these are established, the remaining measurement is determined automatically.

The Design Vehicle is an articulated vehicle with a single axle at the rear of the trailer, of length 15.5 meters. The turning space requirements of this vehicle on a roundabout with an inscribed circle diameter of between 28m and 36m are shown in Figure 2.39 and Table 2.9 shows the turning space requirement. Although this type of vehicle is not common on UK roads, its turning requirements are greater than those for all other vehicles within the normal maximum dimensions permitted in the current Vehicle Construction and Use Regulations, or likely to be permitted in the near future. The requirements for other vehicles (including an 11 meters long rigid vehicle, 12m long coach, 15m bus, 17.9m 'bendibus', 18.35m drawbar-trailer combination, and a 16.5m articulated vehicle) are less onerous.

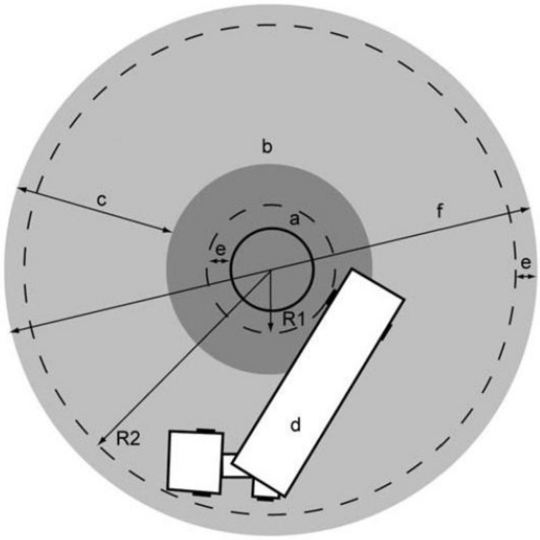


Figure 2.39: The Turning Space Requirement

Table 2.9: The Turning Space Requirement

Central island diameter (m)	R_1(m)	R_2(m)	Minimum ICD(m)
4.0	3.0	13.0	28.0
6.0	4.0	13.4	28.8
8.0	5.0	13.9	29.8
10.0	6.0	14.4	30.8
12.0	7.0	15.0	32.0
14.0	8.0	15.6	33.2
16.0	9.0	16.3	34.6
18.0	10.0	17.0	36.0

Entry Width

One or two extra lanes should be added to the approach at a Normal or Grade Separated Roundabout. However, as a general rule not more than two lanes should be added and no entry should be more than four lanes wide.

Lane widths at the give way line (measured along the normal to the nearside kerb, as for entry width) must be not less than 3m or more than 4.5m, with the 4.5m value appropriate at single lane entries and values of 3 to 3.5m appropriate at multilane entries.

On a single carriageway approach to a Normal Roundabout, the entry width must not exceed 10.5m. On a dual carriageway approach to a Normal Roundabout, the entry width must not exceed 15m.

Flare Length (ℓ')

A minimum length of about 5m in urban areas and 25m in rural areas is desirable, but capacity will be the determining factor.

Sharpness is a measure of the rate at which extra width is developed in the entry flare. The value of S will depend on the available land-take and the capacity required. Values of S greater than unity (S>1) correspond to sharp flares and smaller values ($0 \leq S \leq 1$) to gradual flares. Long gradual flares are most efficient as they make better use of the extra width but sharp flares are more easily achieved in terms of land take. Sharp flares can still give significant increases in capacity and are appropriate where there is pedestrian crossing demand.

Entry Angle

The entry angle, ϕ, should lie between 20 and 60 degrees. Low entry angles force drivers to look over their shoulders or use their mirrors to merge with circulating traffic. Large entry angles tend to have lower capacity and may produce excessive entry deflection which can lead to sharp braking at entries, accompanied by shunt accidents, especially when approach speeds are high.

Entry Kerb Radius

The entry kerb radius should not be less than 10m. Except at Compact Roundabouts, if the approach is intended for regular use by large goods vehicles, the value should not be less than 20m. However, entry kerb radii of 100m or more will tend to result in inadequate entry deflection

Although entry capacity can be increased by increasing the entry kerb radius, once its value reaches 20m, further increases only result in very small capacity improvements. Reducing the entry kerb radius below 15m reduces capacity

Exit Width

At a Normal Roundabout, if the downstream link is a single carriageway road with a long splitter island, the exit width should be between 7m and 7.5m and the exit should taper down to a minimum of 6m, allowing traffic to pass a broken down vehicle. If the link is an all-purpose two-lane dual carriageway, the exit width should be between 10m and 11m and the exit should taper down to two lanes wide.

Normally the width would reduce at a taper of 1:15 to 1:20. Where the exit is on an up gradient, the exit width may be maintained for a short distance before tapering in.

Exit Kerb Radius

At a Compact Roundabout, the value of the exit kerb radius should lie between 15m and 20m.

Cross fall and Drainage

Except on large Grade Separated Roundabouts (where long sections of circulatory carriageway should have appropriate super elevation), cross-fall is required to drain surface water on circulatory carriageways. The normal value is 2% (1 in 50). It should not exceed 2.5% (1 in 40). To avoid ponding, longitudinal edge profiles should be graded at not less than 0.67% (1 in 150), with 0.5% (1 in 200) considered the minimum. The design gradients do not in themselves ensure satisfactory

2.5.5 Dubai guidelines

Inscribed Circle Diameter (ICD)

Minimum Inscribed Circle Diameters varies with the type of the design vehicle. Where ICD is lower than 40m it can be proven that adequacy deflection cannot be achieved.

In the following table 2.10 shows the typical minimum Inscribed Diameters by design vehicle.

Table 2.10: Typical Minimum Inscribed Diameters of Design Vehicle

Description	Design Vehicle	Typical Minimum ICD (m)
Passenger car	P	16
Single unit truck	SU	29
Single unit bus	BUS	31
Articulated bus	A-BUS	29
Semi-trailer intermediate	WB-12	27
Semi-trailer combination large	WB-15	31
Semi-trailer full trailer combination	WB-18	30

Inter-state semi-trailer	WB-19	30
Inter-state semi-trailer	WB-20	36
Triple semi-trailer	WB-29	33
Tumpike double semi-trailer	WB-35	39
Motor home	MH	28
Passenger car with trailer	P/T	21
Passenger car with boat	P/B	18
Motor home with boat trailer	MH/B	33

Circulating Pavement

The circulating pavement should be kept circular in plan if possible. Width should generally not exceed 15m. Width of circulating pavement should be constant and should be between 1.0 and 1.2 times the width of the widest entry. If it exceeds 1.2 on smaller ICD roundabouts, adequate deflection should be provided.

Island diameter less than 30m, the width requirements should always be checked using a relevant software package or swept path templates.

Table 2.11: Minimum width of circulating Pavement

Island diameter (m)	2-lane Circulation	3-lane circulation
30	12.6	Check using template
50	11.1	
75	10.3	15
100	9.9	14.7
150	9.3	13.8
200	9	13.2
250	8.7	12.6

Entry Width

Add at least one extra lane to the number of lanes on the approaching road. (Not more than two lanes)No entry should be more than four lanes wide. The practical range for entry width is 6.0m to 15.0m, but for undivided roads, the upper limit should be 10.5m.

Flare Length (ℓ')

The minimum value of ℓ' should be 5m in an urban area, and 15m in a rural area. The upper limit should be 40m.

Sharpness (S) of flare is a measure of the rate at which extra width is developed, and is calculated from the relationship S= 1.6(e-v)/ℓ'**.** The sharpness of flare should not exceed 1.0 in urban areas or 0.3 in rural areas.

e- Entry width

v- Approaching lane width

Entry Angle

The relationship between entry angle and entry capacity is a weak inverse one; as tile angle increases, so capacity decreases slightly. However, care should be taken in the choice of entry angle, because angles which are too high and angles which are too low may both result in increased accident potential. The Entry Angle should if possible lie between 20° and 60°, with a figure of around 30° being the optimum.

Entry Radius

The optimum entry radius is 20m. The minimum entry radius should be 6m (10m if significant numbers of trucks are anticipated). Radius above 20m produces very little consequent increasing in capacity. Very large entry radii almost certainly result in inadequate entry deflection.

Exit Radius

The principal is easy exits should always be applied. Curb radius about 40m at the mouth of the exit is desirable. In any case, the exit radius should not be less than 20mor greater than 200m. Exit narrowing should be achieved using a taper of between 1:15 and 1:20

Cross fall and Drainage

Steep grades should be avoided on roundabout approaches. Where this cannot be accomplished, they should be flattened to a maximum of 2% before entry. Generally speaking, super elevation is provided in order to assist vehicles when travelling round a curve. Its values, when used, are equal to or greater than those necessary for surface water drainage. Super elevation is not required on 1he circulating pavement of roundabouts irrespective of their size, whereas cross fall is required so that surface water can drain effectively. On the approaches and exits of roundabouts, however, super elevation can be introduced to assist drivers in negotiating the associated curves.

Cross fall on the circulating pavement can be either inwards (towards the central island), or a normal crown profile, or outwards. Inward cross fall may be appropriate on very large roundabouts, where circulating speeds are high, but elsewhere the fall should normally be normal crown or outwards.

To provide comfort and to enable drivers to remain in control, the maximum algebraic sum of opposing cross fall grades at a crown line should not be greater than 5%. Normal cross fall for drainage on roundabouts should not exceed 2%. To avoid ponding, longitudinal edge profiles should be graded at not less than 0.5%. Application of proper grades and cross falls may not necessarily ensure satisfactory drainage, and therefore the correct siting and spacing of gullies is critical to efficient drainage.

Grades

Curves may be tightened and the degree of super elevation should be appropriate to the speed of vehicles as they approach the roundabout. It should not, however, exceed 5%. In cases where super elevation is used, it should be reduced in the vicinity of the "Give Way" line to the cross fall required merely for drainage.

2.5.6 Oman guidelines

The Oman Highway Design Standards provide broad guidance on the responsibilities of particular authorities of organizations and on procedures. The Oman Highway

Design Standards have been prepared under the guidance of a several technical committees. The Oman highway design standards provide broad guidelines on the responsibilities of particular authorities and organizations and on procedures. It has been considered important to maintain the user experience at a level as close as practicable to that to which drivers have accustomed.

Inscribed Circle Diameter (ICD)

It is not recommended that the inscribed circle diameter of Normal Roundabout should exceed 100m. Large diameters give rise to high speeds on the circulatory carriageway and should be discouraged. An alternative to a single large roundabout is to provide two roundabouts with a connecting road.

A minimum va1ue for an inscribed circle diameter for both a Normal and Compact roundabout is 28m. This is the minimum value which allows sufficient space for the swept path of the designated design vehicle (Articulated commercial trailer vehicle with a single axle at the rear and with an overall length of 15.5m)

If an Inscribed circle diameter lies somewhere between 28m and 36m, then provided the traffic can be accommodated, consideration should be given to design the junction as a Compact Roundabout.

Circulating Pavement

The width of the circulatory carriageway must be between 1.0 and 1.2 times the maximum entry width and excluding any overrun area.

At Normal and Grade separated Roundabouts, the width of the circulatory carriageway should not exceed 15m. At Compact Roundabout, it should not exceed 6m, though an additional overrun area may be required for small values of ICD to allow use by the designated design vehicle.

Center Island

The central island should be circular and at least 4m in diameter. The ICD, the width of the circulatory carriageway and the central island diameter are all interdependent from establishing any two of these parameters automatically fixes the third. Roundabout standards are based on a design vehicle which is 15.5m long, articulated with a single rear axle. The turning circle required for this vehicle on a roundabout with an inscribed circle diameter of between 28m and 36m is shown in Figure 2.40 and Table 2.12. This demand is more onerous than for an 11m long rigid vehicle, a 12m long coach, a 15m long bus, 17.9m articulated bus, a 16.6 long articulated vehicle.

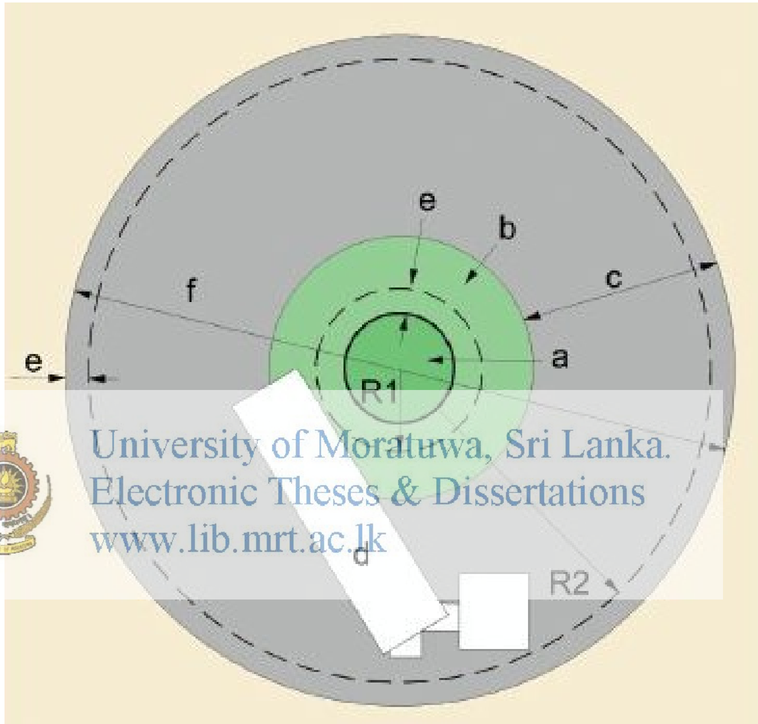


Figure 2.40: Turning Circle Requirement for a Vehicle on a Roundabout with an Inscribed Circle Diameter

a = Main central island

b = Central overrun area, where provided

c = Remaining circulatory carriageway width (1.0 to 1.2 x maximum entry width)

d = Vehicle

e = 1m clearance minimum

f = Inscribed Circle Diameter (ICD)

Table 2.12: Turning Circle Requirement for a Vehicle on a Roundabout with an Inscribed Circle Diameter

Central Island Diameter (m)	R_1 (m)	R_2 (m)	Minimum ICD (m)
4.0	3.0	13.0	28.0
6.0	4.0	13.4	28.8
8.0	5.0	13.9	29.8
10.0	6.0	14.4	30.8
12.0	7.0	15.0	32.0
14.0	8.0	15.6	33.2
16.0	9.0	16.3	34.6
18.0	10.0	17.0	36.0

Entry Width

No roundabout entry should be more than four lanes wide. Lane width at the give way line (measured along the normal to the near side curb, as for entry width) must not be less than 3m or more than 4.5m; with the 4.5m value appropriate at single lane entries and values of3m to 3.5m appropriate at multilane entries

On a single carriageway approach to a Normal roundabout, the entry width must not exceed 10.5m. On a dual carriageway approach to a Normal roundabout, the entry width must not exceed 15m.Where flaring is provided; tapered lanes should have a minimum width of 2.5m.

Flare Length (ℓ')

A minimum length of flare of about 5.0m in urban areas and 25.0m in rural areas is desirable, but capacity should be the determining parameter.

Effective flare lengths greater than 25m may improve the geometric layout of the junction but have little effect of the capacity. Use of effective flare lengths 100m or more is considered to be lane widening (not a flared entry). Where flare lengths are used, they should be developed gradually without any sudden changes in alignment. Value of sharpness which is greater than one corresponds to sharp flare and value of sharpness which is smaller than one corresponds to gradual flare. Long flares are more efficient in terms of driver use, however, sharper flares take less land and more conducive to applying pedestrian crossings.

Entry Angle

The entry angle should lie between 20 degrees and 60 degrees. Low entry angles force the drivers to look over their shoulder or use their mirrors to merge with circulating traffic. Large entry angles include lower capacity and can produce excessive entry deflection which can lead to sharp braking at entry, accompanied by shunt type accidents, particularly speeds are high.

Entry Kerb Radius

The entry kerb radius should not be less than 10m, except at Compact Roundabout. If the approach will be used by large goods vehicles, then in that case, the entry kerb radius shall be not less than 20m. It should be noted that entry curb radii in excess of 100m will produce inadequate deflection.

Increases in capacity can be gained by increasing the curb entry radius, however, once the value of 20m is reached, further increases in kerb entry radius only result in marginal increases in capacity. If the kerb entry radius is reduced below 15m, there is a consequent reduction in capacity.

Exit Width

The exit width should be provided with one more lanes than is present on the road link downstream where possible. The exception to this rule is of course with compact roundabouts which by definition have single lane provision. At a compact roundabout the exit width should be similar to the entry width.

Exit Kerb Radius

At compact roundabout, the value of the exit kerb radius should be lie between 15m to 20m. On other roundabouts, the exit kerb radius should not be less than the 20m or greater than 100m. A kerb radius of 40m is considered desirable.

Cross fall and Drainage

Except in the case of large grade separated roundabouts, where long length of circulatory carriageway might require super-elevation to conform to a link design standards, cross fall is necessary to drain the surface water from the carriageway. The normal value is 2% but it should not exceed 2.5%. Checks must be made to combine vertical alignment with cross-fall to eliminate any areas that might be prone to ponding. An absolute minimum kerb gutter profile of 0.5% can be used in exceptional case, however, a value of 0.67% should be considered to be the practical minimum.

At Normal roundabouts on high speed roads, it is good practice to arrange for super-elevation to assist vehicles in their various maneuvers. This is achieved by providing a crown line by either joining the ends of the splitter islands or by dividing the circulatory carriageway in the proportions 2:1(internal to external) in some cases, a subsidiary crown line can be introduced to advantage in order to reduce the cross over crown line gradient differences.

