

FRAMEWORK FOR SELECTING CENTRE MEDIAN OPENING LOCATIONS

Handun Neththige Prasanga

158323D

Dissertation submitted in partial fulfilment of the requirements for the degree Master of
Science in Transportation

Department of Civil Engineering

University of Moratuwa
Sri Lanka

February 2019

Declaration of the Candidate and Supervisor

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my dissertation, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature:

Date:

The above candidate has carried out research for the Masters Dissertation under my supervision.

Signature of the supervisor:

Date:

Abstract

Currently, many urban roadways in Sri Lanka are being rehabilitated and improved to multi-lane facilities with introducing raised road centre medians. Therefore, the provision of centre median openings for right turns, cross traffic movement & “U” turns is essential.

The study attempts to give a broad framework to adopt in making decisions with regarding to provision of centre median openings by identifying the relevant parameters that should be incorporated and evaluating the impact on traffic operations due to various configurations of centre median openings.

Road network connectivity, road safety, right turning traffic volume density, positioning of road side developments are some of the factors which influence the decision for selecting a proper location for median opening. A microscopic traffic simulation model developed with PTV VISSIM was used to optimize the selected median opening locations with respect to travel time and total delay of the road network. A major urban road corridor was modelled in VISSIM as a case study.

The study found that the median opening spacings are site specific and recommending a general spacing value may not be practical with regard to Sri Lankan Road network. Median opening closure will result to increase the delay to local traffic largely and cannot expect a significant travel time reduction in the main road corridor in the absence of turning/storage areas. It is envisaged that this study would provide a more logical framework for practitioners to adopt in making decisions with regard to centre median opening in urban highway planning.

Acknowledgement

Initially I have great pleasure in thanking the University of Moratuwa for giving me an opportunity to follow master's degree in Transportation. I am grateful to all the lecturers guided me throughout my Master degree programme; especially, Dr.H.R Pasindu, Supervisor of my Research, who was of continuous guidance with worthwhile instructions throughout my research in making it a success.

I wish to extend my gratitude to Prof.J.M.S.J. Bandara and Dr.G.L.D.I.De Silva for valuable instructions given to me throughout my M.Sc course and research period.

Furthermore, I would like to thank Mrs. Namalie Siyambalapitiya Director – Planning, RDA, Mr. R.A. Sudath Deputy Director – Planning III, RDA for their fullest support in helping me to follow lectures throughout my course in the post graduate programme and granting me the necessary provision to get relevant data required for my research.

Moreover, I am grateful to the higher management of my organization, Road Development Authority for providing this valuable opportunity with financial aid to complete M.Sc. in Transportation.

H.N Prasanga

158323D

University of Moratuwa

Table of Contents

Declaration of the Candidate and Supervisor.....	i
Abstract.....	ii
Acknowledgement.....	iii
Table of Contents.....	iv
Table of Figures.....	vii
Table of Table.....	vii
List of Abbreviations.....	viii
1 Introduction.....	1
1.1 General.....	1
1.2 Research Problem.....	3
1.3 Research Objectives.....	3
2 Literature Review.....	4
2.1 Introduction.....	4
2.2 Median Handbook, Florida Department of Transportation (FDOT).....	4
2.2.1 General introduction.....	4
2.2.2 Florida median opening decision process and public involvement.....	6
2.2.3 U-turns in Advance of a Signal.....	7
2.3 Access Management Guidelines, city of Tucson, Arizona.....	8
2.4 Guide to road design part 4: intersections and crossings – general- Austroads 2009 10	
2.5 TRB Access Management Manual- 2003.....	13
2.5.1 General.....	13
2.5.2 Medians and public involvement.....	13
2.6 Kentucky access management manual.....	14
2.7 National Cooperative Highway Research Program (NCHRP) Report 348.....	14
2.8 The Use of Vissim microscopic simulation model to evaluate the operational impacts with raised medians.....	16

2.9	Current Practice in Sri Lanka	17
3	Methodology.....	18
3.1	Study of international access management guidelines.....	18
3.2	Study of research papers related to vissim simulation/median opening	18
3.3	Derive a minimum median opening spacing value	18
3.4	Selection of a road corridor	19
3.5	Gather turning movements traffic and geometric data.....	19
3.6	Select best locations for median openings.	19
3.7	“VISSIM” microscopic simulation model.	19
3.8	Optimization of opening locations through “VISSIM”.....	20
4	Factors affecting Centre median Openings	21
4.1	Right turning traffic volume density	21
4.2	Road network connectivity.....	22
4.3	Concentration on Traffic Safety	23
4.3.1	Stopping sight Distance	23
4.3.2	Intersection sight distance.....	24
4.3.3	Sight distance for “U” turns	24
4.3.4	Landscaping and sight distance issues	25
4.4	Concentration on Traffic Efficiency	25
4.4.1	Consideration Functional area of the intersection	25
4.4.2	Provision for queue storage	26
4.4.3	Decision Distance	26
4.4.4	Deceleration distance	27
4.4.5	Concentration on public requests.....	28
4.5	Other considerations.....	28
4.5.1	“U” turns in advance of a signal	28
4.5.2	Openings for emergency cases.....	29

4.5.3	Issues with the directional opening.....	29
5	Development of Framework for Center Median Opening Decision Making.....	30
5.1	Framework Development.....	30
5.2	Simplified Work Flow Chart for the Centre median opening selection process.....	31
5.3	Case Study on Galle Road (From Maliban Junction to Temples road junction)	32
5.3.1	Roadway, geometric features, traffic volumes, speeds, access density etc.	32
5.4	Step 1: identification of existing situation.....	33
5.5	Step 2: carryout necessary surveys for traffic modelling and investigations.....	34
5.6	Step 3: Identify potential locations for providing median openings	35
5.6.1	Minimum spacing as per the functional requirements.....	35
5.7	Step 4: Check for safety requirements	37
5.8	Step 5: Model the corridor using VISSIM	37
6	Conclusions	43
6.1	Summary of the research study methodology and findings	44
	45	
6.2	Further studies needed.....	46
7	References	47

Table of Figures

Figure 1-1 Existing Median Openings	1
Figure 1-2 Full & directional median openings	2
Figure 2-1 Functional Area of a Median Opening	5
Figure 2-2 U - Turn before Signal	7
Figure 2-3 Typical Mid-block median Opening	11
Figure 4-1: Connectivity through Hena Road.....	22
Figure 4-2 Functional Area of an Intersection	26
Figure 4-3 Issues at the Direction Openings.....	29
Figure 5-1 A section of Galle Road	32
Figure 5-2:Galle road cross section	32
Figure 5-3:Study Area.....	33
Figure 5-4:Potential Opening locations and Spacings	36
Figure 5-5:Road Network Model in VISSIM	38
Figure 5-6:Road Network Model in VISSIM	39
Figure 5-7 Finalized Opening locations and Spacings	41

Table of Table

Table 2-1 Median Opening Spacing - FDOT	5
Table 2-2 Minimum Spacing Values	8
Table 2-3 Guidelines for Spacing	9
Table 2-4 Suggested Kentucky Median Criteria.....	14
Table 2-5 Median Spacing – NCHRP.....	15
Table 2-6 Guideline for Spacing of Unsignalized Median Openings.....	15
Table 4-1 Minimum Stopping Sight Distance	23
Table 4-2 Minimum Intersection Sight Distance.....	24
Table 4-3 Sight Distance for U Turns at un-Signalized Median Openings	25
Table 4-4 Required decision distances	27
Table 4-5 Deceleration Distance Required	27
Table 5-1 Travel Time of Galle Road with/without considering the opening at Sri Dharmadara road	38
Table 5-2 Travel Time of Galle Road with/without considering the opening at St Ritas road.....	39

List of Abbreviations

RDA	-	Road Development Authority
FDOT	-	Florida Department of Transportation
TRB	-	Transportation Research Board
NCHRP	-	National Cooperative Highway Research Programme
TWLTL	-	Two-Way Left-Turn Lane
AGRDR	-	Austrroads Guide to Road Design
SLTB	-	Sri Lanka Transport Board

1 Introduction

1.1 General

Medians are paved or landscaped areas in the middle of roadways that separate traffic traveling in opposite directions. A raised median with well-designed median openings is one of the most important tools to create a safe and efficient highway system. The benefits of a raised center median can be summarized as follows.

- Improves vehicular safety (Florida Median Handbook, 2014)
- Improves pedestrian safety (Florida Median Handbook, 2014)
- Improves the Operational Efficiency of the highway
- Improve Aesthetics

Therefore, a well-designed raised center median with properly located median openings is very important to ensure the safety and efficiency of a particular highway system since it reduces the number of decisions should take at a single time by the road user. Moreover, it reflects the degree of access management of the highway.

At the moment it can be clearly identified that the many urban Roadways are being rehabilitated and improved to multi-lane facilities with the introduction of raised road centre medians. Therefore, the provision of centre median openings for right turns, cross traffic movement & “U” turns is essential.



Figure 1-1 Existing Median Openings

It can facilitate with two types of median openings for a highway.

- Full median openings
- Directional median openings

A full median opening will allow for several numbers of traffic movements and a directional median opening will allow for selected and few traffic movements through the opening. Therefore, a directional opening has a smaller number of conflicting movements comparing to full median opening.



Figure 1-2 Full & directional median openings

However, now, there is no proper guideline or methodology available within road agencies in Sri Lanka to follow when deciding the appropriate locations for median openings of a particular highway. Frequent changes occur to the initial designs of the center median and median opening locations due to the unavailability of a proper guideline.

Recently RDA has completed the construction of centre medians at A1, A3, A4, B84, B47 roads .Often, there are many requests by the public and various other groups for new median opening locations. Lack of guidelines to evaluate these requests on the logical and systematic basis results in the planning and design process having to make several changes or allocate significant time to give justification to the public complaints/requests This results in the delay in the completion of the centre median construction work or provision of additional openings which in detrimental to the original objective of provision of the centre median.

The current study proposes a framework to develop a guideline based on international access management practices and local experience. Decision making criteria when justifying median opening locations is somewhat complex in nature since there is no proper legal framework available in Sri Lanka for access management.

1.2 Research Problem

Lack of appropriate criteria or a guideline to determine centre median opening is a major setback to complete urban roadway projects in Sri Lanka. Lack of such guidelines allow provision of such opening on an ad-hoc basis based on subjective judgement. This may have a long-term impact on the efficiency of the traffic flow and the road user safety.

1.3 Research Objectives

Identify the key attributes that should be incorporated into determination of centre median opening type and location along an urban roadway. Develop a framework to assist decision makers to incorporate the above factors in designing centre median opening.

2 Literature Review

2.1 Introduction

Even though Sri Lankan guidelines available for median opening decision process are quite few, there are plenty of researches and guidelines have developed internationally to standardize the criteria of median opening decision process. Some of the most acceptable international guidelines are as below.

1. Median Handbook, Florida Department of Transportation (FDOT), Sep 2014
2. Access Management Guidelines, city of Tucson, Arizona
3. Access Management Manual, Mississippi Department of Transportation
4. Guide to road design part 4: intersections and crossings – general- Austroads 2009
5. AASHTO Green Book – 2001
6. TRB Access Management Manual- 2003
7. Kentucky access management manual
8. NCHRP 348 report

2.2 Median Handbook, Florida Department of Transportation (FDOT)

2.2.1 General introduction

Median hand book published by the Florida Department of Transportation has been considered as one of the most comprehensive guidelines developed on raised road Centre medians. Most of the time, Florida guidelines have been referred to develop other guidelines developed for centre median design process.