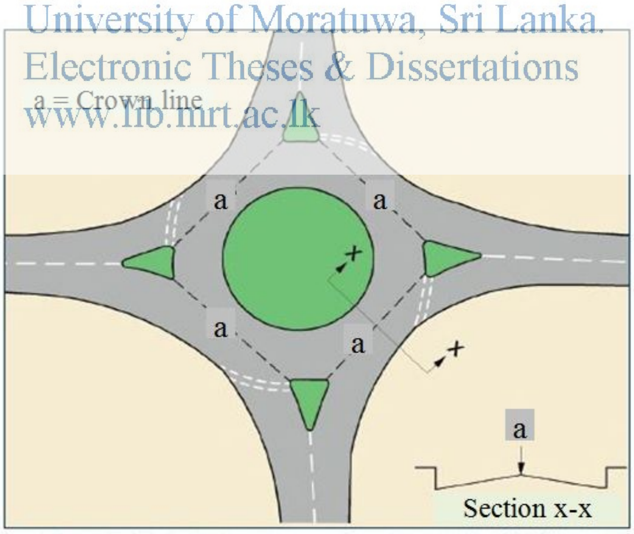


Figure 2.41: Using One Crown Line to Join Splitter Islands

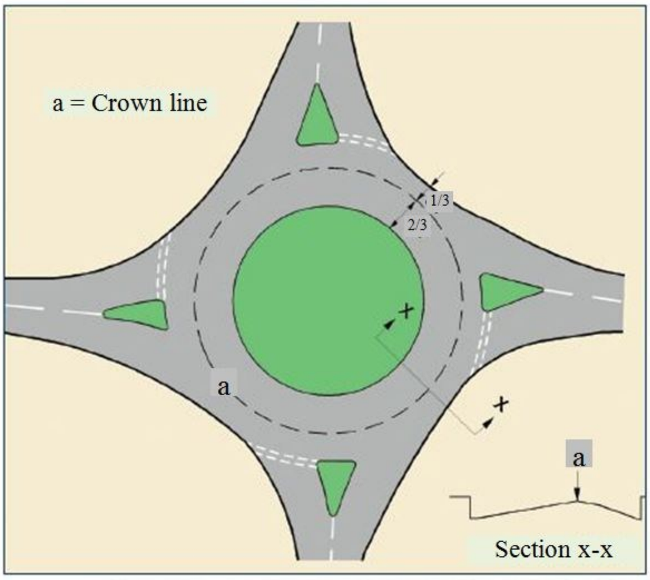


Figure 2.42: Using One Crown Line to Divide the Carriageway in the Ratio 2:1

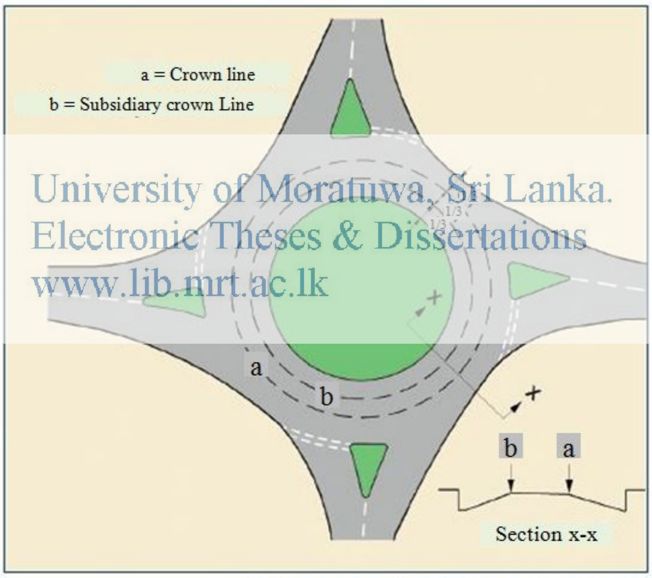


Figure 2.43: Using Two Crown Line to Divide the Carriageway in the Ratio 2:1

Grades

At roundabout approaches, steep gradients should be avoided wherever possible of flattened to 2% before entry.

2.5.7 Summary of guidelines

Table 2.13 shows a summary of guidelines discussed in literature.

Table 2.13: Summary of guidelines

Roundabout	Austroads	AASHTO	DMRB	DUBAI	OMAN
Inscribed Circle Diameter, m	25-37	25-30	min 28	min 29	min 28
Center Island Diameter (m)	10	based on design vehicle	min 4	min 4	min 4
Circulation Width Single Lane (m)	7.6	(1-1.2)* MEW	(1-1.2)* MEW	(1-1.2)* MEW	(1-1.2)* MEW
Entry Radius (m)	max 60	10-100	10-100	10-20	10-100
Exit Radius (m)	straight as possible	straight as possible	20-100 (opt. 40)	20-200	Exit R >= Entry R
Entry Width (m)	5	6-15	min 4.5	6-15	min 4.5
Exit Width (m)	5	based on exit curve R	7-7.5	7.3	7-7.5
Entry Angle (^{0})	-	-	20-60	20-60 (30 opt.)	20-60
Approach Path Deflection Radius (m)	100	100	100	100	100

MEW-Maximum Entry Width

CHAPTER THREE

METHODOLOGY

3.1 Operational Framework

The operational framework used for the study is illustrated in Figure 3.1. This includes identifying major roundabouts, collection of roundabout parameters, review of design guidelines and analysis Sri Lankan Roundabouts with international guidelines.

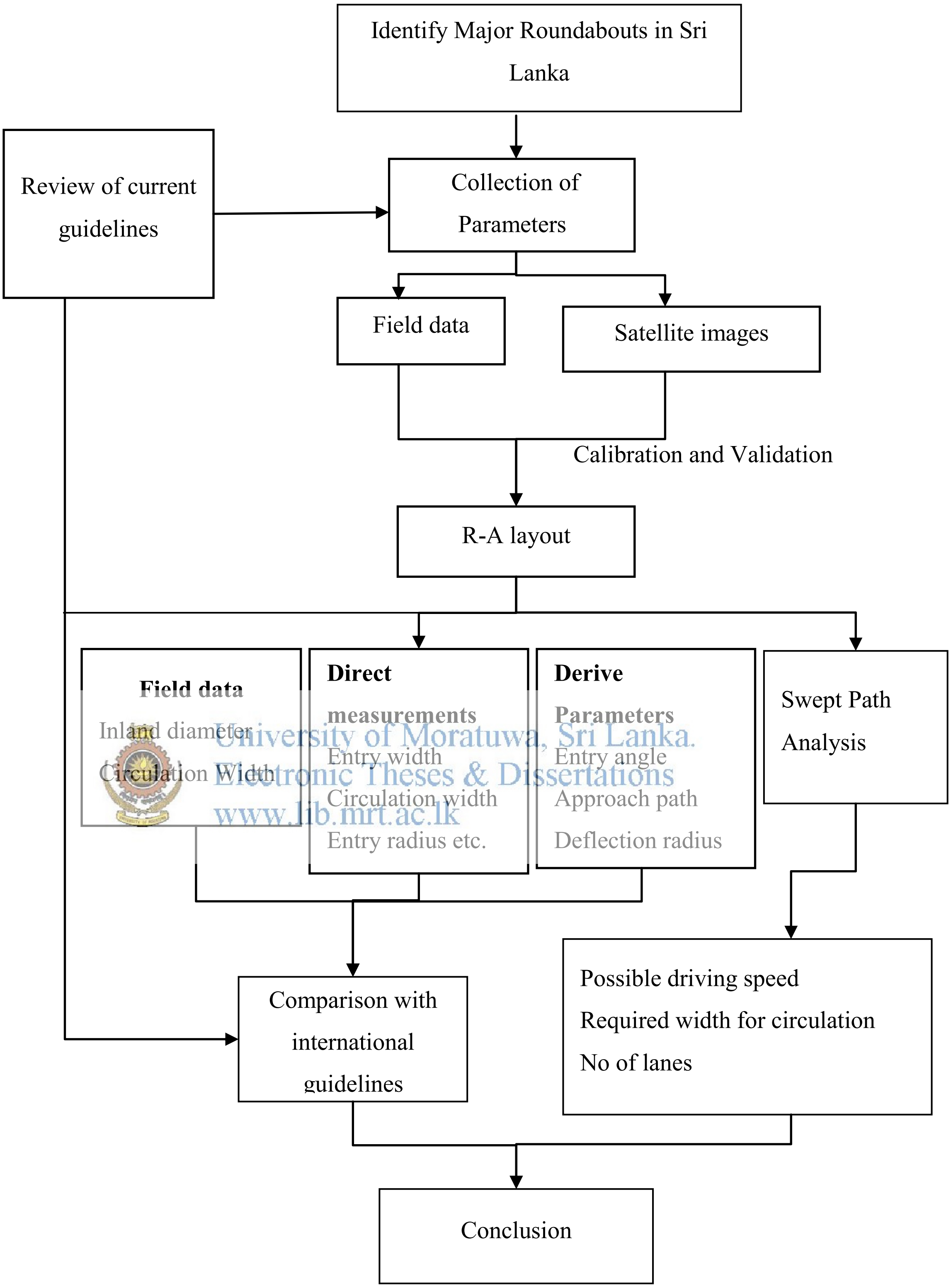


Figure 3.1: Operational Frame Work

3.2 Identification of Suitable Roundabouts

Mainly roundabouts can be seen in many parts around the country. But for the study selection of roundabouts was based on the following criterion.

1. Roundabouts located in major cities with high vehicle capacity
2. Roundabout that act as a node for multiple major roads
3. Cities with frequent roundabouts with minimal restrictions by surrounding.

Within the scope of the study, all main cities in the country with roundabouts is not feasible for the research. Roundabouts located in Colombo, Panadura, Kaluthara, Kurunegala and Anuradhapura were selected for the study.

Roundabouts in Colombo, Panadura and Kaluthara mainly falls to the roundabouts are with high vehicle capacity. In Colombo not all but the most important roundabouts were selected such as Borella Roundabout, Lipton Roundabout, Thalawathugoda Roundabout and Galleface roundabout.

Roundabout located in Kurunegala city is the best location with important connecting nodes as well as high capacity. Anuradhapura is a city with significant number of roundabouts. Also it has ample space to rehabilitate or widen the roundabouts if a design change is needed. The locations of the selected roundabouts are shown in Table 3.1 and satellite images corresponding to following locations are attached in Appendix 1.

Table 3.1: Locations of Selected Roundabouts

No.	Code	Roundabout	City
1	AN-01	Jayanthi Viharaya	Anuradhapura
2	AN-02	Sri Sarananda Viharaya	
3	AN-03	Isurumuniya Junction	
4	AN-04	Dahaiyagama Junction	
5	AN-05	Bank Town	
6	AN-06	Provincial Council	
7	AN-07	Pothanegama	

8	AN-08	Talawa	
9	KG-01	Clock Tower	Kurunegala
10	KG-02	Kadurugas Junction	
11	KG-03	Puwakgas Junction	
12	KG-04	Daladagama	
13	CO-01	Thalawathugoda	Colombo
14	CO-02	Paalam Thuna	
15	CO-03	Borella Cemetary	
16	CO-04	Lipton	
17	CO-05	Galle Face	
18	CO-06	Galadari	
19	PN-01	Egoda Uyana	Panadura
20	PN-02	Golden Statue	
21	KT-01	Church	Kalutara
22	GL-01	Vidyaloka	Gale
23	GL-02	Police	
24	GL-03	Stadium	

3.3 Roundabout Design Guidelines

Many developed Countries in the world such as USA, UK, Australia, France, Denmark, Oman, Dubai etc. have developed their own guidelines for designing Roundabouts. These guidelines are being followed by other countries in their Roundabout design. In this study, several roundabout design guidelines were selected for comparison of design parameters of selected guidelines.

3.4 Development of Roundabout Layout

It is a very costly exercise to measure all the roundabout parameters with in a very short period in the highly populated urban areas considered for the research. To develop the roundabout lay out, the following procedure was adopted.

1. Measure limited dimensions through field measurements.
2. Calibration of satellite images.
3. Validation of parameters.

3.4.1 Field measurements

Roundabout diameter and circulated width were measured through field data collection.

3.4.2 Calibration of satellite images

Satellite images of the selected roundabout for the study were obtained using the satellite maps and special consideration was given to obtain clear and updated images. Then the field measurements of ICD (Inscribed Circle Diameter) were compared with the satellite image and then calibrate the image in AutoCAD drawing to suit to field measurements.

3.4.3 Validation of parameters

Remaining field measurements were used to validate the calibrated roundabout image. Here in AutoCAD remaining field measurements (Entry width and length of the splitter island) were compared with that of the calibrated roundabout image. If the both values are same the validation process will be completed for the selected roundabouts. Validated roundabout layouts were used to obtain the other parameters of the roundabout.

Then the detailed roundabout layouts were developed in AutoCAD, construction lines were drawn on validated images to obtain the other roundabout parameters discussed in section 3.6.

3.5 Roundabout Parameters

Definitions of roundabout parameters according to widely used roundabout guidelines are discussed in chapter 2. Roundabout parameters can be categorised in to 3 types as per the method adopted to obtain the parameters.

1. Through field Measurements

2. Extracted Parameters from validated roundabout.
3. Derived Parameters using construction line drawn on Autocad drawings.

3.5.1 Field measurements

These parameters can be directly obtained from roundabout and they can be easily measured. Examples for such parameters are inland diameter, Circulation width and splitter island width. They can be measured easily in a roundabout even with a highly traffic situation.

3.5.2 Extracted measurements

Using the direct measurements roundabout layout was drawn with the aid of satellite images. Using the roundabout lay out other important parameters can also be extracted. They are;

- Entry width
- Exit width
- Entry radius
- Exit radius

3.5.3 Derived parameters

Using the roundabout layout other important parameters can be derived by modifying the geometric features of the lay out. These modifications are discussed in chapter 2. Roundabout design guidelines follow more or less similar methods to these modifications. These parameters are;

- Entry angle
- Exit angle
- Approach path radius

3.6 Design Vehicle

Roundabouts should always be designed for the largest vehicle that can be reasonably anticipated and it is called the design vehicle. For single-lane roundabouts, this may require the use of a mountable apron around the perimeter of the central island to provide the additional width needed for tracking the trailer wheels. At double-lane roundabouts, large vehicles may track across the whole width of the circulatory roadway to negotiate the roundabout. In Sri Lankan context the most frequent largest vehicle come across a roundabout is the Single Unit truck. In highway design practice, it is known as AASHTO SU vehicle. The details of the vehicle are shown in Figure 3.2. The swept path envelope of AASHTO SU vehicle is shown in Figure 3.3. This vehicle will be used for swept path analysis in the existing roundabout to check whether the present parameters of the roundabout are sufficient for its satisfactory operation.

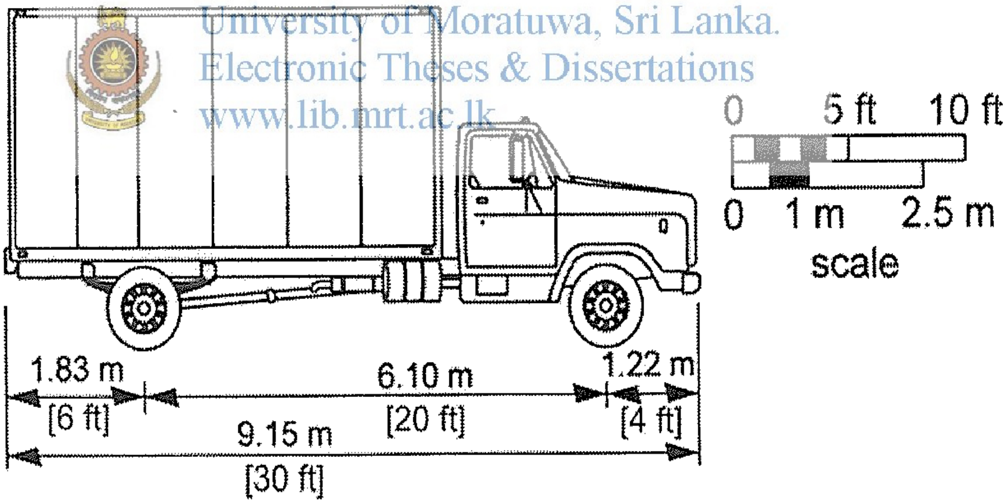


Figure 3.2: Details of the design vehicle

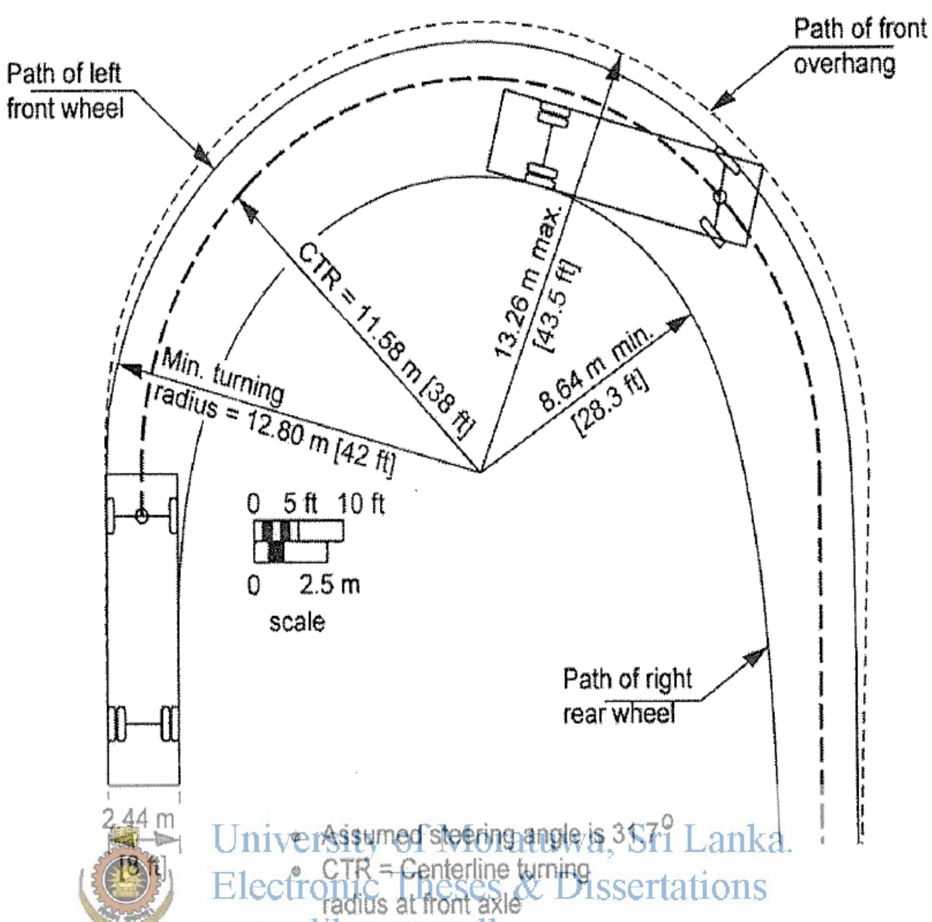


Figure 3.3: The swept path envelope of AASHTO SU Vehicle

3.7 Swept Path Analysis

The drawn layout of the roundabout was used to model the vehicle turning simulation with aid of computer program which is called 'Vehicle TURN'. This is a widely used software and used in well-known highway design software such as Auto cad civil 3D and Bentley Inroads.

The software gives a graphical representation of the vehicle path inside the roundabout. Using this graphical representation one can get a clear idea whether the roundabout is functioning properly or not. For the swept path, following critical turns would be analysed. In addition swept path analysis software can be used to identify the parameters which need to be improved.

1. Straight path movement
2. U turn movement
3. Left Turn movement

Also using the swept path analysis highest possible speed for SU, required width for circulation and possible no of lanes and possible largest vehicle that can pass through the roundabout can be obtained.

The result of the points illustrated in the methodology was included in Chapter 4 and 5. These results were analysed to obtain the final conclusion and recommendations for the study.

CHAPTER FOUR

DATA COLLECTION

4.1 Field Measurements

In this research study, main geometric parameters of each roundabout were collected. Field measurements of following parameters were obtained.

- Inland diameter
- Circulation width
- Split island width
- Split island length

Figure 4.1 depicts the geometric parameters collected through field measurements Table 4.1 shows the field measurements of the selected roundabouts.