As per the Median Handbook developed by the FDOT, Median opening decisions are guided by the following principles

- Traffic Safety
- Traffic Efficiency
- Functional Integrity

However as per the access management standards, they have developed following predefined median opening spacings for their highway network based on the different road classes.

Table 2-1 Median Opening Spacing - FDOT

Access Management Standards From Rule 14-97						
Class	Medians	Median Openings		Signal	Connection	
		Full	Directional		More than 45 mph Posted Speed	45 mph and less Posted Speed
2	Restrictive w/Service Roads	2,640	1,320	2,640	1,320	660
3	Restrictive	2,640	1,320	2,640	660	440
4	Non-Restrictive			2,640	660	440
5	Restrictive	2,640 at greater than 45 mph Posted Speed	660	2,640 at greater than 45 mph Posted Speed	440	245
		1,320 At 45 mph or less Posted Speed		1,320 At 45 mph or less Posted Speed		
6	Non-Restrictive			1,320	440	245
7	Both Median Types	660	330	1,320	125	125

(Florida Median Handbook, 2014)

As per the median opening placement principles stated in the chapter 2.1 of the median handbook, Median openings should not encroach on the functional area of another median opening or intersection as shown in the following exhibit,

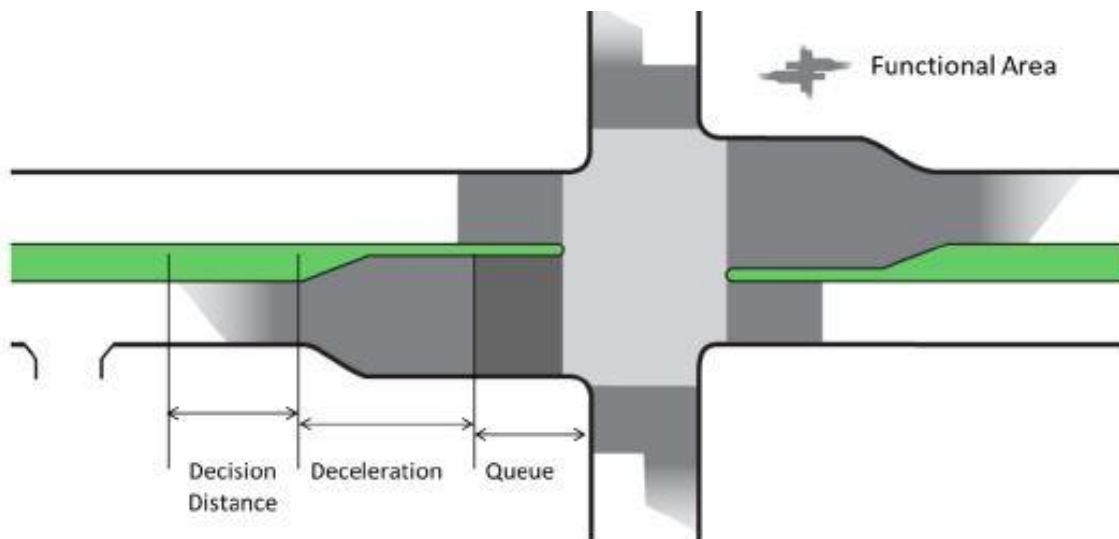


Figure 2-1 Functional Area of a Median Opening

(Florida Median Handbook, 2014)

In the chapter 2.1 of the book, the intersection functional area consists of three basic elements as follows,

- Distance travelled during decision time,
- Manoeuvre-deceleration distance, and
- Queue-storage distance

As per the chapter 3 of the median hand book, the decided locations of median openings should satisfy the following sight distance requirements to ensure the safety requirements.

- Stopping Sight Distance
- Intersection Sight Distance
- Sight distance for “U” turns
- Sight Distance for Left-Turn into Side Street.
- Left Turn Lane Offset
- Landscaping and sight distance issues

2.2.2 Florida median opening decision process and public involvement

In the Florida median hand book, it has given special attention to the involvement of the public participation and awareness in the median opening location selection process. In the FDOT median handbook it states that, “Whenever the Department of Transportation proposes any project on the State Highway System which will divide a state highway, erect median barriers modifying currently available vehicle turning movements, or have the effect of closing or modifying an existing access to an abutting property owner, the Department shall notify all affected property owners, municipalities, and counties at least 180 days before the design of the project is finalized.” (Florida Median Handbook, 2014)

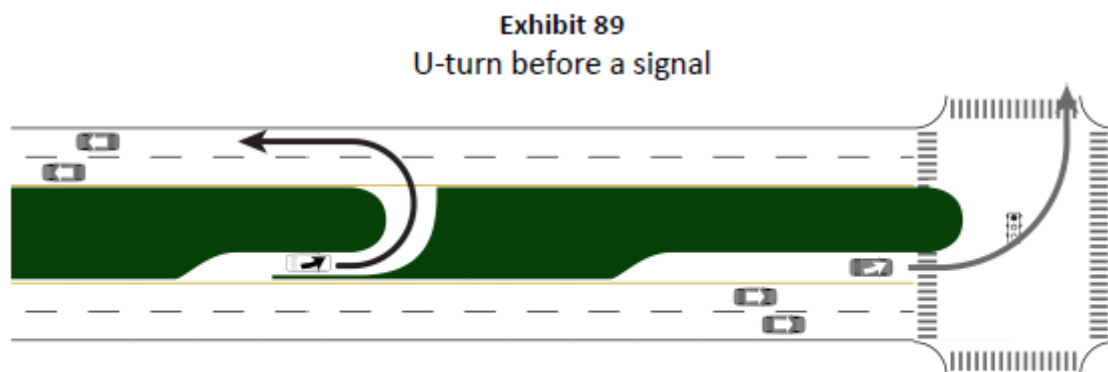
Therefore, as per the FDOT median handbook, it requires the FDOT to,

- Notify, in writing, the Chief Elected Official of the City and/or County as well as property owners
- Conduct at least one public hearing
- Local governments should notice impacted property owners at least 180 days before the design of the project is finalized.

- consult with applicable local government on its final design and allows the local government to present alternatives to relieve impacts to commercial business properties
- hold at least one public hearing to determine how the project will affect access to businesses and the potential economic impact of the project on the local business community; and
- take all comments into consideration in final design of the project.

2.2.3 U-turns in Advance of a Signal

In the FDOT Median handbook, it has highlighted the importance of the provision of a “U” turning location before a signalized intersection. It is very beneficial since it can greatly reduce the delay in the signalized intersection caused due to the vehicles taking “U” turns. However, the median opening should be located avoiding the queuing length of the signalized intersection.



Source: Safety and Operational Evaluation of Right Turns Followed By U-turns as an Alternative to Direct Left Turns, Dr. John Lu, University of South Florida

Figure 2-2 U - Turn before Signal

(Florida Median Handbook, 2014)

2.3 Access Management Guidelines, city of Tucson, Arizona

As per the Access Management Guidelines, city of Tucson, Arizona published in 2011, “Median openings are provided at all signalized at-grade intersections, and generally at unsignalized junctions of arterial and collector streets. They may be provided where they will have minimum impact on roadway flow”.

Minimum desired spacing of unsignalized median openings as functions of speed are given in Table 2-2.

Table 2-2 Minimum Spacing Values

Speed Limit(mph)	Minimum Spacing (feet)
30	370
35	460
40	530
45	670
50	780
55	910

(Access Management Guidelines, City of Tucson, 2011)

Minimum desired spacing of unsignalized median openings as a function of roadway functional classification are given in Table 2-3.

Table 2-3 Guidelines for Spacing

Street Functional Classification	Spacing of Median Openings (in feet)		
	Urban	Suburban	Rural
Arterial	660	660	1320
Collector	330	660	1320

(Access Management Guidelines, City of Tucson, 2011)

As per the Access Management Guidelines, city of Tucson, Arizona, the following will be considered when evaluating a request for a median opening:

1. Traffic engineering analysis by a professional traffic engineer
2. Directional median openings will be considered as first option before granting a full median opening.
3. The new median opening should not course any additional issues to the main flow traffic
4. It has emphasized the value of sharing the provided median opening with adjacent property owners.
5. The cost for the new median opening should be borne by the people who request the new median opening. (if it is a private property only)
6. Must implement a proper geometric design for the new median opening
7. The new median opening should not disturb the smooth functioning of the emergency access points like police and hospitals

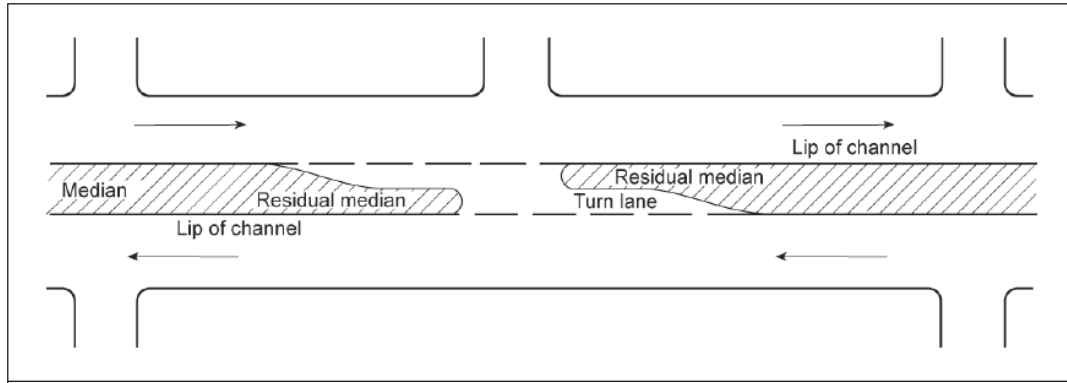
2.4 Guide to road design part 4: intersections and crossings – general- Austroads 2009

It has included several important aspects in the Austroads guidelines regarding the median openings and spacings. In the guidelines it states that “The spacing of median openings is an integral part of access management planning. The justification for a median opening is an economic issue, requiring comparison of the cost of providing the opening with the cost of extra travel and inconvenience. The increase in the number of potential conflict points must also be considered in comparison with the traffic manoeuvres likely to occur without median openings” (Guide to Road Design, Austroads, 2009).

Furthermore, as per the Austroads guidelines, it has indicated that “The desirable spacing of median openings is a complex question to which there is no definitive answer. On the one hand it is desirable to space openings as far apart as possible, keeping the number of potential conflict points to a minimum. On the other hand, infrequent openings can significantly increase travel distances for local traffic and the demand for turning manoeuvres at intersections. Where the median is too narrow to accommodate a sheltered right-turn lane, a good design practice is to provide openings at most, if not all, intersecting streets with an important local service function. Where the median width is sufficient to accommodate right-turn lanes, a spacing of 120 m will permit successive development of right-turn lanes. Greater spacing is required where high storage demands occur”.

The above explanation is very suitable to Sri Lanka; hence Our urban road networks are specially connected with many local roads providing access to residential areas. Therefore, special consideration should be given to provide centre median openings at designated places where the important local roads meet the main road with raised centre median.

A typical mid-block median opening is shown in the following Figure,



Source: Queensland Department of Transport and Main Roads (Queensland DTMR).