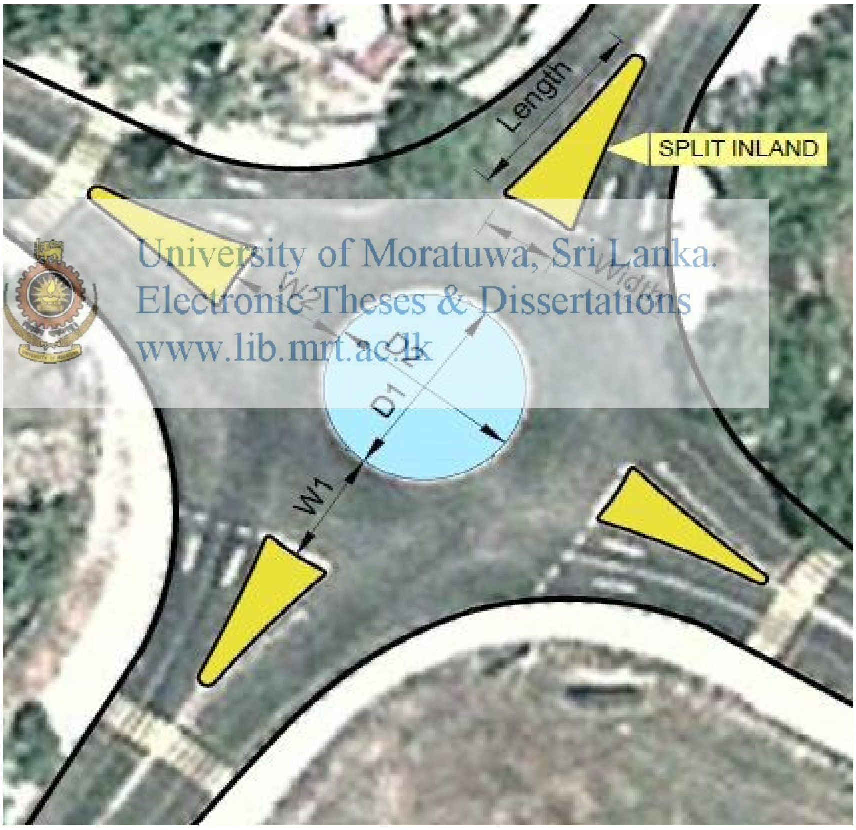


Figure 4.1: Measured geometric parameters of roundabout

Table 4.1: Field Measurements

No.	Code	Roundabout	Inland Diameter (m)		Circular Width (m)		Split Inland (m)		City
			D1	D2	W1	W2	Width	Length	
1	AN-01	Jayanthi Viharaya	18	18	11	11	6.5	15.5	Anuradhapura
2	AN-02	Sri Sarananda Viharaya	9.4	9.4	10.3	10.3	3.4	11	
3	AN-03	Isurumuniya Junction	8	8	11	11	3	16	
4	AN-04	Dahaiyagama Junction	8.2	8.2	11	11.2	2.8	5.7	
5	AN-05	Bank Town	10.5	18	8.1	8	4.5	12.3	
6	AN-06	Provincial Council	24.2	24.2	8.4	8.4	3.3	6.8	
7	AN-07	Pothanegama	8	7.9	11	11	2.8	30.3	
8	AN-08	Talawa	11	11	11	11.1	3.2	9.6	
9	KG-01	Clock Tower	9.9	9.9	13.1	13	3.4	9.8	Kurunegala
10	KG-02	Kadurugas Junction	11	11	8	8	5	9.6	
11	KG-03	Puwakgas Junction	11	11	8.5	8.5	5	10	
12	KG-04	Daladagama	10.8	10.8	11.9	12	2.4	5.5	
13	CO-01	Thalawathugoda	7.9	7.9	11	11.2	3	7.2	Colombo
14	CO-02	PaalamThuna	9.9	9.9	11.4	11.2	3.7	17	
15	CO-03	Borella Cemetary	17.9	37.2	10	16.3	12.7	58	
16	CO-04	Lipton	23	23	18.5	18.5	5.5	30	
17	CO-05	Galle Face	11.8	11.8	11	11	2.5	5.5	
18	CO-06	Galadari	35.8	45	11.1	11.1	10.3	22	
19	PN-01	Egoda Uyana	9.5	9.5	11	11	4.7	28	Panadura
20	PN-02	Golden Statue	7.6	7.6	12	12.0	2.5	9.7	
21	KT-01	Church	5.9	6	11.7	12	3.6	33.5	Kalutara
22	GL-01	Vidyaloka	8	8	8	8	5.1	15.8	Galle

23	GL-02	Police	12.2	12.2	11.9	11.9	3.5	10.4	
24	GL-03	Stadium	13	13	9.8	9.8	5.5	17	

4.2 Direct Measurements and Extracted Parameters

Roundabout layouts are attached in Appendix 1.After that, satellite images were calibrated using some of field measurements. Calibrated satellite images were verified by checking the other field measurements. Verified Autocad drawings were used to extract the following parameters

1. Entry width
2. Exit width
3. Entry radius
4. Exit radius

With developed roundabout layout,

- Entry angle
- Approach path radius was derived.

Table 4.2 show the extracted and derived parameters obtained in this research study. All parameters were derived for all directions for a particular roundabout.

Table 4.2: Design Parameters

R-A Location	Inscribed circle Diameter (m)	Center Island Diameter (m)	Circulation Width (m)	Entry from	Entry Radius (m)		Exit Radius (m)		Entry width (m)	exit width (m)	Entry Angle	Approach path radius (m)
					Outside Entry Curve	Inside Entry Curve	Outside Exit Curve	Inside Exit Curve				
AN -01	40	18	11	Railway Station	60	100	60	100	8.23	8.20	26.11	153.82
				Police Station	45	100	50	100	7.43	8.04	28.87	200.22
				Open University	60	100	75	80	8.28	9.31	26.09	154.57

Table 4.2: Design parameters cont.

				Isurumuniya	50	90	80	100	8.49	9.08	30.15	146.26
AN -02	30	9.4	10.3	Jayanthi Viharaya	150	100	250	150	9.20	8.78	22.88	179.32
				German Bridge	60	100	100	100	7.46	7.77	28.69	161.28
				Isurumuniya	100	150	100	150	7.85	7.75	22.57	364.55
				Sarananda Pirivena	100	100	120	100	9.04	8.38	29.79	65.76
AN -03	30	8	11	Srimaha Bodhiya	320	200	110	200	9.92	8.59	15.45	∞
				Jayanthi Viharaya	100	156	70	156	8.36	7.73	21.54	333.92
				Kurunegala Road	125	156	80	156	8.74	8.32	20.38	360.10
				Isurumuniya	125	156	125	156	8.67	8.73	20.38	363.35
AN -04	30.4	8.2	11.1	New Town	45	150	45	150	7.16	7.02	28.20	NR-83.03
				SOS village	30	180	30	100	6.07	6.45	34.13	NR-219.74
				Pubudupura	50	150	50	120	6.64	6.84	25.89	NR-1141.1
				Puttalam road	40	120	20	120	6.98	6.42	29.04	535.49
AN -05	19.5/ 26	10.5/ 18	8	Market side	45	150	40	150	6.37	6.56	oval	∞
				Provincial Council	40	80	40	80	7.05	7.05	49.30	176.31
				Police Station	60	180	60	200	8.06	8.28	oval	∞
				Central Collage	40	80	40	80	8.29	8.48	49.08	280.85
AN -06	41	24.2	8.4	Old bus stand	30	35	40	35	6.04	6.85	34.76	62.38
				General Hospital	35	30	35	30	6.77	6.00	35.93	74.27
				Anuradhapura Court	35	40	35	35	5.83	6.13	32.39	94.03
				Bank town	30	30	40	30	6.99	7.78	36.87	113.73
AN -07	30	8	11	Isurumuniya	80	120	120	200	8.34	8.21	24.27	∞
				New Town	100	100	100	100	8.68	8.80	32.71	410.63
				Srawasthipura	120	120	∞	∞	8.78	6.25	22.05	427.06
				Pandulagama	100	120	80	100	8.57	8.31	23.01	374.17
AN -08	33	11	11	Anuradhapura	65	100	80	100	7.97	8.72	28.21	∞

Table 4.2: Design parameters cont.

				Kakirwa	20	40	80	120	6.86	7.54	43.19	141.00
				Thambuththegama	45	100	65	100	6.94	7.71	28.46	1625.7
				Village	50	100	65	100	7.57	8.08	27.91	∞
KG -01	36	9.9	13.05	Maligapitiya Ground	75	100	75	100	9.34	9.34	28.00	∞
				Katugastota-Kurunagala-Puttlam Rd	40	50	60	150	7.44	8.19	29.71	251.52
				Colombo	50	100	50	150	8.35	7.90	30.77	∞
				Yanthampalawa	50	120	50	120	8.45	7.85	29.60	598.25
KG -02	27	11	8	Bus Stand	100	100	100	100	6.98	7.07	20.09	∞
				UB Wanninayaka MW	100	100	100	100	7.06	6.55	20.10	∞
				Colombo	200	150	100	150	7.61	6.56	16.29	∞
				Mills RD	100	150	100	100	6.54	7.09	18.06	∞
KG -03	28	11	8.5	Bus Stand	50	100	75	100	5.77	6.57	24.15	399.81
				Mills RD	100	100	75	150	7.25	6.05	20.74	891.44
				Negumbo RD	100	150	100	200	6.64	6.30	18.59	983.53
				Circular RD west	100	100	100	100	6.89	7.27	20.69	∞
KG -04	34.7	10.8	11.95	Ambanpola	100	100	100	100	9.43	9.22	25.24	∞
				Maho	75	100	100	100	8.71	9.26	26.852	∞
				Kurunegala	75	100	75	100	8.69	8.62	26.85	∞
				Nikaweratiya	75	100	100	100	8.19	8.87	26.82	922.92
CO -01	30	7.9	11.05	Batharamulla	50	76	70	-497	9.10	7.71	30.45	1267.2
				Thalawathugoda	30	150	60	200	5.83	6.98	11.6	853.24
				Pannipitiya	60	907	40	71	7.63	8.40	17.90	∞
				Kotte	70	150	20	39	6.30	7.24	8.83	NR-80.50
CO -02	32.5	9.9	11.3	Batharamulla	60	150	50	100	7.59	8.41	24.98	∞
				DenzilKobekaduwa RD	75	120	90	100	8.29	8.88	24.73	∞
				Pannipitiya	25	50	100	150	7.15	8.17	39.61	136.78

Table 4.2: Design parameters cont.

				Parliament	35	120	60	120	7.30	8.09	30.09	2305.9
CO -03	27.9 /47.2	17.9/ 37.2	10	D.S Senanayake RD	∞	∞	3975	135	9.60	13.0	14.5	∞
				Elwitigala RD	450	250	∞	∞	9.50	9.40	18.26	∞
				Wijerama RD	50	∞	1000	1000	10.60	9.30	60.79	1271.7
				Kency RD	88	88	255	286	6.60	5.20	20.64	200.00
CO -04	60	23	18.5	Anagarlika Dammapala RD	15	200	100	300	11	14.6	26.51	∞
				Ministry of health	400	400	89	89	14.1	15.0	15.20	NR-164.63
				Ward Place	40	100	150	120	10.9	13.9	36.73	∞
				Nelum Pokuna	100	200	250	600	13.2	14.4	25.43	∞
CO -05	33.8	11.8	11	Colombo Fort	40	80	50	120	7.98	7.92	31.04	257.03
				Macan Marcar RD	25	50	15	50	7.83	6.67	49.77	∞
				Kollupitiya	12	80	40	120	6.73	7.78	49.17	∞
				Galle Face	15	75	15	75	5.10	5.02	38.63	87.59
CO -06	35.8/ 45	35.8	11.1	Janadipathi RD	60	50	100	150	11.8	8.59	20.80	87.47
				Lotus RD	50	60	100	80	9.67	10.6	29.55	87.64
				Kollupitiya	150	100	40	25	10.6	12.9	19.74	420.26
				Colombo Fort	80	50	150	200	11.2	7.57	30.53	76.83
PN -01	31.5	9.5	11	Colombo	150	265	50	∞	9.08	7.50	16.65	∞
				Moratuwa	60	120	100	120	7.41	8.30	25.78	2903.2
				Panadura	100	300	30	250	8.24	6.65	18.87	∞
				Harbour	30	120	75	120	5.64	7.19	30.18	142.78
PN -02	31.6	7.6	11	Walana	150	1000	15	80	7.77	6.27	15.30	NR-205.57
				Panadura	80	∞	80	120	8.05	9.91	18.42	∞
				Colombo	70	200	80	200	8.07	8.37	23.77	∞
KT -01	29.6	5.9	11.88	Heenatiyagala	30	35	100	∞	9.7	10.2	39.4	35
				Colombo	150	400	150	400	9.5	8.5	58.6	∞
				Galle	400	400	400	400	9.7	10.2	52.3	∞

Table 4.2: Design parameters cont.

GL -01	24	8	8	Wakwella RD	200	300	50	60	7.88	6.43	Non exist	230.99
				1st cross Street	40	236	80	-71	6.70	7.21	29.79	45.00
				Galle Port	40	100	200	500	6.21	7.12	25.61	∞
GL -02	36	12.2	11.9	Colombo	50	60	∞	200	9.95	10.23	33.23	213.52
				Wakwella RD	80	100	180	200	8.80	9.79	25.94	∞
				Sea Street	200	150	200	400	11.0	9.58	19.02	4047.5
				Custom RD	60	60	∞	-200	10.5	9.07	32.02	94.04
GL -03	32.6	13	9.8	Samanala Stadium	150	120	75	180	10.1	6.90	19.43	∞
				Harbour	110	147	120	132	7.86	10.5	19.60	∞
				BOC Building	45	58	30	58	6.37	5.34	30.40	79.31

The drawn layout of the roundabout was used to model the vehicle turning simulation with aid of computer program which is called 'Vehicle TURN'. The software gives a graphical representation of the vehicle path inside the roundabout. Therefore, efficiency of the roundabout and parameters needed to be modified can be identified. Results obtained in swept path analysis are also presented in Chapter 5.

CHAPTER FIVE

ANALYSIS AND DISCUSSION OF RESULTS

5.1 Comparison of International Guidelines

In this chapter, five major international guidelines were selected to compare geometry parameters of roundabout. Table 5.1 represents comparison of roundabout parameters with various international guidelines.

Table 5.1: Comparison of Roundabout Parameters with International Guidelines

Roundabout	Austroads	AASHTO	DMRB	DUBAI	OMAN
Inscribed Circle Diameter (m)	25-37	25-30	min 28	min 29	min 28
Center Island Diameter (m)	10	based on design vehicle	min 4	min 4	min 4
Circulation Width Single Lane (m)	7.6	(1-1.2)* MEW	(1-1.2)* MEW	(1-1.2)* MEW	(1-1.2)* MEW
Entry Radius (m)	max 60	10-100	10-100	10-20	10-100
Exit Radius (m)	straight as possible	straight as possible	20-100 (opt. 40)	20-200	Exit R >= Entry R
Entry Width (m)	5	6-15	min 4.5	6-15	min 4.5
Exit Width (m)	5	based on exit curve R	7-7.5	7.3	7-7.5
Entry Angle (^{0})	-	-	20-60	20-60 (30 opt.)	20-60
Approach Path Deflection Radius (m)	100	100	100	100	100

MEW = Maximum Entry Width

5.2 Comparison of parameters of selected roundabouts

In this section, each measured, derived and extracted parameter is further analysed. They were compared with international guidelines. The following parameters of the selected roundabouts were compared with international guidelines.

5.2.1 Inscribed Circle Diameter - ICD

As discussed earlier, inscribed circle diameter is defined as the distance across the circle inscribed by the outer curb (or edge) of the circulatory roadway. Increasing the diameter of a roundabout usually enables provision of better approach geometry which leads to a reduction in vehicle approach speeds. Therefore, both Oman and DMRB guidelines discuss that minimum inscribed diameter should be 28m while Dubai guidelines states that it should be 29m.Larger diameters will encourage high circulating speeds and may leads erroneous movements if drivers perceive that the time taken to traverse the roundabout is too long. Therefore, Austroads and AASHTO provide an optimum region for ICD. According to Austroads the optimum region lies between 25-37 m, while AASHTO lies between 25-30 m.

Figure 5.1 illustrates the measured Inscribed Circle Diameter values of selected roundabouts and the recommended diameter of the guidelines. For ellipsoidal RAs minimum diameter was considered for the analysis as it is being the critical diameter of ICD.

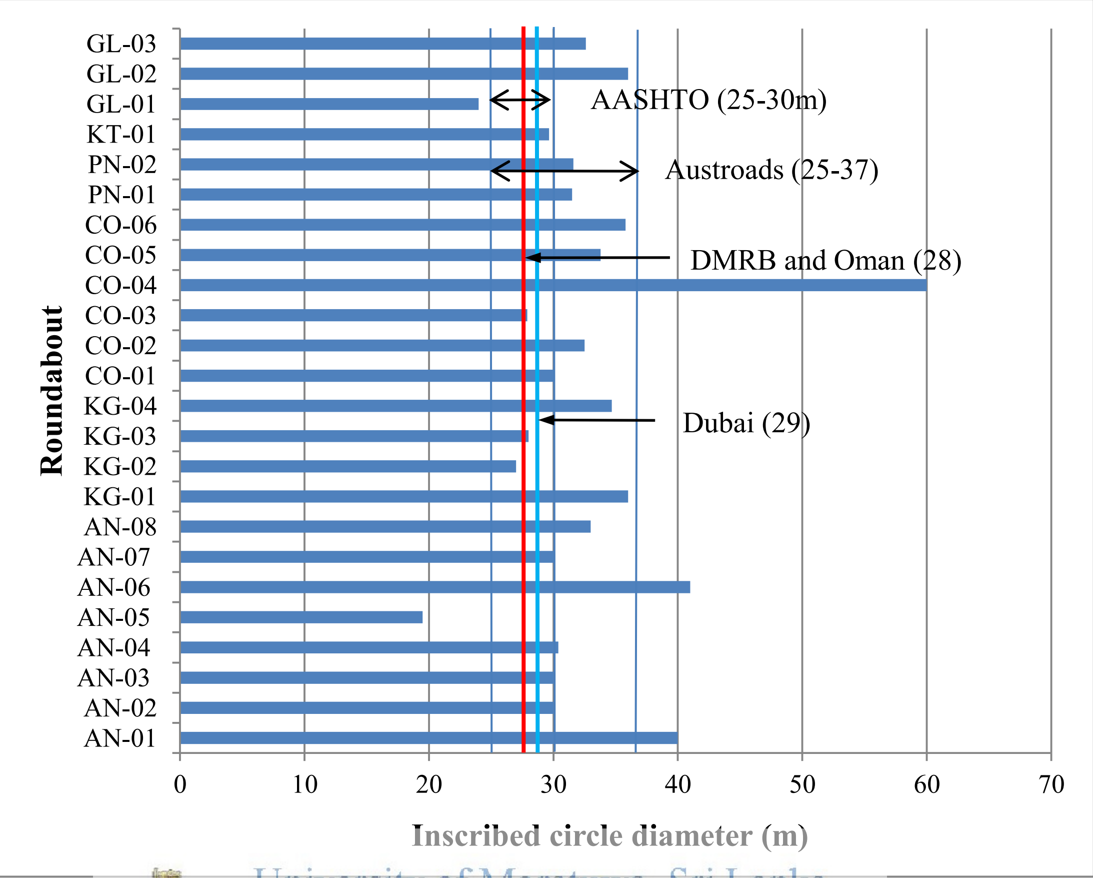


Figure 5.1: Analysis of Inscribed Circle Diameter

According to Figure 5.1, it can be observed that the largest Inscribed Circle Diameter of 60m in Nelum Pokuna roundabout (CO-04) in Colombo. Next two largest values can be seen Provincial Council roundabout (AN-06) and Jayanthi Vihara (AN-01) roundabout in Anuradhapura with 41m and 40m respectively. The smallest inscribed circle diameter was reported in Galle stadium roundabout (GL-01) with the value of 24 m. Also Bank Town RA Anuradhapura (ellipsoidal) has 19.5 m minimum ICD value. However, it can be concluded that most of roundabouts considered in this study satisfy the guidelines provided in AASHTO, DMRB, Oman and Dubai Guidelines.