Figure 2-3 Typical Mid-block median Opening

(Guide to Road Design, Austroads, 2009)

As per the Austroads the dimensions and treatment of the median opening is governed by the following factors;

- the median width
- the presence of a median safety barrier
- the type of vehicle using it
- whether the site is in a high-speed or low-speed environment

As per the Austroads, in determining the location of a median opening the following points should be considered:

- desirable locations are sags and straights where sight distance is the greatest
- it is undesirable for median openings to be located on horizontal curves or crests
- on high-speed rural roads median openings should be located at a maximum spacing of 5 km, and not be within 3 km of an intersection or interchange
- median openings should be located immediately downstream of median drainage pits, thus eliminating the necessity for installation of a pipe and associated headwalls
- the preferred location is a distance downstream (for traffic flow) of emergency telephone bays on freeways, and of property access points on non-freeway type roads, that is sufficient to enable drivers to join the traffic stream and weave across to a deceleration lane in the median.

In the Austroads it states that “Ideally, on urban roads it is desirable to coordinate the openings with street intersections at 400 m to 800 m intervals and provide signalization. Shorter spacing

reduces indirect travel but creates more conflicts, while longer spacing improves safety and operation but can make trips more circuitous. The minimum distance between intermediate median openings should be 150 m.”

As per the Austroads in general, to determine the location of median openings on urban roads a designer should

- identify the most important intersecting roads to determine where median openings must be provided, and where it is desirable that they should be provided
- select intermediate openings to provide adequate local service, to comply with the functional requirements of the road and adjacent development
- Examine the proposed geometric alignment, cross-section and visibility to ensure that chosen locations will satisfy the geometric design and safety guidelines.

Other factors to consider include:

- on new projects, the adjacent median planting should be restricted to relatively low vegetation to enhance driver sight distance
- median openings of heavily planted medians on existing roads should only be installed where corrective measures can be undertaken to ensure that sight distance requirements are met
- On wide medians, a desirable slope of 10:1 (6:1 maximum) between the median opening and the median invert (measured longitudinally) should be used.

A driver having a need to use a median opening should be able to recognize that the opening exists from at least 300 m in either direction.

2.5 TRB Access Management Manual- 2003

2.5.1 General

Transportation Research Board access management manual published in 2003 can be considered as one of the main guidelines used by many of the other countries to develop access management manuals. In the TRB access management manual, it says that, “In rural areas, median openings commonly will permit all movements. When providing a median opening on the fringe of an urban area, however, it is important to consider the potential for future signalization. A full median opening that is located where signalization will interfere with efficient traffic progression may need to be closed or reconstructed as a directional opening.” In the TRB access management manual it has indicated the importance of providing the directional median openings in between the signalized full median opening locations for providing access to the properties at either side of the road.

2.5.2 Medians and public involvement

In the access management manual, it has indicated the importance of the public awareness and participation to the median opening selection process. In the manual it has indicated that the “Public opposition and appeals to agency management or elected officials are common with non-traversable median projects. Public concerns related to median projects typically include effects on business activity, concerns related to U-turns, and conflicts related to the placement of median openings. Some considerations in involving the public in median projects are to

- Involve primary stakeholders as early as possible and explain to them how they can get involved in the process;
- Be prepared to address concerns about effects on business activity, delivery trucks, and safety of U-turns;
- Be responsive to public concerns and proposed alternatives; and
- Brief upper management and elected officials on the project and the process under way to address public concerns.

2.6 Kentucky access management manual

As per the access management manual developed for the state of Kentucky, USA by the University of Kentucky, there are several important aspects regarding the median opening selection process.

For the preparation of the Kentucky median opening spacing criteria, they have referred to many of the access management guidelines practiced by the other USA states like Texas, Florida, Montana, South Dakota, Missouri and NHCRP reports. After incorporating information included in the other access management manuals the state of Kentucky suggests the following median opening spacing for their highways.

Table 2-4 Suggested Kentucky Median Criteria

Category	Desirable Median Type		Opening Spacing (ft)	
	Traversable	Non-traversable	Full	Directional
Urban I		X	2,400	1,200
Urban II	X	X	2,400	1,200
Urban III	n/a	X*	1,200	600
Urban IV	n/a	n/a	n/a	n/a
Rural I		X	2,400	2,400
Rural II	X	X	1,200	1,200
Rural III	n/a	X*	1,200	600
Rural IV	n/a	n/a	n/a	n/a

* Recommended for multi-lane facilities.

(Access Management for Kentucky, 2004)

2.7 National Cooperative Highway Research Program (NCHRP) Report 348

As per the National Cooperative Highway Research Program (NCHRP) Report 348 published in 1992 regarding the Access Management Guidelines for Activity Centers, there are many important aspects that we can gather regarding median opening spacing. In the report, it states that the “Median openings are provided at all signalized at-grade intersections. They also are generally provided at unsignalized junctions of arterial and collector streets. They may be provided at driveways, where they will have minimum impact on roadway flow”.

Minimum desired spacings of unsignalized median openings at driveways as a function of speed are given in Table 2-5.

Table 2-5 Median Spacing – NCHRP

Speed (mph)	Speed Recommendations (feet) Desirable Minimum
30	370
35	460
40	530
45	670
50	780
55	910

(NCHRP Report 348, 1992)

In the NHCRP report it has indicated some guidelines that can be applicable for the spacing and design of median openings on divided roadways:

Table 2-6 Guideline for Spacing of Unsignalized Median Openings

Level of Access	Urban	Suburban	Rural
1	NA	NA	NA
2	NA	NA	NA
3	NA	NA	NA
4	660(a)	660(a)	1320(a)
5	660	(b)	(b)
6	330	660	1320
7	-	-	-

NOTES:

NA Not Applicable

(a) Left turn entrance only - must accommodate left turn storage requirements, but may not be closer than values shown.