5.2.2 Central Island Diameter -CID

The central island of a roundabout is the raised, non-traversable area encompassed by circulatory roadway. When the central island diameter is considerably large, that enables good speed of vehicles. Therefore, according to DMRB guidelines, minimum Central Island Diameter should be 4m. Austroads proposes the optimum Central Island Diameter as 10m. Considering the studied roundabouts, almost all had circular shaped central islands. However, there are exceptions such as Borella Cemetery roundabout (CO-03) and Galadari roundabout. In general, it is considered that the central island should be circular in shape because, a circular-shaped central island with a constant-radius circulatory roadway helps promote constant speeds around the central island. Oval or irregular shapes, on the other hand, are more difficult to drive and can promote higher speeds on the straight sections and reduce speeds on the arcs of the oval.

Figure 5.2 illustrates the measured central island diameter values of selected roundabouts and the recommended values of international guidelines.

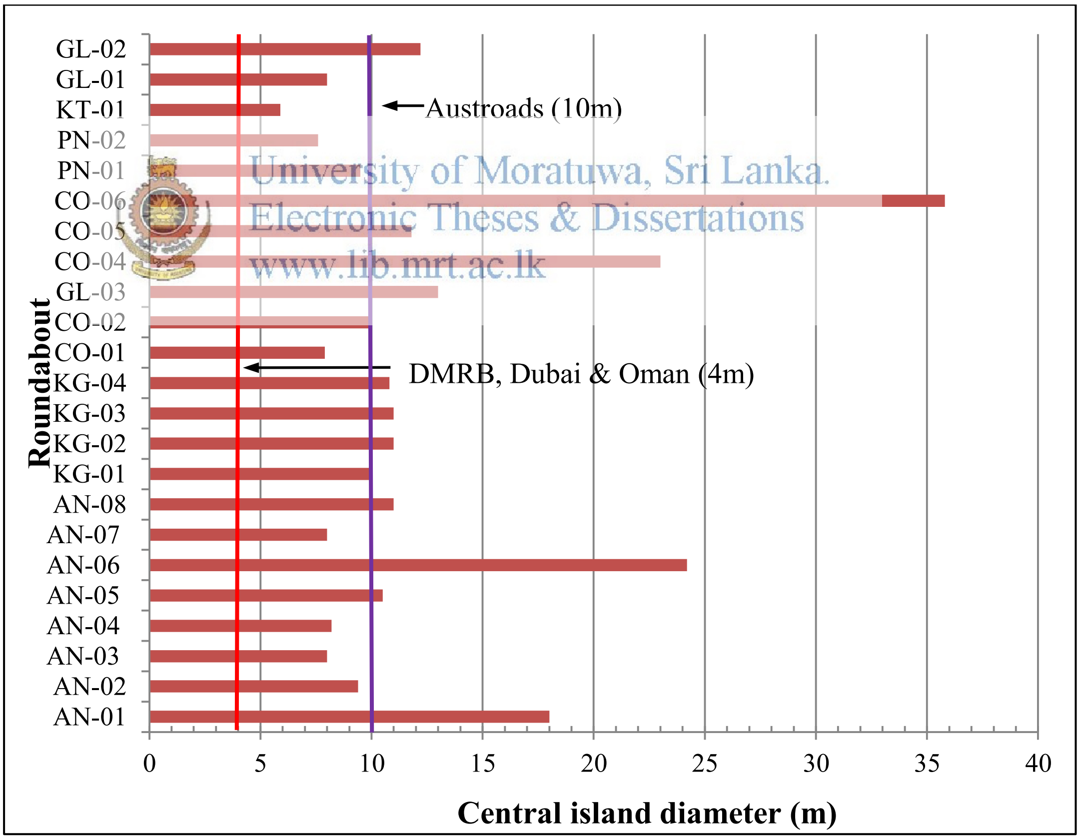


Figure 5.2: Analysis of Central Island Diameter

According to Figure 5.2, it is clear that none of the selected roundabouts violate the given minimum criteria for Central Island Diameter. The smallest and the most critical value is reported in Kalutara Church roundabout with 5.9 m. Further, it can be observed that the largest Central Island Diameter of 38.5 m in Galle Face roundabout (CO-06). Next two largest values; 24.2mand 23m can be seen at Provincial Council roundabout in Anuradhapura (AN-06) and Nelum Pokuna roundabout in Colombo (CO-04).

5.2.3 Circulation width

The required width of the circulatory roadway is determined by the width of the entries and the turning requirements of the design vehicle. According to Austroads guidelines minimum circulation width can be identified as 7.6m. AASTO, DMRB, Oman and Dubai guidelines suggest the minimum circulation width as (1-1.2) x Maximum entry width. Figure 5.3 illustrates the measured circulation width values of selected roundabouts and recommended values in Austroads guidelines.

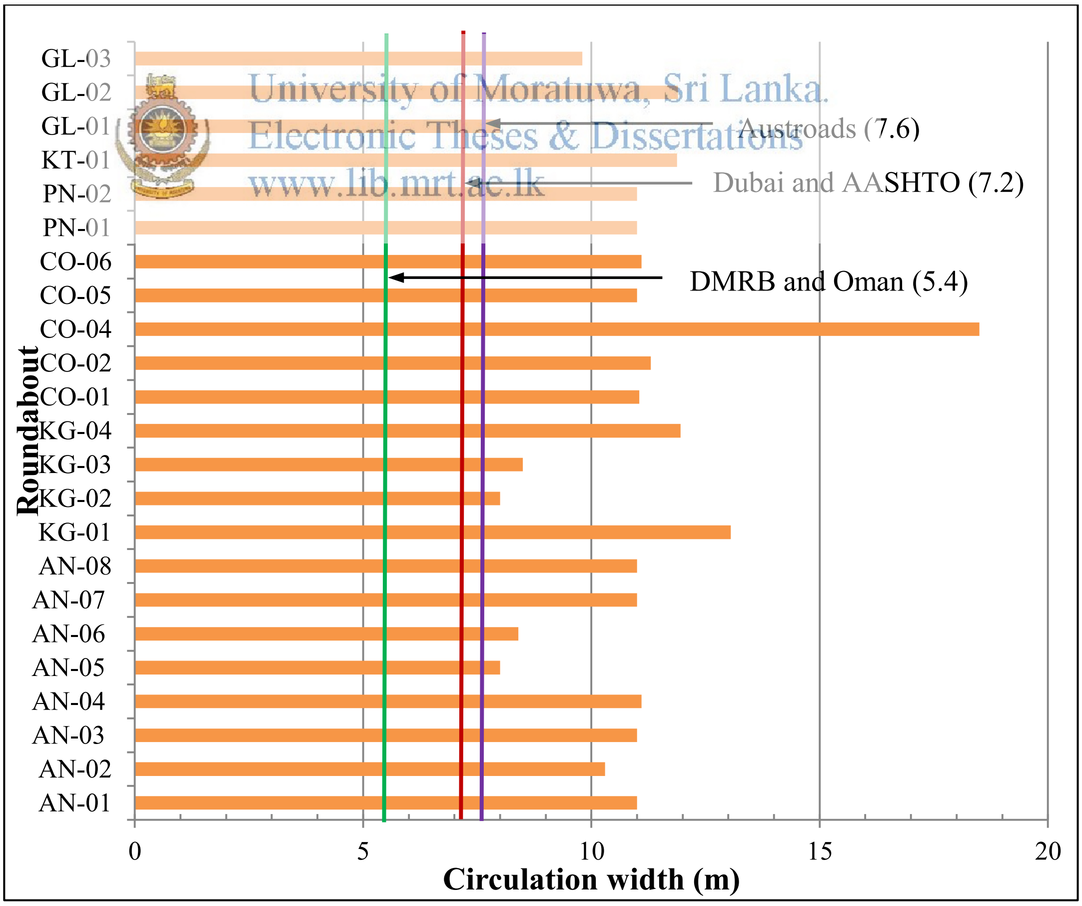


Figure 5.3: Analysis of Circulation Width

According to Figure 5.3, it is clear that none of selected roundabouts violate the given minimum criteria for circulation width (7.6 m) stated in Austroads guidelines. The smallest and the most critical values are reported in Kadurugas Junction roundabout in Kurunegala (KG-02) and Bank Town roundabout in Anuradhapura (AN-05) with 8.0 m. Further, it can be observed that the relatively largest circulation width of 38.5 m in Nelum Pokuna roundabout (CO-04). Most of the roundabouts have circulation width between 10- 12 m.

Table 5.2 illustrates the measured circulation width values of selected roundabouts and comparison with DMRB, and Oman and Dubai guidelines. Here, the critical circulation width was considered as maximum entry width.

Table 5.2: Analysis of Circulation Width

R-A Location	Circulation Width (m)	Critical Circulation Width (m)	Comparison with AASHTO, DMRB, Dubai and Oman Guidelines
AN-01	11	8.5	Satisfied
AN-02	10.3	9.2	Satisfied
AN-03	11	9.9	Satisfied
AN-04	11.1	7.2	Satisfied
AN-05	8	8.3	Not Satisfied
AN-06	8.4	7.0	Satisfied
AN-07	11	8.8	Satisfied
AN-08	11	8.0	Satisfied
KG-01	13.1	9.3	Satisfied
KG-02	8	7.6	Satisfied
KG-03	8.5	7.3	Satisfied
KG-04	11.9	9.4	Satisfied
CO-01	11.1	9.1	Satisfied
CO-02	11.3	8.3	Satisfied
CO-04	18.5	14.1	Satisfied
CO-05	11	8.0	Satisfied
CO-06	11.1	11.8	Not Satisfied
PN-01	11	9.1	Satisfied
PN-02	11	8.1	Satisfied
KT-01	11.9	9.7	Satisfied
GL-01	8	7.8	Satisfied
GL-02	11.9	11.0	Satisfied

GL-03	9.8	8.3	Satisfied

According to Table 5.2, it is clear that most of the selected roundabouts satisfy AASHTO, DMRB, Dubai and Oman Guidelines except Bank Town roundabout at Anuradhapura (AN-05) and Galle Face roundabout (CO-06). However, those roundabouts circulation width maintain at the critical circulation width.

5.2.4 Entry width

Entry width is the largest determinant of a roundabout's capacity. The capacity of an approach is not dependent merely on the number of entering lanes, but on the total width of the entry.

In order to having an optimum functioning of a roundabout, it is recommended an optimum range by the international guidelines instead of critical value for the entry width. In order to overcome the complexity of data representation, only maximum and minimum entry angles were selected for further analysis.Figure 5.4 illustrates the entry width of selected roundabouts and specified width in international standards.

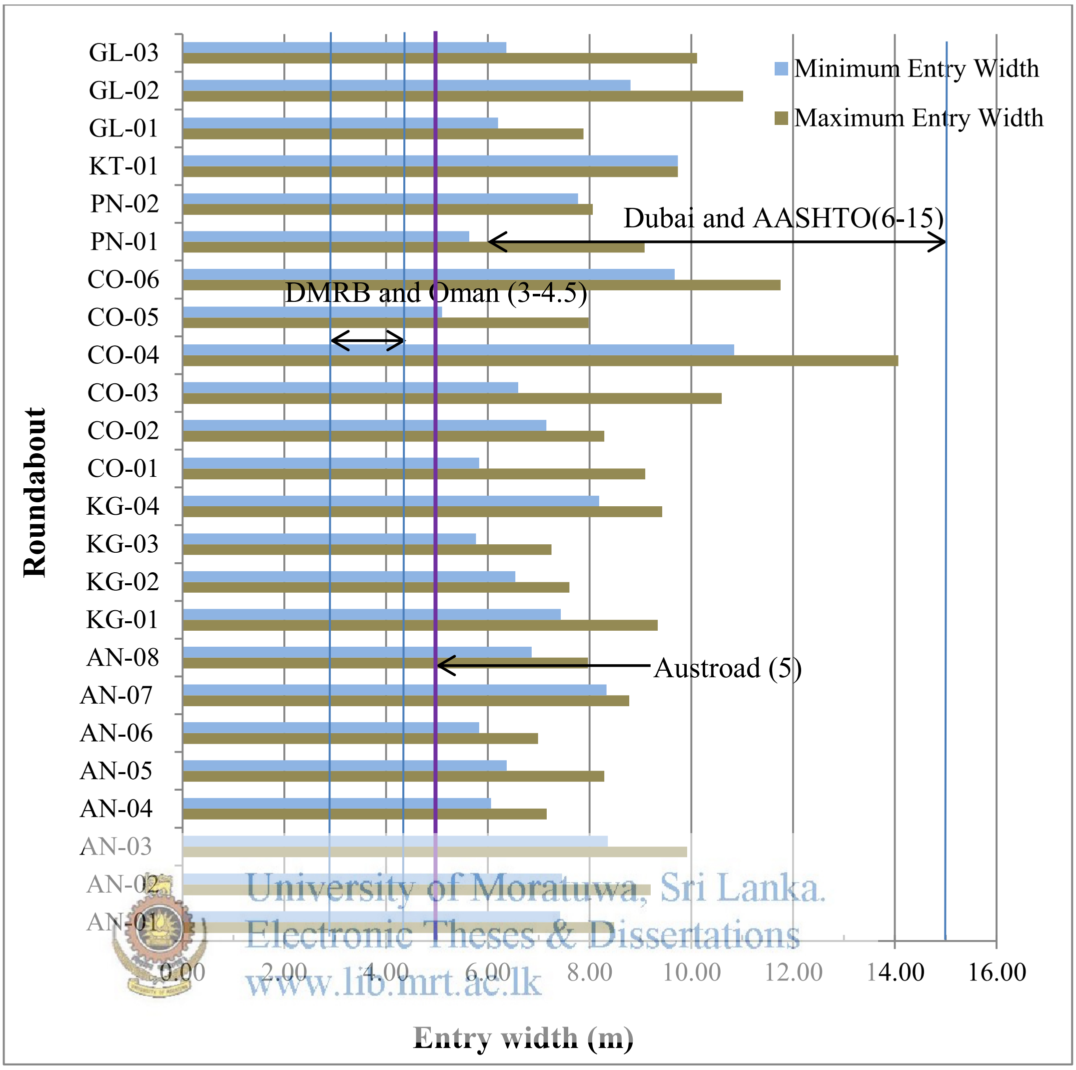


Figure 5.4: Analysis of Entry Width

According to international guidelines, entry width should be in between 3-15m and Dubai guidelines identify that optimum entry width is 6-15m. Maximum entry widths of all roundabouts are complied with the Dubai guideline. It can be identified that that most of selected roundabouts satisfy those international guidelines. However Nelum Pokuna and Galle face roundabouts have relatively higher entry widths.

5.2.5 Exit width

Exit width is also a key measurement of capacity of the roundabout. To facilitate the best outflow movements, a larger exit width is required. From the selected international guidelines, two guidelines, Austroad and DMRB, have recommended the exit width standards. Austroad guideline has recommended the exit width as 5m, while DMRB provides an optimum range for the exit width. Figure 5.5 illustrates the exit width values of selected roundabouts and the recommended values of above guidelines.

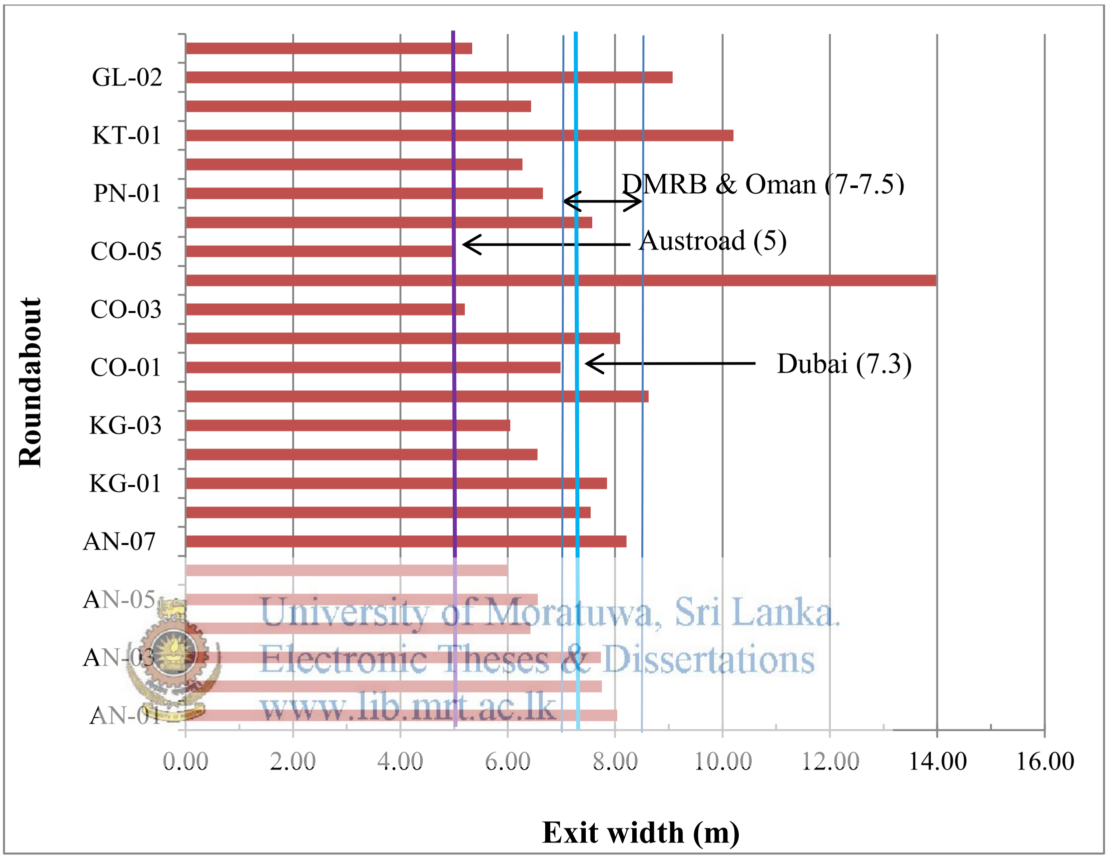


Figure 5.5: Analysis of Exit Width

According to the Figure 5.5 most of the roundabouts are complying with the Austroad standards. Only the Nelum Pokuna roundabout shows the higher deviation from the other roundabouts.