(b) Function of traffic signal spacing requirements.

(NCHRP Report 348, 1992)

2.8 The Use of Vissim microscopic simulation model to evaluate the operational impacts with raised medians

Microscopic simulation is a strong tool that can be used to evaluate the performance characteristics of road ways like travel time, delay and queue length with the introduction raised centre medias and different combinations of median openings. When we consider about the international researches done related to access management, the PTV Vissim microscopic simulation model has been widely used to evaluate the operational impacts of access management techniques. (Eisele, 2004)

“VISSIM is a microscopic, time step, and behaviour-based model developed to simulate urban traffic and transit operations. The research team chose this micro-simulation tool for its unique ability to simulate multiple conflict points and dynamics associated with a Two way Left turn lane (TWLTL) arterial environment. The research team used the model to quantify the performance measures of travel time, speed, and delay along the study corridors.” (Eisele, 2004)

“VISSIM is an ideal tool for modelling changes from a TWLTL to a raised median because of its dynamic routing system. When a route is removed (i.e., a left-turn movement is eliminated when a raised median is installed), VISSIM causes the vehicle to automatically find the next shortest route, which is the next raised median opening. VISSIM can also animate the simulation. Therefore, the user can visually identify any problems occurring in the model and check the model for visual accuracy. This visual animation is also an informative tool that the public can easily see and understand.” (Eisele, 2004)

Also in this research it has highlighted importance of the calibration and correct data input of the vissim model to get the reliable out puts from the simulations. In the report it has stated as “Once the VISSIM model was completed, it was tested and calibrated. Researchers reviewed the on-screen animation and model outputs to determine the model’s accuracy in simulating field operations. The user then viewed the on-screen animation to check the realism of queue lengths. The researchers then compared the travel time outputs to those collected with the field travel time runs. Speed distributions were altered slightly (when necessary) to ensure that the VISSIM model’s travel times were similar to the floating-car travel time data collected in the field” (Eisele, 2004)

2.9 Current Practice in Sri Lanka

The current experience and the condition of median opening decision process is complex and inconsistent due to lack objective logical process and subjectivity in the decision making. The main reason for this is the inadequacy of a proper guideline to follow. Additionally, there is no sound system to cater the public desires into the median opening selection process. Often there are many public requests for median openings and changes. It is very difficult to accommodate the public queries and give rational reasoning for acceptance/rejection of their request without a proper guideline. Sometimes people have filed human rights violations cases against the road authorities regarding median closures or opening changes. Most of the time the business communities who are having business premises close to the road corridors make strong objections for raised median installation and always demand for median openings. Therefore, the authorities find it very difficult to handle this situation without a proper guideline.

Therefore, it is also evident in addition to the engineering aspects that should be incorporated in the determining centre median openings, the public participation and awareness to the median opening selection process is very important to avoid any unnecessary delays to median construction and to keep the objective of placing the raised centre medians.

3 Methodology

3.1 Study of international access management guidelines

For this purpose, I referred to many international access management guidelines and research papers related to median opening selection decision process. The selected guidelines and research papers can be summarised as below,

1. Median Handbook, Florida Department of Transportation (FDOT), Sep 2014
2. Access Management Guidelines, city of Tucson, Arizona
3. Access Management Manual, Mississippi Department of Transportation
4. Guide to road design part 4: intersections and crossings – general- Austroads 2009
5. AASHTO Green Book – 2001
6. TRB Access Management Manual- 2003
7. Kentucky access management manual
8. NCHRP 348 report

3.2 Study of research papers related to vissim simulation/median opening

Since the decision-making criteria is somewhat complex in nature, it is desirable to use a traffic analysis tool for decision making. In view of that, PTV VISSIM microsimulation software was used. Therefore, in this research the guidance was taken from international conference papers conducted related to vissim microscopic simulation and median opening decisions criteria.

3.3 Derive a minimum median opening spacing value

As discussed in the literature review, many of the guidelines on access management, has specified the minimum spacing values for median openings. However, with the unplanned urban road network (with different connecting road densities), it is difficult to recommend a minimum spacing value for the median openings. Therefore, as specified in the Austroads, the minimum stopping site distance vale and additional length for queue storage was considered as the minimum distance between two median openings.

3.4 Selection of a road corridor

Since in this research the main objective was to find the optimum spacing between two median openings for better road performance, it is not acceptable to select a road with existing centre median and median openings. Therefore, the Galle road section from Maliban junction to Temples road junction was selected since the road has undivided four lanes, two lanes per each direction. Moreover, the road has closely spaced by roads with uneven distribution.

3.5 Gather turning movements traffic and geometric data

Manual classified turning movement counts were carried out at junction where each byroad connected to the major roads. The lane widths, shoulder widths and other geometric properties were collected through a recently carried out topographical survey of the road section. Turning movement counts and the signal timing data was obtained from relevant division in RDA. Additional required data was collected at site.

3.6 Select best locations for median openings.

As per the literature review, the best way to locate median openings without violating safety is considering the stopping sight distance and the provision for queue storage facilities for a functional area of a median opening. Therefore, the best locations were selected according to above argument.

3.7 “VISSIM” microscopic simulation model.

A high-quality Google earth image downloaded from the Google Earth Pro software covering Galle road from Maliban junction to Temples road junction was used as the background image to model the road corridor. The collected turning movement and signal data was fed to the software after filtering and analysing. The calibrated driver behaviour parameter was used to match the model parameters with the real situation. Test runs were carried out before collecting the data for the accuracy of the model. Model was run based on the morning peak traffic and evening peak traffic separately to see the different in the morning and evening traffic situations.