5.2.6 Entry radius

Entry radius is a critical geometrical parameter of a roundabout which contributes significantly on its functionality. As discussed earlier, entry curve defines the approach to a roundabout. The entry radius will decide the efficient circulation of traffic and space consumption of roundabout. Increasing entry usually enables provision of better approach geometry which leads to a reduction in vehicle approach speeds. Both Oman and DMRB guidelines discuss that minimum entry radius should be 10m while Dubai guidelines states, it should be minimum of 6m or 10m and optimum value of 20m. AASHTO, DMRB and Oman provides a region for entry radius. According to Austroad the optimum region lies between 10-100m.

Figure 5.6 illustrates the entry radius values of selected roundabouts with comparison with above guidelines.

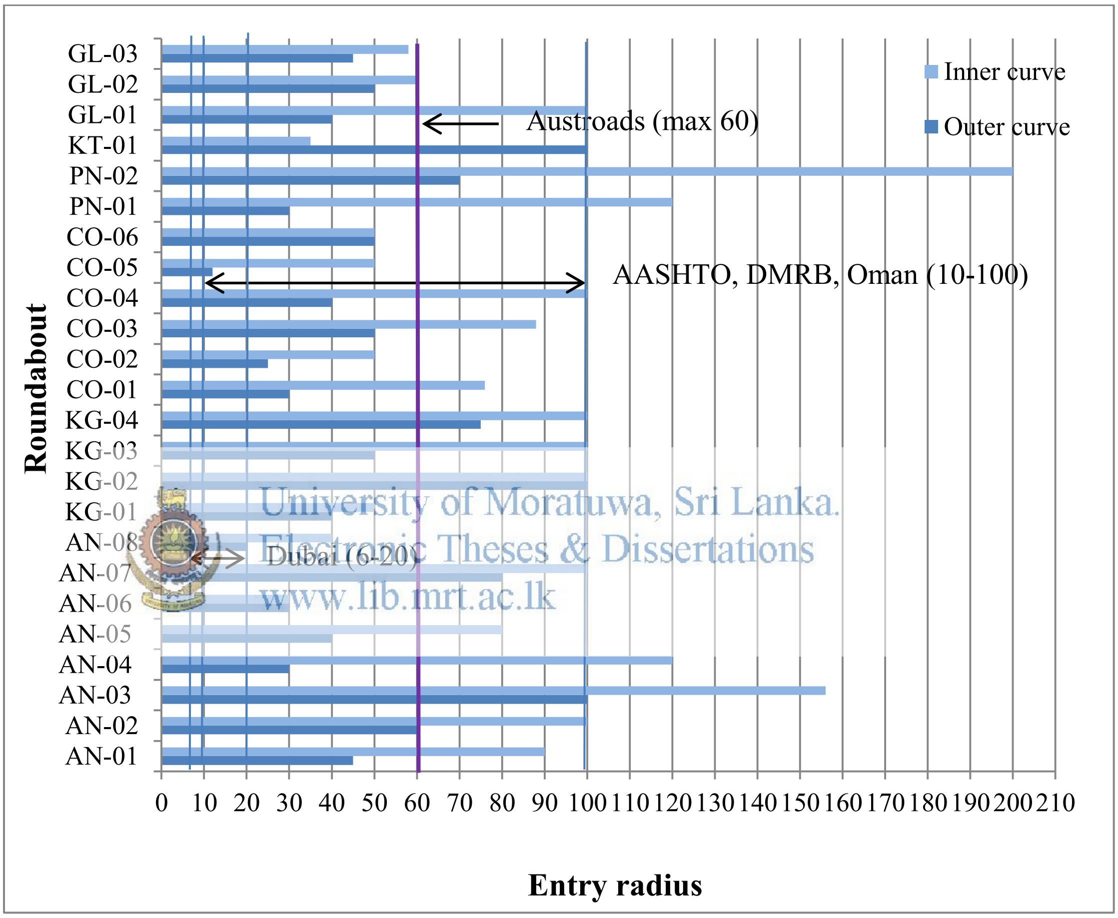


Figure 5.6: Analysis of Entry Radius

According to the selected international guidelines, entry radius should be in between 6-100m. With results, it can be identified that most of selected roundabouts satisfy those international guidelines. However, Egoda Uyana, Panadura golden statue, Dhaiyagama junction and Isurumuniya junction roundabouts have their minimum entry radius which exceeds the all discussed.

5.2.7 Exit radius

Exit radius is one of the factor contributes for the efficiency of the roundabout. Larger exit radius facilitates the better outflow from the roundabout. So the exits radius recommended in guidelines were selected. Dubai and DMRB guidelines provide a region for the exit radius. Dubai guidelines states, it should be within 20 to 200m while providing an optimum value of 40m for exit radius. Larger exit radius will encourage high outflow speeds and may encourage efficient roundabout action. Therefore, Austroad and AASHTO recommend the exit radius to be as much as straight. And AASHTO provide a minimum value of 15m for exit radius. Meantime Oman guidelines state that exit radius should be selected as equal as or larger than the entry radius. Figure 5.7 illustrates the measured Exit Radius values of selected roundabouts and the recommended range of international guidelines.

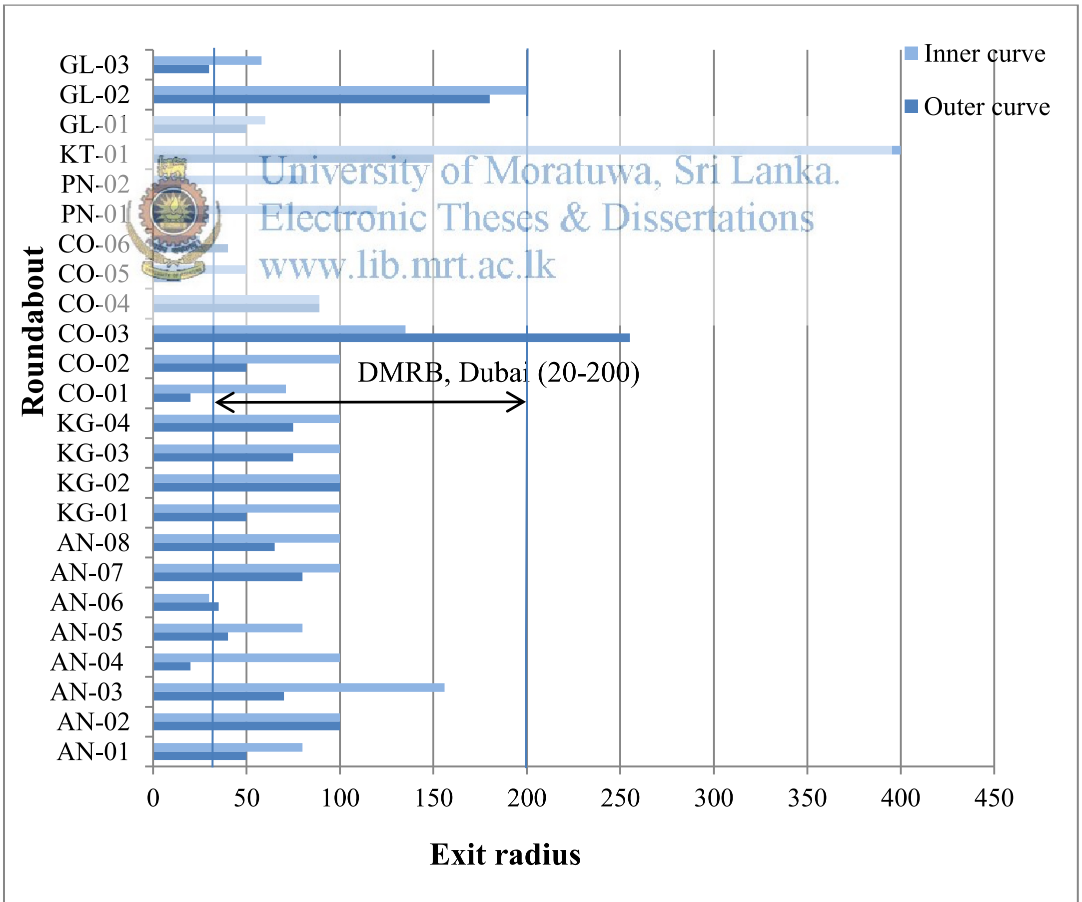


Figure 5.7: Analysis of Exit Radius

According to international guidelines, exit radius should not be less than 15m. With results, it can be identified that most of selected roundabouts satisfy those international guidelines, except Lipton and golden statue roundabouts. Exit radii of Lipton and golden statue are 89m and 15m respectively.

5.2.8 Entry angle

An Entry angle serves as a geometric property for the conflict angle between entering and circulating streams. The entry angle was derived in accordance with Figure 2.22 and 2.23 for all directions for a particular roundabout. In order to overcome the complexity of data representation, only maximum and minimum entry angles were selected for further analysis.

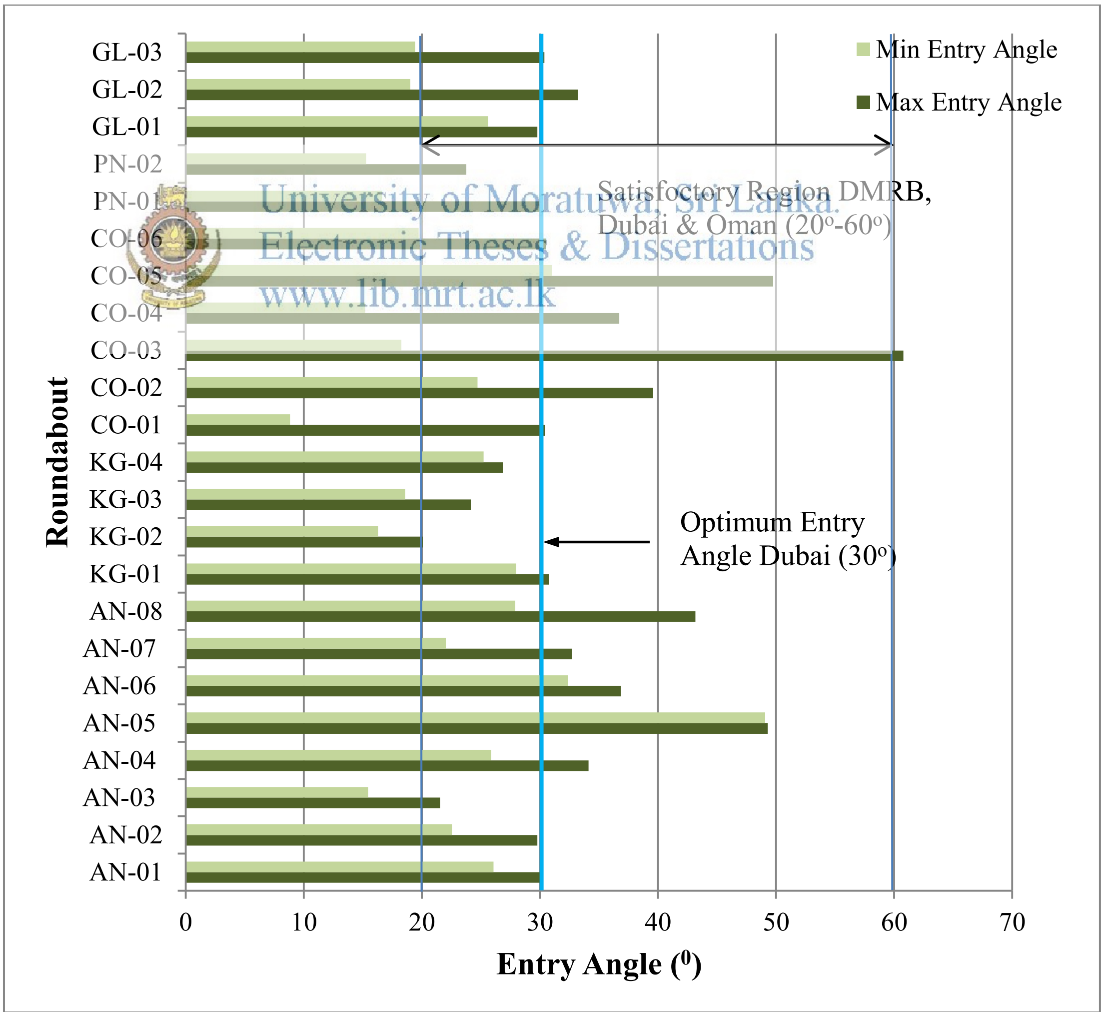


Figure 5.8: Analysis of Entry Angle

According to DMRB, Dubai and Oman guidelines, the entry angle should be in between 20^o-60^o and Dubai guidelines identify that optimum entry angle is 30^o. It can be concluded that most of selected roundabouts satisfy the international guidelines. However Isurumuniya Junction roundabout at Anuradhapura (AN-03), Kadurugas Junction roundabout in Kurunegala (KG-02) and Golden Statue roundabout in Panadura (PN-02) can be identified as roundabouts with small entry angles.

5.2.9 Approach path radius

Approach path radius is very important for roundabout action. According to Austroads guidelines, optimum approach path radius is 100 m. In this study, all of approach path radii were derived for each roundabout. Since the maximum approach path radius is more critical for roundabout action. The derived values of maximum approach path radii are presented in Table 5.3.

Table 5.3: Approach Path Radius

Roundabout Location	Maximum Approach Path Radius (m)
AN-01	200.2
AN-02	364.6
AN-03	Infinity
AN-04	1141.1
AN-05	Infinity
AN-06	113.7
AN-07	427.1
AN-08	1625.7
KG-01	Infinity
KG-02	Infinity
KG-03	983.5
KG-04	Infinity
CO-01	Infinity
CO-02	Infinity
CO-04	Infinity
CO-05	Infinity
CO-06	420.3

PN-01	Infinity
PN-02	Infinity
GL-01	Infinity
GL-02	Infinity
GL-03	Infinity

It is clear that many of the roundabouts approach path radii are very much higher than the recommended value in international guidelines. It is important to maintain optimum approach path radius to lower the approach speed. Hence only Anuradhapura provincial council roundabout (AN-06) maintains 113.7m which is very much close to optimum value.

5.2.10 Compatibility of Exit Radius against Entry Radius

In area where there are no pedestrians the exit from a roundabout should be as easy to negotiate as practicable. After having been slowed down by the entry and circulating curves, vehicles should be able to accelerate on the exit (AUSTROADS, 1993).Hence exit radius should not be less than the entry radius.

Table 5.4: Exit radius and entry radius

R-A Location	Road	Entry Radius (m)	Exit Radius (m)	Status
AN-01	Railway Station	60	60	Satisfy
	Police Station	45	50	Satisfy
	Open University	60	75	Satisfy
	Isurumuniya	50	80	Satisfy
AN-02	Jayanthi Viharaya	150	250	Satisfy
	German Bridge	60	100	Satisfy
	Isurumuniya	100	100	Satisfy
	Sarananda Pirivena	100	120	Satisfy
AN-03	Srimaha Bodhiya	320	110	Not satisfy
	Jayanthi Viharaya	100	70	Not satisfy
	Kurunegala Road	125	80	Not satisfy
	Isurumuniya	125	125	Satisfy
AN-04	New Town	45	45	Satisfy
	SOS village	30	30	Satisfy
	Pubudupura	50	50	Satisfy
	Puttalam road	40	20	Not satisfy
AN-05	Market side	45	40	Not satisfy
	Provincial Council	40	40	Satisfy

Table 5.4: Exit radius and entry radius cont.

	Police Station	60	60	Satisfy
	Central Collage	40	40	Satisfy
AN-06	Old bus stand	30	40	Satisfy
	General Hospital	35	35	Satisfy
	Anuradhapura Court	35	35	Satisfy
	Bank town	30	40	Satisfy
AN-07	Isurumuniya	80	120	Satisfy
	New Town	100	100	Satisfy
	Srawasthipura	120	∞	Satisfy
	Pndulagama	100	80	Not satisfy
AN-08	Anuradhapura	65	80	Satisfy
	Kakirwa	20	80	Satisfy
	Thambuththegama	45	65	Satisfy
	Village	50	65	Satisfy
KG-01	Maligapitiya Ground	75	75	Satisfy
	Katugastota-Kurunagala-Puttlam Rd	40	60	Satisfy
	Colombo	50	50	Satisfy
	Yanthampalawa	50	50	Satisfy
KG-02	Bus Stand	100	100	Satisfy
	UB Wanninayaka MW	100	100	Satisfy
	Colombo	200	100	Not satisfy
	Mills RD	100	100	Satisfy
KG-03	Bus Stand	50	75	Satisfy
	Mills RD	100	75	Not satisfy
	Negumbo RD	100	100	Satisfy
	Circular RD west	100	100	Satisfy
KG-04	Ambanpola	100	100	Satisfy
	Maho	75	100	Satisfy
	Kurunegala	75	75	Satisfy
	Nikaweratiya	75	100	Satisfy
CO-01	Batharamulla	50	70	Satisfy
	Thalawathugoda	30	60	Satisfy
	Pannipitiya	60	40	Not satisfy
	Kotte	70	20	Not satisfy
CO-02	Batharamulla	60	50	Not satisfy
	DenzilKobekaduwa	75	90	Satisfy
	Pannipitiya	25	100	Satisfy
	Parliament	35	60	Satisfy
CO-03	D.S Senanayake RD	∞	3975	Not satisfy
	Elwitigala RD	450	∞	Satisfy
	Wijerama RD	50	1000	Satisfy
	Kency RD	88	255	Satisfy
CO-04	Anagarlika Dammapala RD	15	100	Satisfy
	Ministry of health	400	89	Not satisfy
	Ward Place	40	150	Satisfy

Table 5.4: Exit radius and entry radius cont.

	NelumPokuna	100	250	Satisfy
CO-05	Colombo Fort	40	50	Satisfy
	Macan Marcar RD	25	15	Not satisfy
	Kollupitiya	12	40	Satisfy
	Galle Face	15	15	Satisfy
CO-06	Janadipathi RD	60	100	Satisfy
	Lotus RD	50	100	Satisfy
	Kollupitiya	150	40	Not satisfy
	Colombo Fort	80	150	Satisfy
PN-01	Colombo	150	50	Not satisfy
	Moratuwa	60	100	Satisfy
	Panadura	100	30	Not satisfy
	Harbour	30	75	Satisfy
PN-02	Walana	150	15	Not satisfy
	Panadura	80	80	Satisfy
	Colombo	70	80	Satisfy
KT-01	Heenatiyagala	30	100	Satisfy
	Colombo	150	150	Satisfy
	Galle	400	400	Satisfy
GL-01	Wakwella RD	200	50	Not satisfy
	1st cross Street	40	80	Satisfy
	Galle Port	40	200	Satisfy
GL-02	Colombo	50	∞	Satisfy
	Wakwella RD	80	180	Satisfy
	Sea Street	200	200	Satisfy
	Custom RD	60	∞	Satisfy
GL-03	Samanala Stadium	150	75	Not satisfy
	Harbour	110	120	Satisfy
	BOC Building	45	30	Not satisfy

5.3 Swept Path Analysis

Swept Path Analysis is the calculation and analysis of the movement and path of a vehicle when that vehicle is undertaking a turning manoeuvre. At a basic level, this includes calculating the path taken by each wheel during the turn and also calculating the space needed by the vehicle body during the turn. Initially this form of calculation was carried out by manually, but in recent years, software has been developed. Some of the swept path analysis programs available in industry are Auto TURN, Auto Track and Vehicle TURN. In this research, Vehicle TURN program was used to conduct swept path analysis.Figure5.9 shows the interface for entering vehicle dimensions.