3.8 Optimization of opening locations through “VISSIM”.

Travel times were obtained based on the different travel paths including the byroad network and the Galle Road. Different median opening locations were tested against the travel time. The median opening locations, which has some issues, will be tested through this travel time values. Then the final locations were selected according to the minimum travel time criteria.

4 Factors affecting Centre median Openings

Based on the criteria used in international access management guidelines and on median opening selection process, followings should be considered when selecting appropriate locations for median openings.

1. Road network connectivity
2. Road safety
3. Traffic efficiency
4. Right turning traffic volume density
5. Positioning of road side developments
6. Other considerations (“U” turn in advance of a signal, Opening for emergency cases)

4.1 Right turning traffic volume density

Right turning traffic volume density plays a major role in determining the locations for median openings. When the demand increases for right turning traffic volumes, it is necessary to provide the median openings to suit to the requirements. Most of the time the demand for right turning traffic creates due to the positioning of connecting by roads to the main road corridor. There can be cross traffic movements in the road sections, most of the time the cross-traffic movement situations are low compared to the turning movements situations.

Generally, our major road network is consisted with many connecting by roads. When there is a demand for right turning traffic movements due to a by road connecting to the major road network, whenever possible it is needed to provide a centre median opening at that location to suit to the traffic demand. Otherwise the weaving traffic movements created due to the right turning traffic will result to create the traffic congestion situation on that road section.

Since our road network is consisted with limited right of way in the urban areas, the width allocated for raised centre median is minimum. Most of the time, the median widths are narrow to accommodate separate turning movement bays in that situations. Therefore, as explained in the Austroads, is needed to provide full median opening to those locations other than the directional median openings.

4.2 Road network connectivity

Road network connectivity is one of the most important aspects to be considered in deciding locations for median opening spacings. When there is a by road with important connectivity aspects connecting to the main road corridor having the raised center median, whenever possible it is needed to provide median opening to these locations to improve the connectivity of that road network. In the following figure, it shows the connectivity of Templers road to the Galle road through the Hena road

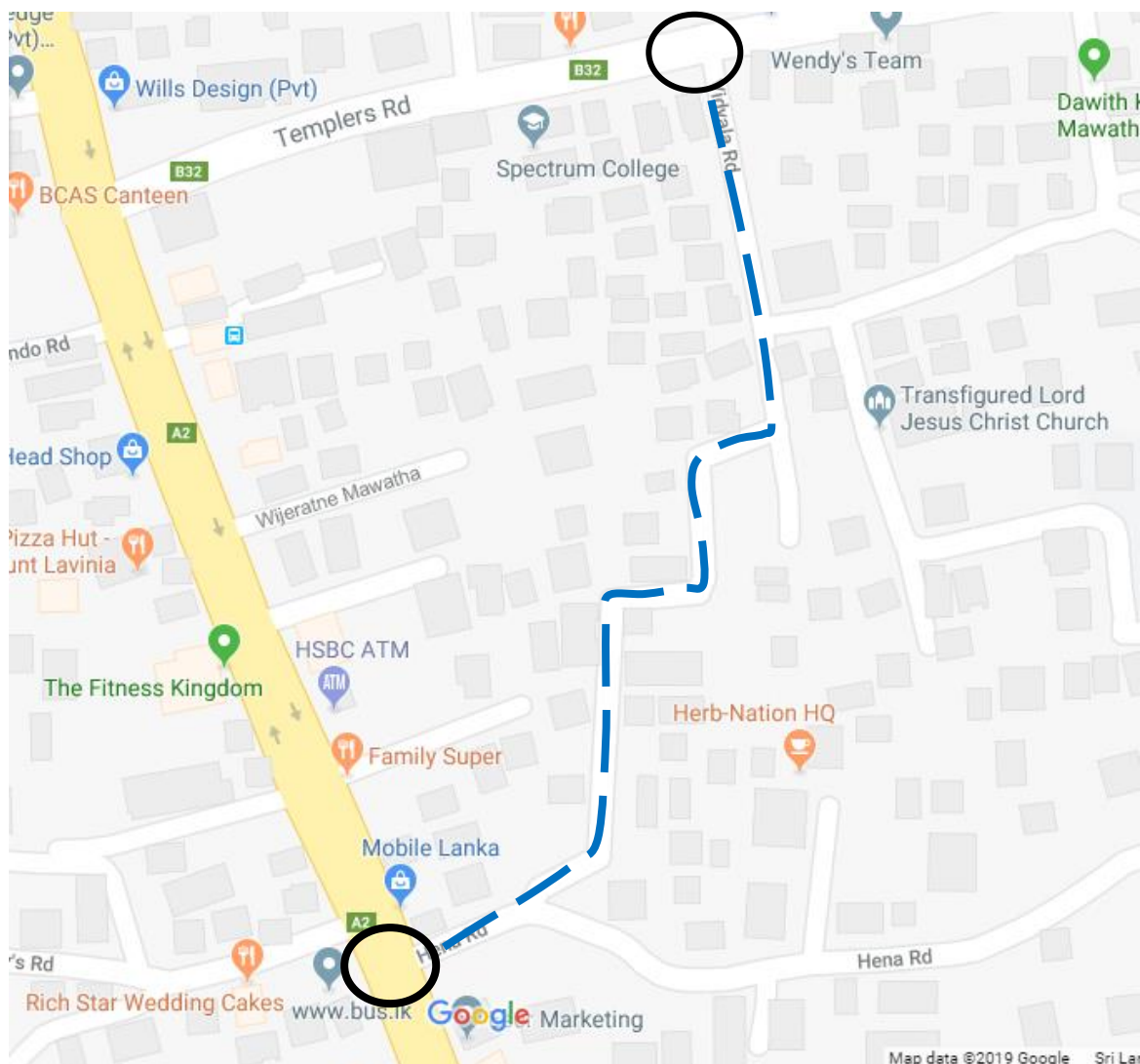


Figure 4-1: Connectivity through Hena Road

However, if a by road is having access from other road network with less turning traffic volume, it is not always necessary to provide a median opening to that by road. Therefore, it is very important to study the connectivity of the local road network connected with the main road, before selecting the proper locations for median opening