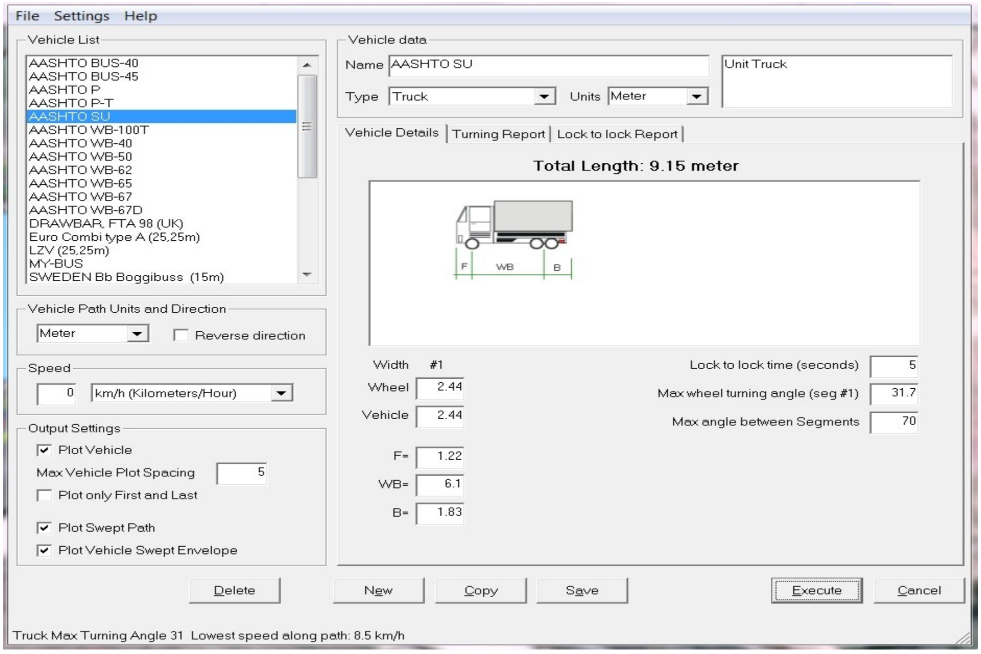


Figure 5.9: Dimensions of the Vehicle adopted for Swept Path Analysis

The swept path analysis results obtained from Vehicle TURN simulations are tabulated in Table 5.5 and corresponding diagrams are attached in Appendix 1.

Table 5.5: Results Obtained for SU Vehicle from Vehicle TURN Simulation

Code	Roundabout	By inner lane						By Outer lane	
		SU-Min speed (km/h) (A)	Width of Traced path (m) (B)	Required Circulation Width (m) (C)	Available Circulation Width (m) (D)	Balance Circulation Width (m) (E=D-C)	Max Possible no of Lanes (F=(E/B) +1)	SU-Min speed (km/h)	Width of Traced path (m)
AN-01	Jayanthi Viharaya	8.5	4.6	4.7	11.0	6.3	2.4	11.8	3.9
AN-02	Sri SaranandaViharaya	8.7	4.6	9.0	11.3	1.3	1.3	10.1	4.4
AN-03	Isurumuniya Junction	7.9	4.6	9.5	11.0	1.5	1.3	9.3	4.4
AN-04	Dahaiyagama Junction	6.0	4.6	9.4	11.0	1.6	1.3	8.7	4.4
AN-05	Bank Town*#	8.8	4.6	8.5	8.0	-	-	8.8	4.6
AN-06	Provincial Council	9.6	4.2	4.3	8.4	4.1	2.0	10.2	3.8

AN-07	Pothanegama	8.1	4.6	9.7	11.0	1.3	1.3	9.6	4.3
AN-08	Talawa	8.3	4.6	8.0	11.0	3	1.7	9.5	4.2
KG-01	Clock Tower	7.5	4.6	8.7	13.0	4.3	1.9	10.1	4.0
KG-02	Kadurugas Junction	8.4	4.6	8.0	8.0	0	1	8.6	4.6
KG-03	Puwakgas Junction	7.9	4.6	8.0	8.5	0.5	1.1	9.0	4.5
KG-04	Daladagama	8.0	4.6	8.1	11.9	3.8	1.8	10.7	4.1
CO-01	Thalawathugoda	6.8	4.6	9.5	11.0	1.5	1.3	7.9	4.4
CO-02	Paalam Thuna	7.5	4.6	8.5	11.2	2.7	1.6	8.6	4.2
CO-03	Borella Cemetary*	2.1	4.5	5.7	10.0	4.3	2.0	8.1	4.5
CO-04	Lipton	10.4	4.3	4.7	18.5	13.8	4.2	18.7	3.5
CO-05	Galle Face	6.5	4.6	7.8	11.0	3.2	1.7	7.0	4.0
CO-06	Galadari*	3.5	4.7	4.7	11.1	6.4	2.4	3.6	3.2
PN-01	Egoda Uyana	8.3	4.6	8.7	11.0	2.3	1.5	9.8	4.2
PN-02	Golden Statue	7.8	4.6	9.7	12.0	2.3	1.5	9.7	4.2
KT-01	Church	7.9	4.5	10.5	11.7	1.2	1.3	9.8	4.4
GL-01	Vidyaloka#	7.8	4.6	9.6	8.0	-	-	7.8	4.6
GL-02	Police	8.8	4.6	7.6	11.9	4.3	1.9	12.3	4.0
GL-03	Stadium	7.9	4.6	7.2	9.8	2.6	1.6	8.2	4.1

*- Ellipsoidal roundabout #- Inadequate circulation width

Considering the above results, it can be observed that Borella Cemetery roundabout (CO -03) and Galadari roundabout (CO -6) with minimum SU speed by inner lane of 2.1 kmph and 3.5 kmph respectively. Average SU speed by inner lane is 7.6 kmph while average SU speed by inner lane is 9.5 kmph. Figure 5.9 illustrates, required circulation width and available circulation width of each roundabouts.

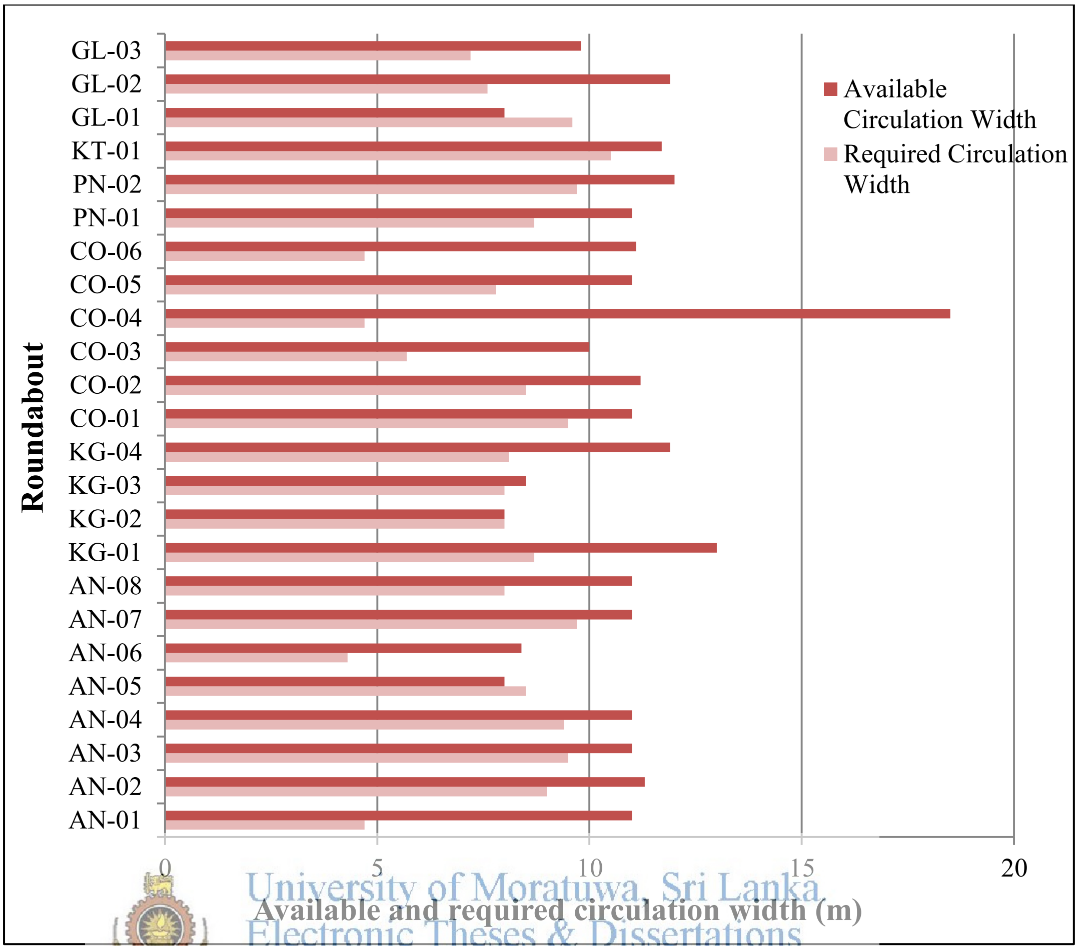


Figure 5.9: Comparison of Available Circulation Width with Swept Path Analysis Results

It can be concluded that roundabouts except Bank town (AN-05) and Vidyaloka (GL-01) have satisfactory ICD and circulation width. Circulation width of Bank town roundabout (AN-05) and Vidyaloka roundabout (GL-01) is 8m.

5.4 Development of Roundabout Guidelines for Sri Lanka

Many of the roundabout parameters of the selected roundabouts were satisfied with the values proposed in international guidelines. The satisfied and unsatisfied parameters of selected roundabouts are shown in Table 5.6.

Table 5.6: Comparison of roundabout parameters of Sri Lanka against international guidelines.

Roundabout	AustRoad	AASHTO	DMRB	DUBAI	OMAN	Sri Lanka
Inscribed Circle Diameter (m)	25-37	25-30	min 28	min 29	min 28	Satisfy
Center Island Diameter (m)	10	based on design vehicle	min 4	min 4	min 4	Satisfy
Circulation Width Single Lane (m)	7.6	(1-1.2)* MEW	(1-1.2)* MEW	(1-1.2)* MEW	(1-1.2)* MEW	Satisfy
Entry Radius (m)	max 60	10-100	10-100	10-20	10-100	Not satisfy
Exit Radius (m)	straight as possible	straight as possible	20-100 (opt. 40)	20-200	Exit R >= Entry R	Satisfy
Entry Width (m)	5	6-15	min 4.5	6-15	min 4.5	Satisfy
Exit Width (m)	5	based on exit curve R	7-7.5	7.3	7-7.5	Satisfy
Entry Angle (^{0})	-	-	20-60	20-60 (30 opt.)	20-60	Not satisfy
Approach Path Deflection radius (m)	100	100	100	100	100	Not satisfy

MEW-Maximum Entry Width

For proper functioning of roundabout, speed of the entry vehicle should be lowered and vehicle should be circulated around the centre island. This requirement mainly depends on the unsatisfied parameters (Entry radius, Entry angle and Approach path deflection radius) of above Table 5.6.

Hence considering the international guidelines proposed values for Sri Lanka are;

- Entry radius - 20m – 60m
- Entry angle - 20^{o} – 60^{o}
- Approach path deflection radius - 100m

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Roundabouts provide solutions for intersections having capacity/delay issues, intersections in which traffic signal were requested but not warranted and etc. Well-designed roundabouts have proven to be safe and efficient forms of intersection control. In Sri Lanka, roundabouts are frequently used in urban areas with high mobility cities such as Colombo, Gampaha, Anuradhapura and Galle. But the use of roundabout in Sri Lankan road network does not have long history. Hence, it is timely requirement to propose the parameters that need to be improved on existing roundabout and factors to be considered in developing a design guideline for Sri Lanka.

Twenty four no of major roundabouts in Sri Lanka were identified for the study. They were selected considering three factors such as RA located in major cities with high traffic, RA act as a node for multiple major roads and RA in cities with frequent roundabouts with minimal restrictions by surrounding. Limited no of field data were collected from selected roundabouts. Collected field data and satellite images were combined to develop the roundabout layout. Then design parameters extracted from RA layout were compared with the values proposed in international design guidelines. Finally swept path analysis was carried out for SU vehicle to check the adequacy of entry width, circulation width, exit width and operational speed.

Considering the results obtained in parameter analysis and swept path analysis, it can be concluded that sizes of all most all (96%) roundabouts are satisfying the minimum of minimum requirement of international guidelines (ICD). It can be identified that except few situations most roundabouts are satisfying the maximum of minimum requirement of international guideline for center island diameter (100%), circulation width (92%), exit radius (92%), entry width (79%) and exit width (50%).

However, Entry radius shows higher values than the recommended values in international guidelines. Only 13% of selected RAs, values of minimum entry angle were within the range of entry angle proposed by international guidelines. Many of the roundabout approach path radii are very much higher than the recommended value of 100m, in international guidelines. This can be resulted in serious safety concerns when roundabout is operating at lower speed. (Approach path speed is higher than the circulated speed of the roundabout) Approach speed should be lowered by geometric design reducing the entry radius and approach path radius.

Entry radius of 23% of roundabouts is higher than the exit radius. Those RA shows lower value of SU minimum speed. In general practice exit radius should be larger than entry radius for easy exit from the RA.

According to swept path analysis results, Two RAs (out of twenty four) are not satisfying the minimum requirement of ICD, hence the circulation width. It was confirmed by the parameter analysis results as well. Also it can be concluded that the circular roundabouts are more likely to be functioned efficiently than the ellipsoidal roundabouts according to minimum SU speed.

6.2 Recommendations

- It is recommended to consider guidelines provided for entry radius, entry angle and approach path deflection radii in order to improve the geometry of RA as roundabout is operating at lower speed
- It is recommended to have higher value for exit radius than entry radius.
- RA with circular central island is more effective than the ellipsoidal central island
- In selection of roundabout locations, it is important to identify sites where satisfactory geometric design can be provided. It can be recommended signals interconnected system as alternative, in order to improve level of service.

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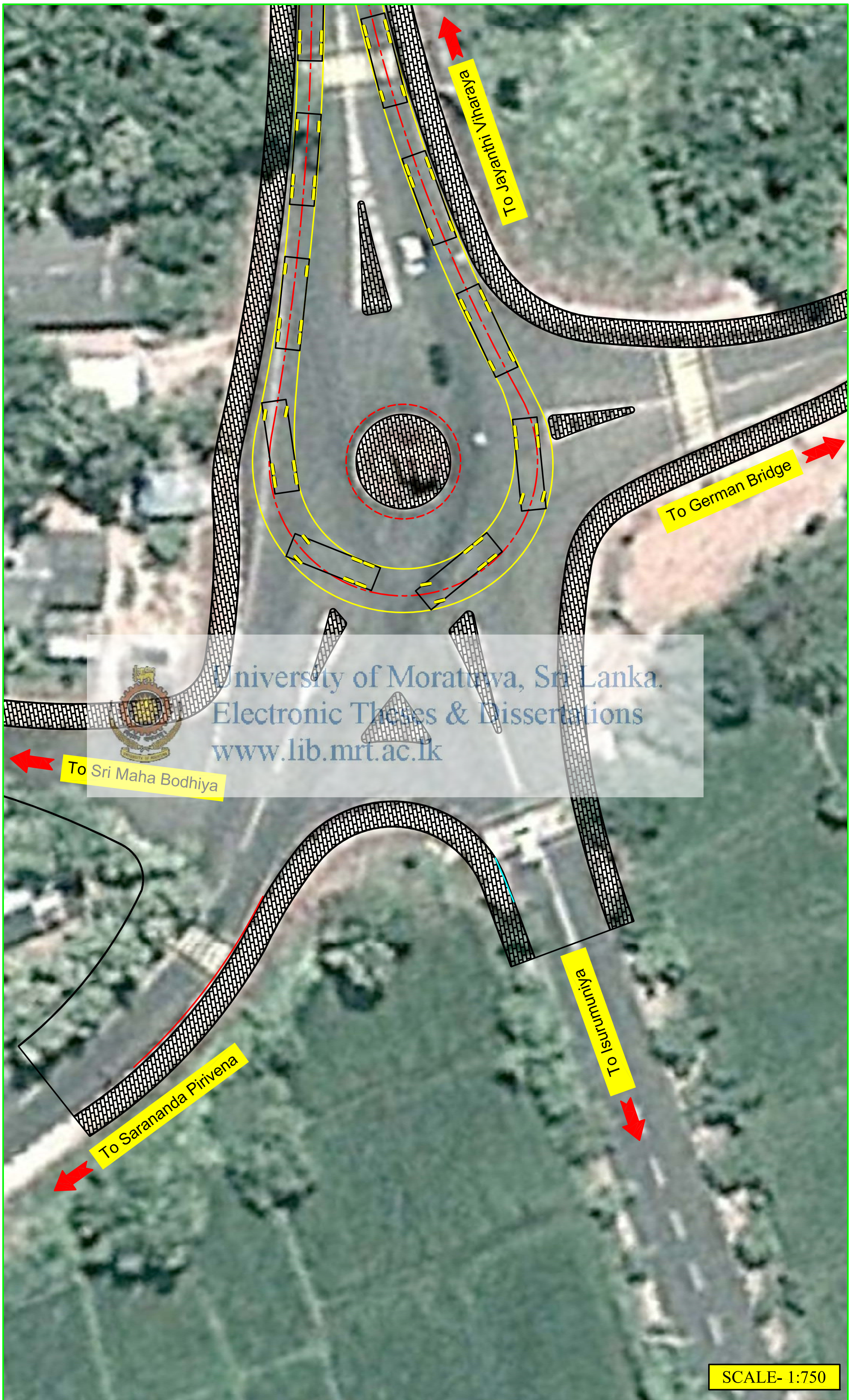
APPENDIX 1

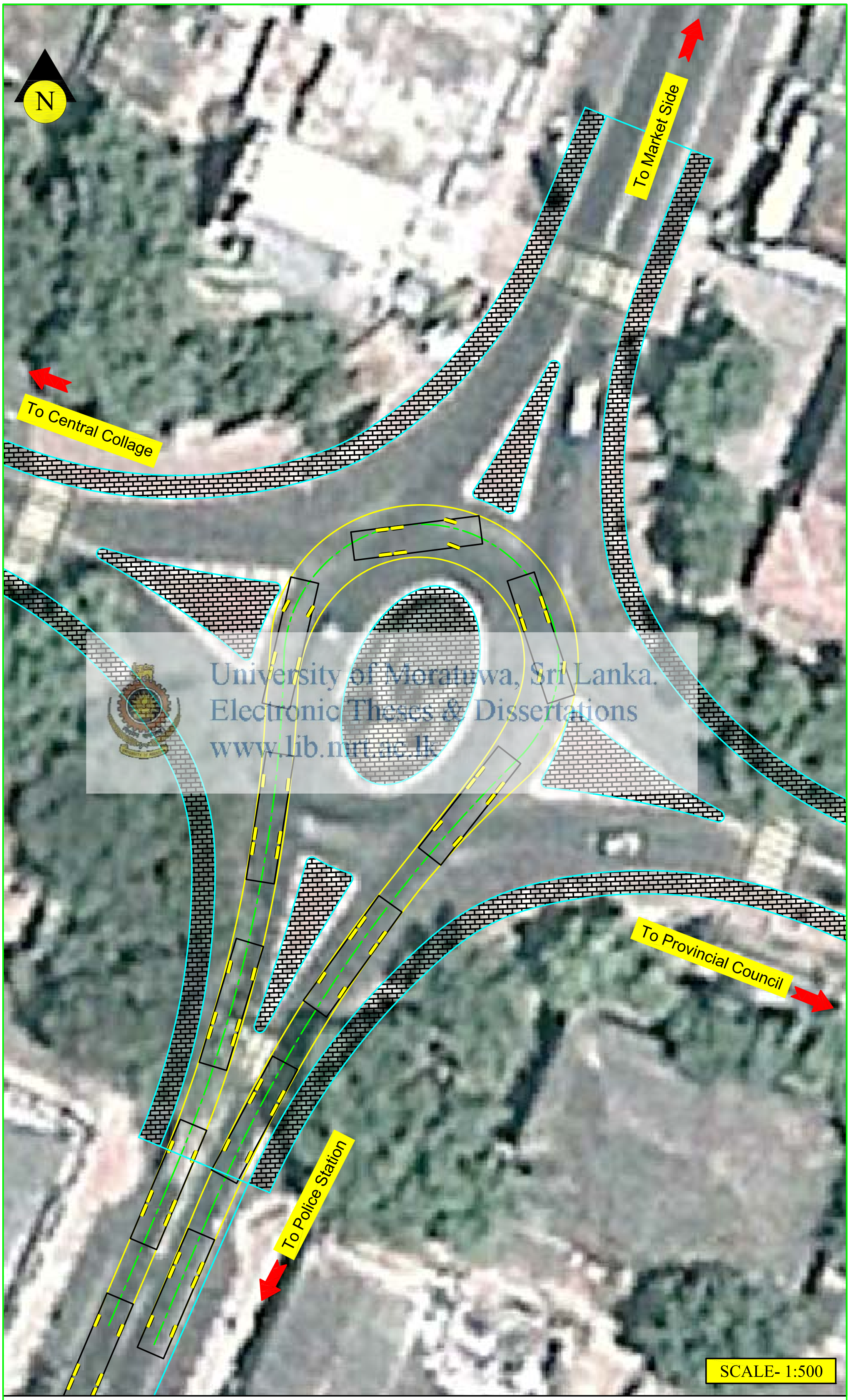
AN-01, Roundabout at Jayanthi Viharaya-Anuradhapura



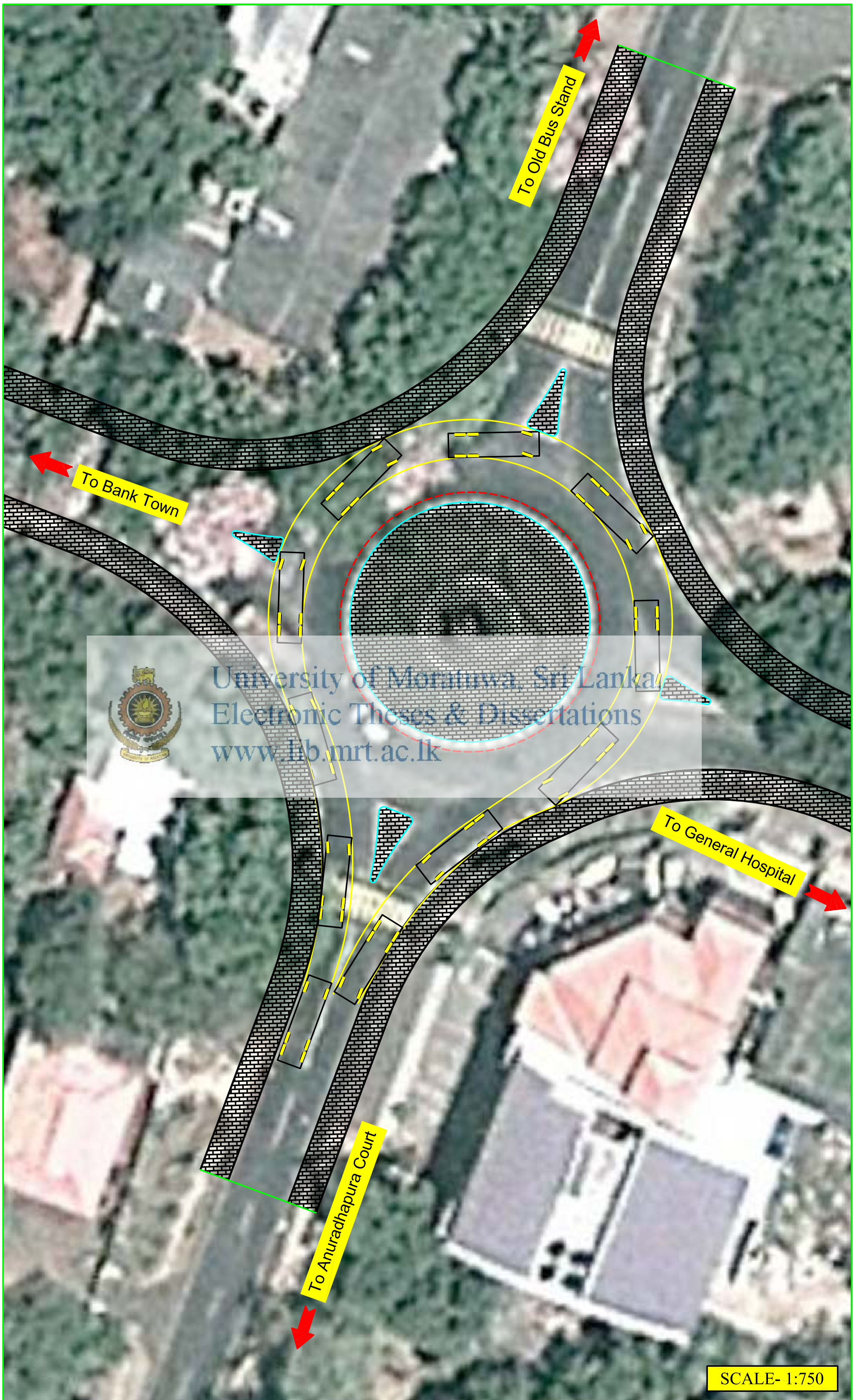
AN-02, Roundabout at Sri Sarananda Viharaya-Anuradhapura

AN-03, Roundabout at Isurumuniya Junction-Anuradhapura

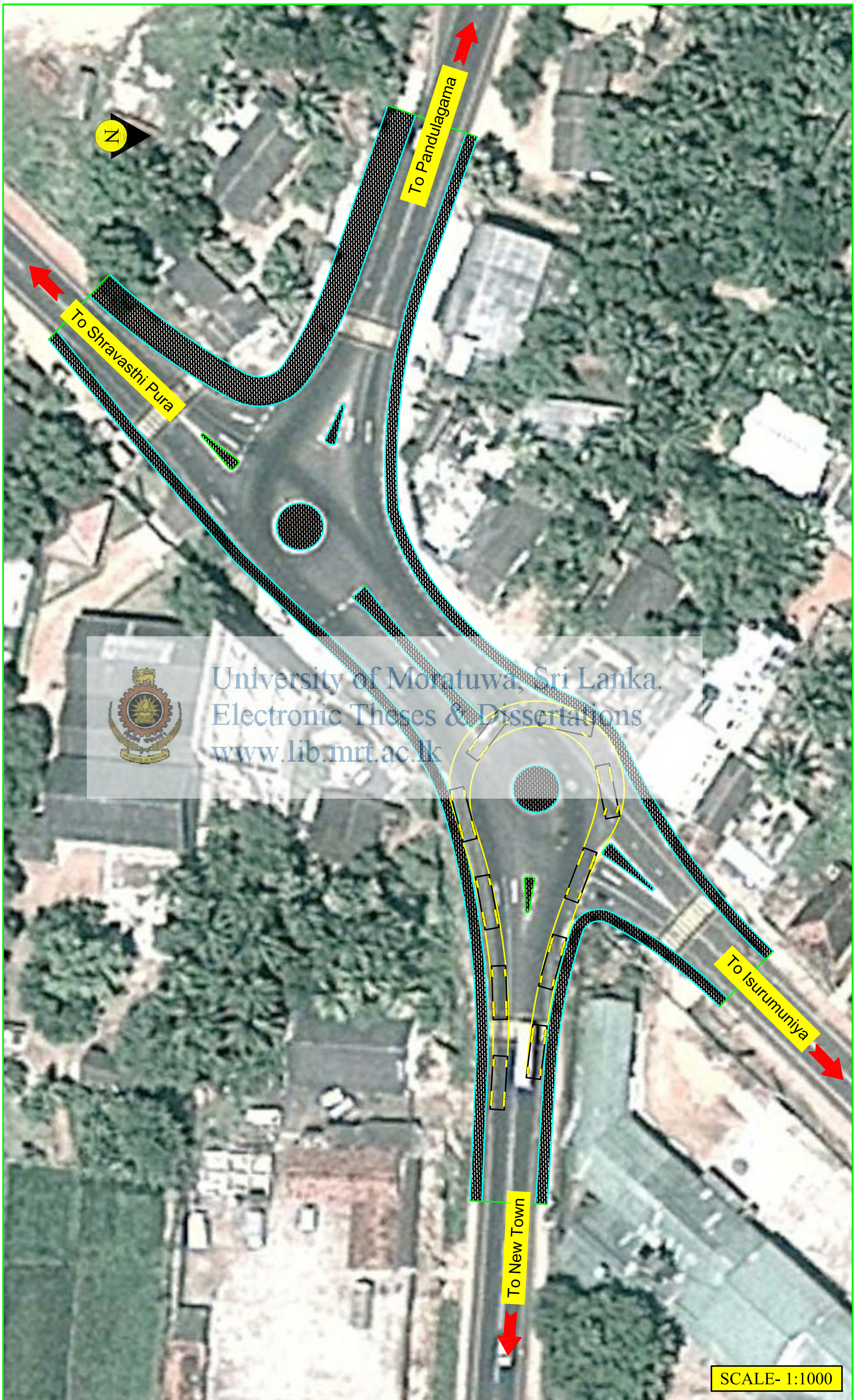
AN-04, Roundabout at Dahaiyagama Junction-Anuradhapura



AN-05, Roundabout at Bank Town-Anuradhapura

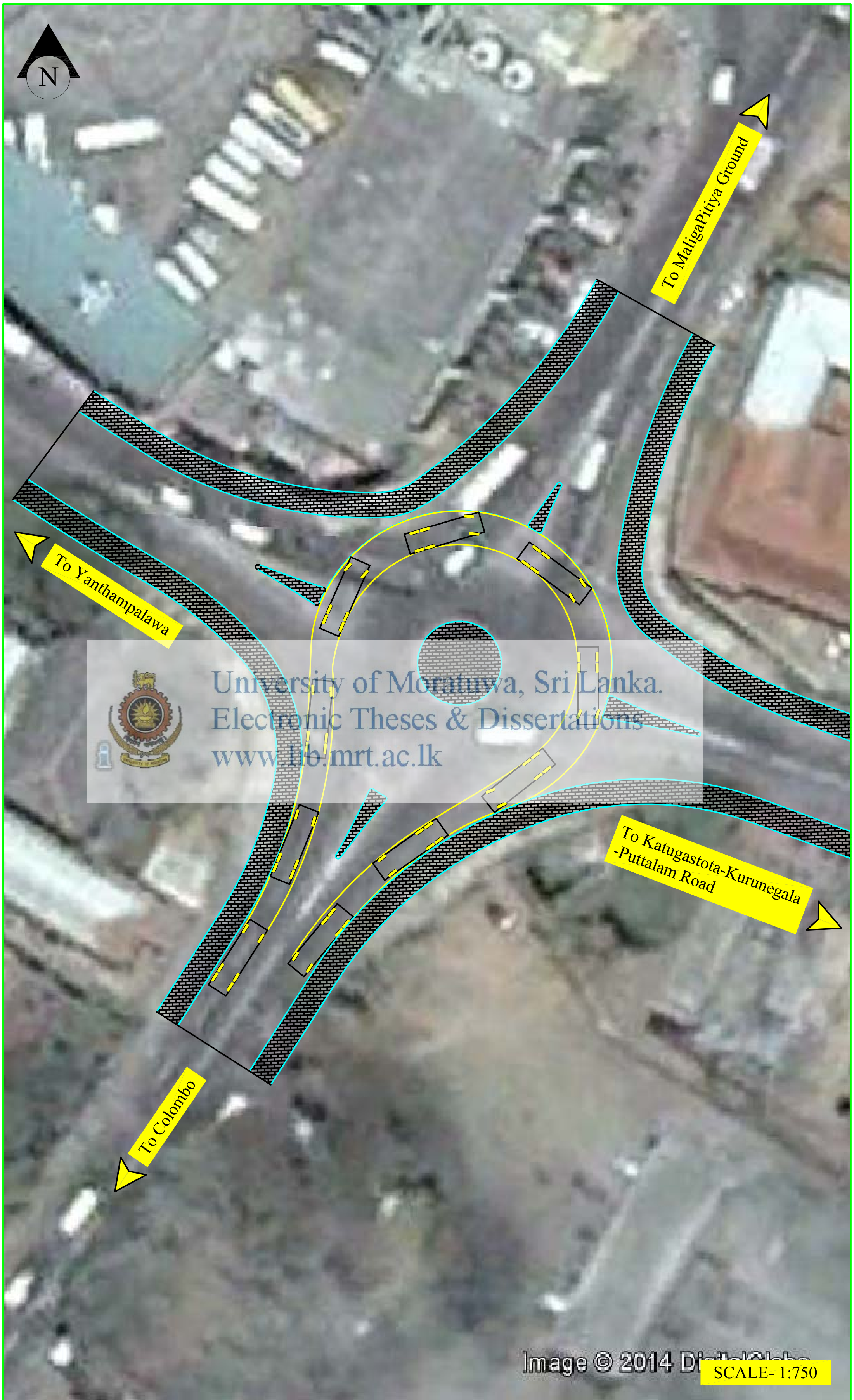


AN-06, Roundabout at Provincial Council-Anuradhapura

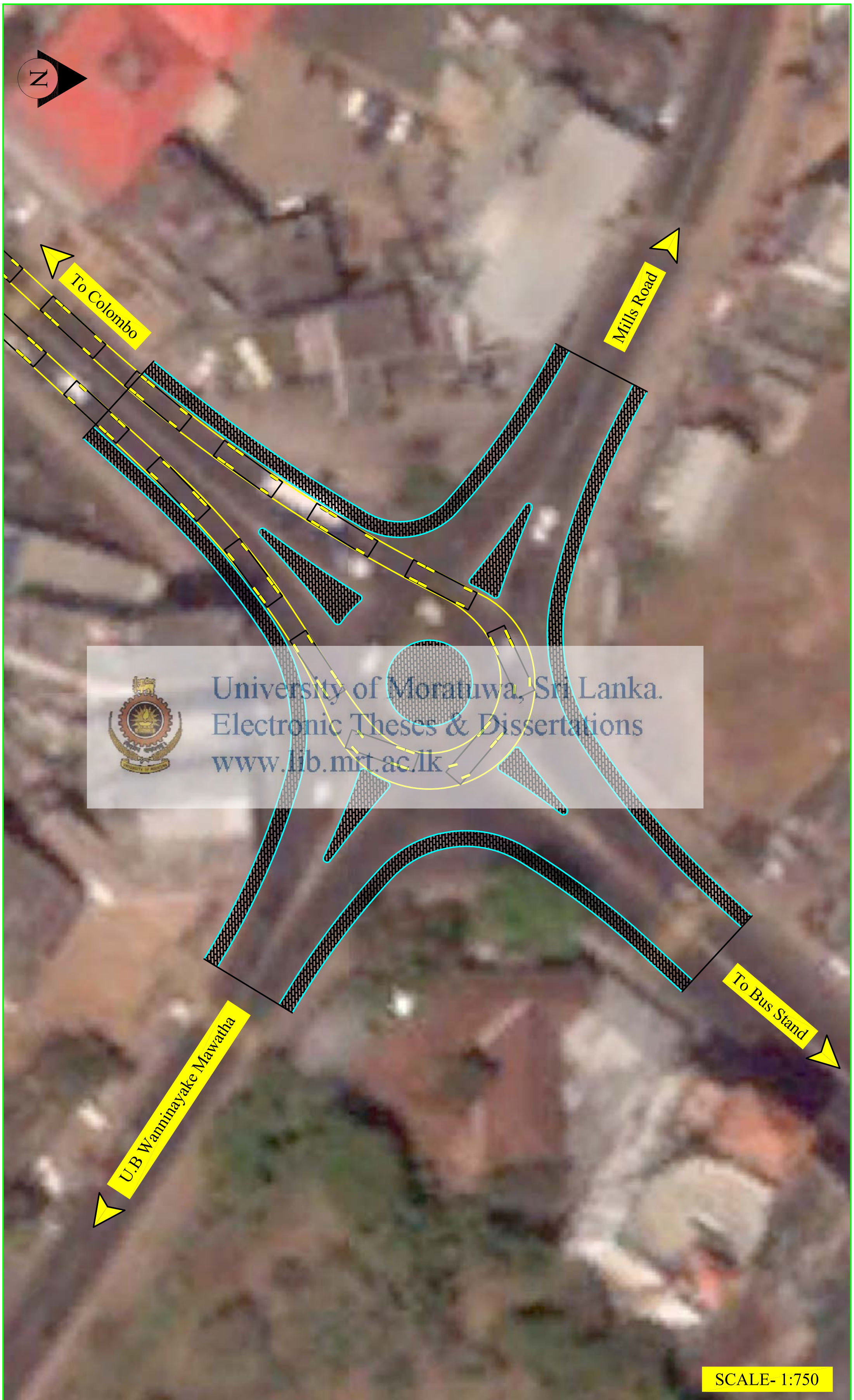


AN-07, Roundabout at Pothanegama Junction-Anuradhapura

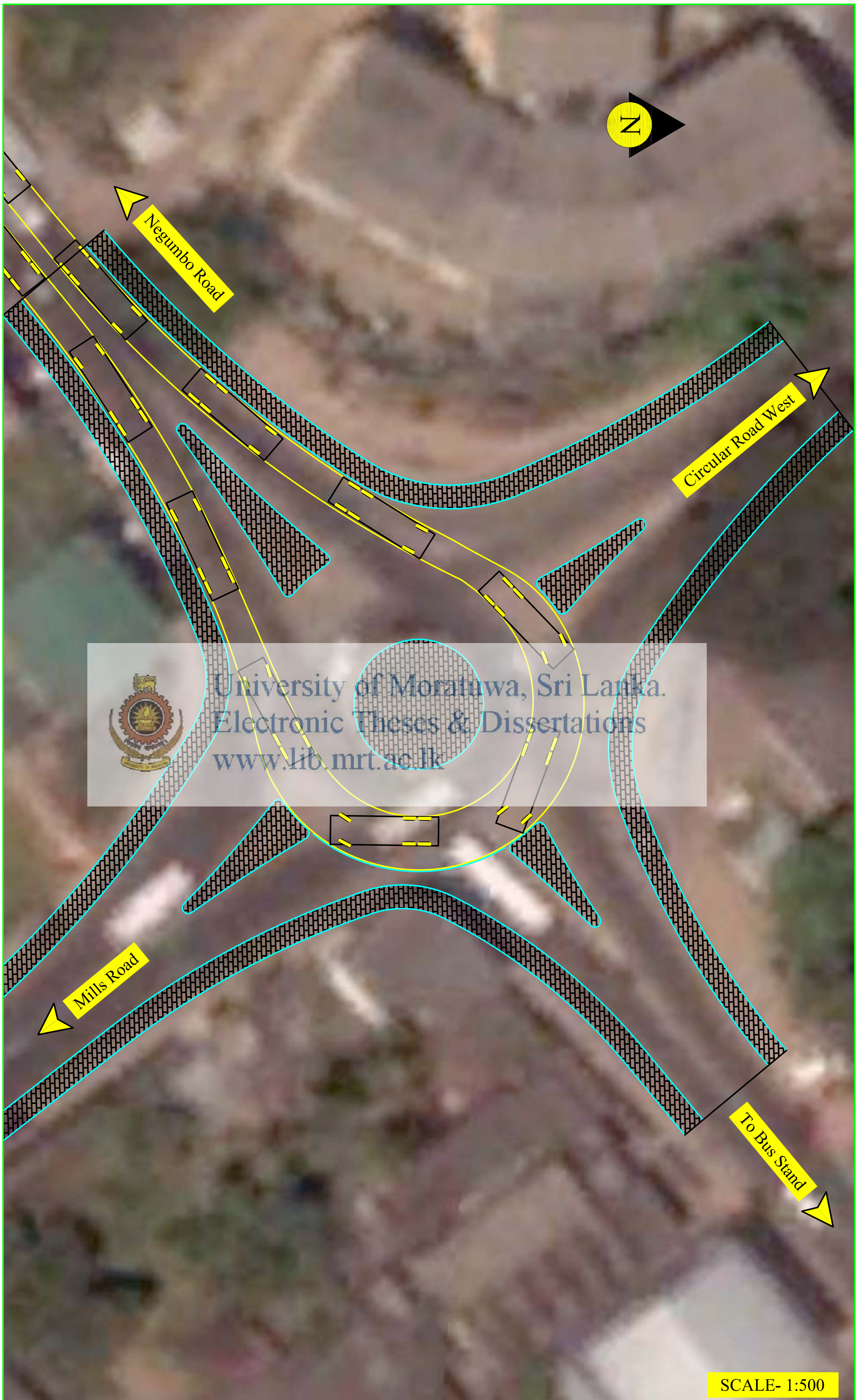
AN-08, Roundabout at Talawa Town-Talawa



KG-01, Roundabout at Clock Tower-Kurunegala



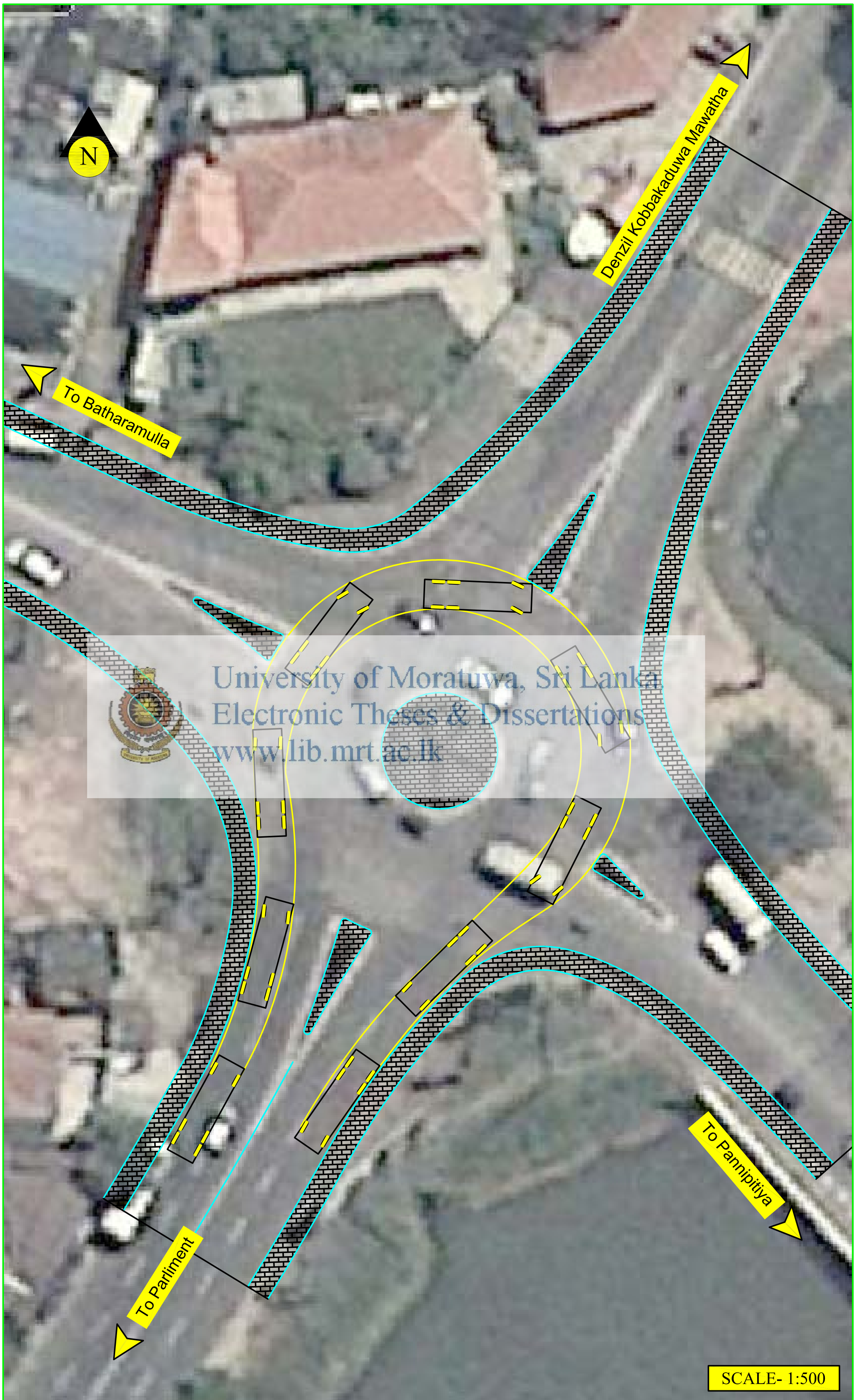
KG-02, Roundabout at Kadurugas Junction-Kurunegala



KG-03, Roundabout at Puwakgas Junction-Kurunegala

KG-04, Roundabout at Dalandagama Junction-Kurunegala

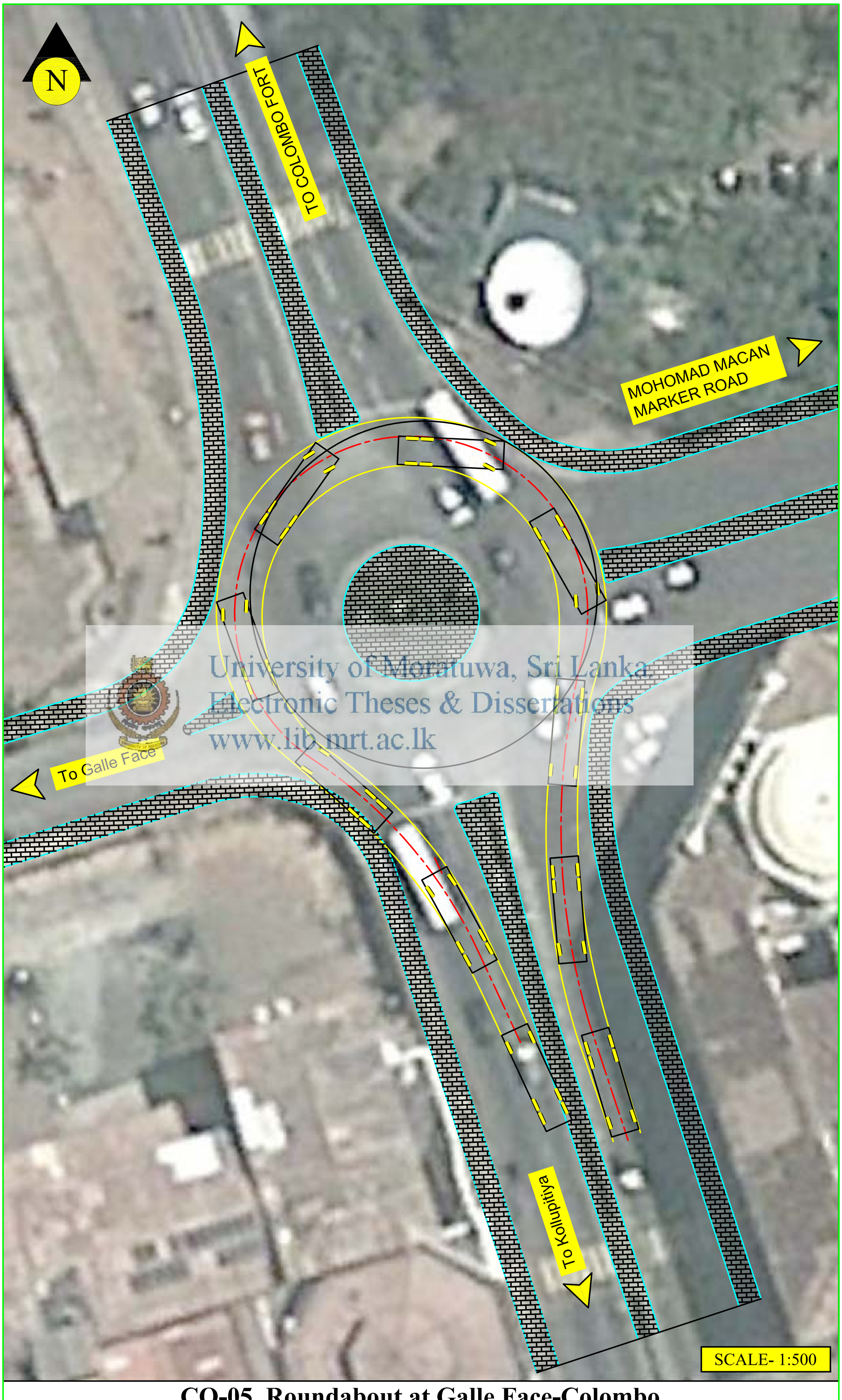
CO-01, Roundabout at Thalawathugoda-Colombo



CO-02, Roundabout at Palam Thuna Junction-Colombo

CO-03, Roundabout at Borella Cemetary-Colombo

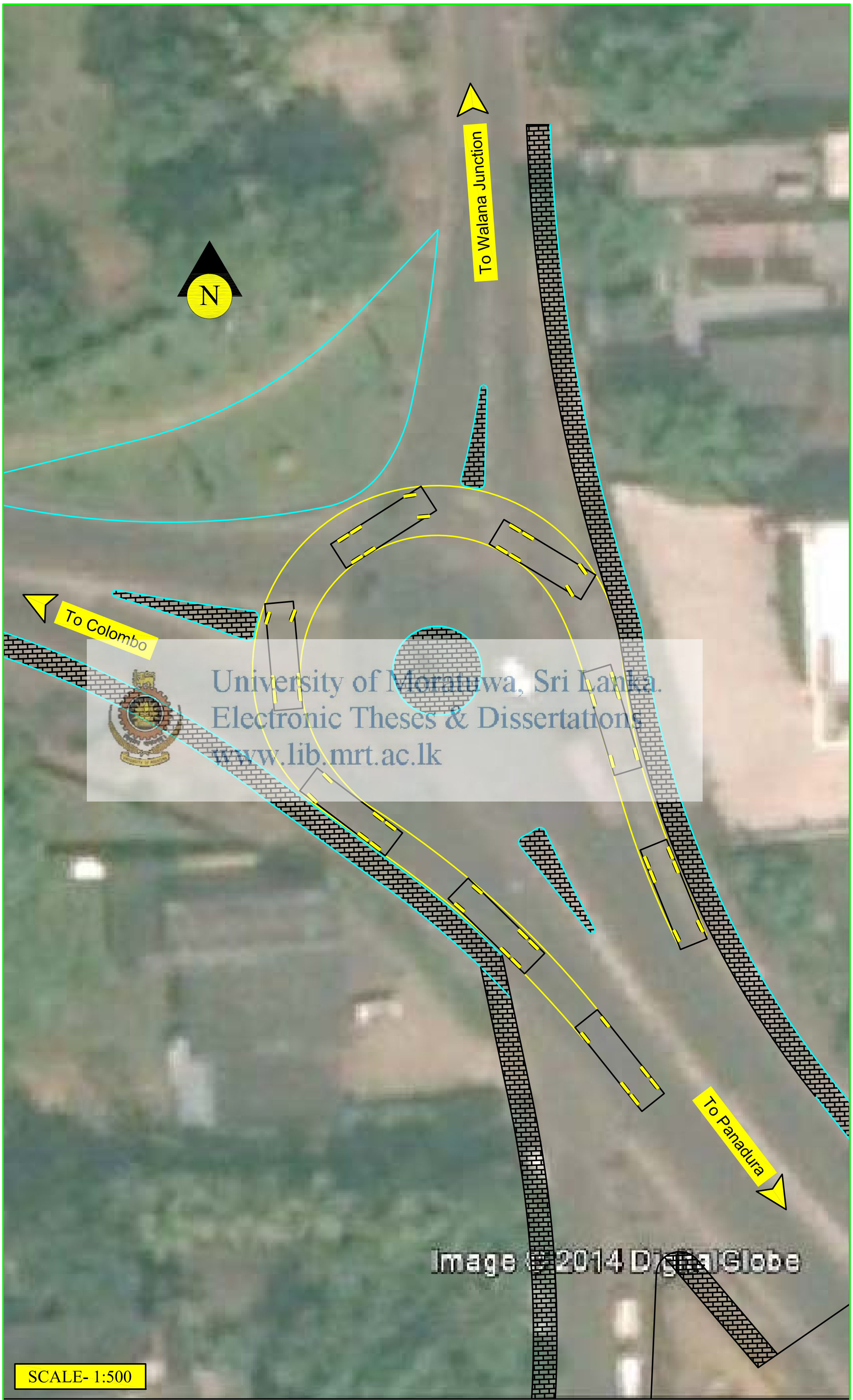
CO-04, Roundabout at Lipton-Colombo



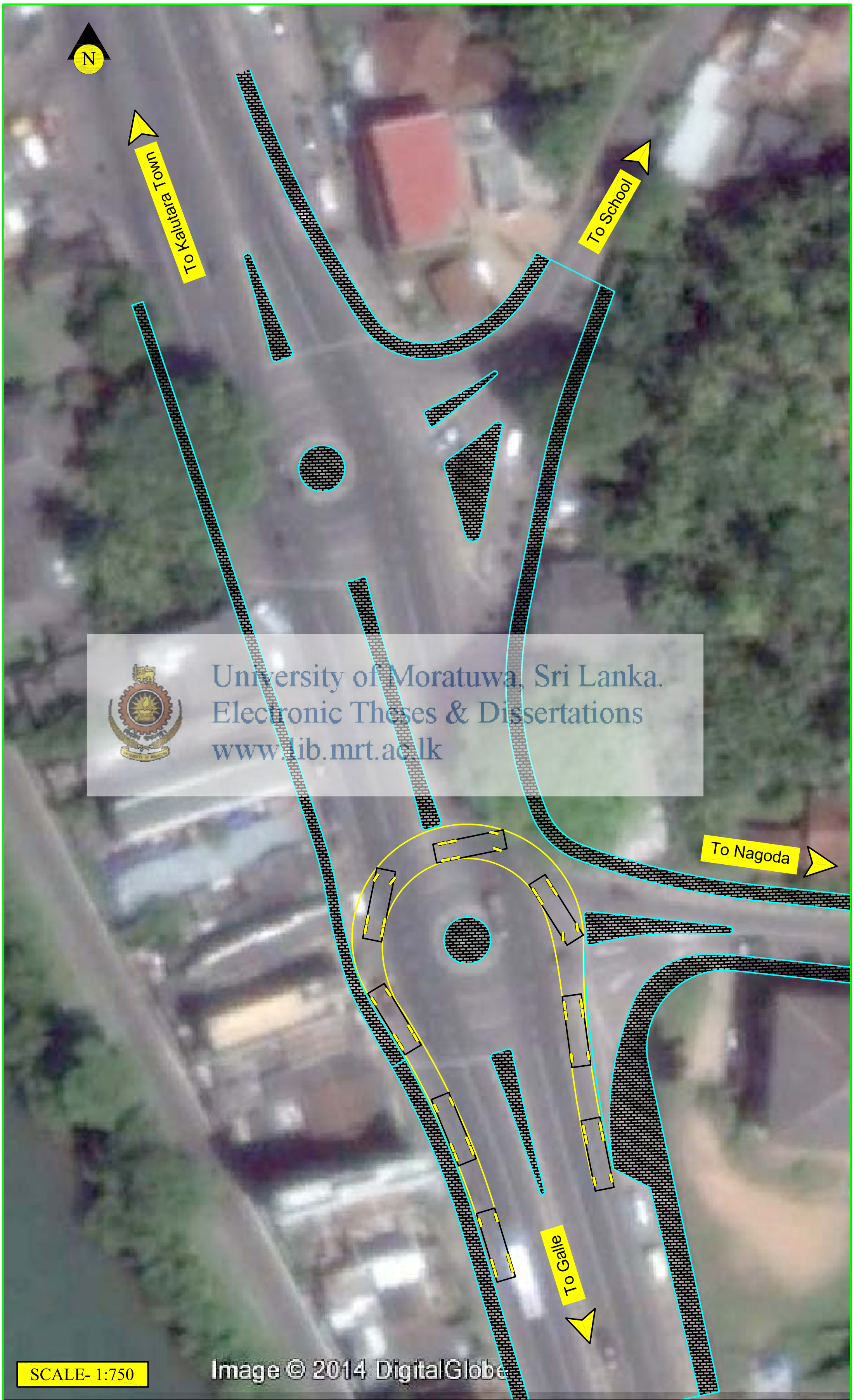
CO-05, Roundabout at Galle Face-Colombo

CO-06, Roundabout at Galadari Hotel-Colombo

PN-01, Roundabout at Egoda Uyana-Panadura



PN-02, Roundabout at Golden Statue-Panadura



KT-01, Roundabout at Holly Cross Church-Kalutara

GL-01, Roundabout at Vidyaloka School- Galle

GL-02, Roundabout at Police- Galle

GL-03, Roundabout at Stadium- Galle