4.3 Concentration on Traffic Safety

Since the median opening acts as an intersection on a roadway with increased conflicting movements, special care should be given to ensure the safety on these locations. Therefore, the potential locations should fulfil the safety requirements listed below. Otherwise the potential locations cannot be provided with median openings. The safety requirements can be listed as follows

- Stopping Sight Distance
- Intersection Sight Distance
- Sight distance for “U” turns
- Landscaping and sight distance issues

4.3.1 Stopping sight Distance

To ensure the safety of the road, the minimum sight distance requirements should be fulfilled in every location of the highway. When we consider about median openings, the potential locations identified for median openings should fulfil the minimum sight distance requirements as listed below

Table 4-1 Minimum Stopping Sight Distance

Design Speed (km/h)	Minimum stopping sight distance (m)
30	30
40	45
50	65
60	85
70	115
80	140
100	205

4.3.2 Intersection sight distance

Since the median opening acts as an un-signalized intersection on the road way, intersection sight distance is very important to ensure the safety of the selected locations for median openings.

Intersection sight distance is the minimum standard which should be provided on the major road at any intersection. It provides enough distance for a driver of a vehicle on the major road to observe a vehicle form a minor road and to decelerate to a stop before reaching the collision point in any emergency.

Table 4-2 Minimum Intersection Sight Distance

Design Speed (km/h)	Minimum intersection sight distance (m)
30	30
40	73
50	97
60	123
70	151
80	181
100	248

(Guide to Road Design, Austroads, 2009)

4.3.3 Sight distance for “U” turns

Since there is a possibility for “U” turns taking at median opening locations, it is important to provide necessary select locations for median openings with required sight distances for “U” turns. The following are the sight distances mentioned in the FDOT, median handbook.

Table 4-3 Sight Distance for U Turns at un-Signalized Median Openings

Speed (mph)	Sight Distance (ft)
35	520
40	640
45	830
50	1,040
55	1,250
60	1,540

4.3.4 Landscaping and sight distance issues

To ensure the safe visibility requirements, it is required to maintain a low ground cover in the intersection area on the raised center medians. Therefore, no trees shall be permitted within 30m of the center median in the intersection area. Moreover, it is very important to ensure the visibility requirements at median opening locations for safer highways.

4.4 Concentration on Traffic Efficiency

Since median opening acts as a congestion point in the highway, it is needed to ensure the smooth functioning of median openings. Therefore, there are several factors needed to be considered when deciding centre median openings. Some are as follows,

- Consideration Functional area of the intersection
- Provision for queue storage
- Deceleration distance

4.4.1 Consideration Functional area of the intersection

Median openings should not encroach on the functional area of another median opening or intersection. The functional area of the median opening consists with following main aspects,

- Queue length
- Deceleration distance

- Decision distance

Moreover, the median openings should not allow on following locations.

- Across exclusive right turn lanes
- Across regularly forming queues from neighbouring intersections

Therefore, when positioning median openings, special care should be given to position them as per the above conditions.

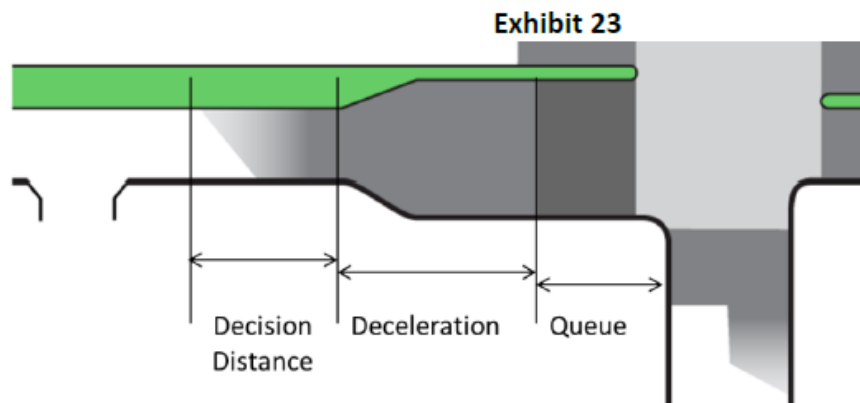


Figure 4-2 Functional Area of an Intersection

(Florida Median Handbook, 2014)

4.4.2 Provision for queue storage

It is necessary to include enough vehicle storage facilities in centre median opening areas for the vehicles waiting to take right turns. Otherwise the vehicles waiting to take right turns will create a conflicting situation with through moving vehicles.

It is recommended to provide separate right turning lanes (storage capacity) in each centre median opening locations at least for two vehicles. However, it is difficult to provide such storage facilities with the current road space available in our road network.

4.4.3 Decision Distance

The perception-reaction time required by the driver to make a decision varies. For motorists who frequently use the corridor this may be as little as one second or less. However, unfamiliar drivers may not be in the proper lane to execute the desired maneuver and may require three or more seconds.

The required decision distances are as follows.

Table 4-4 Required decision distances

Area	Seconds	30km/h	40km/h	50km/h	60km/h	70km/h	80km/h	90km/h	100km/h
Rural	2.5	21	28	35	42	49	56	63	69
Suburban	2.0	17	22	28	33	39	44	50	56
Urban	1.0	8	11	14	17	19	22	25	28

(Guide to Road Design, Austroads, 2009)

4.4.4 Deceleration distance

The deceleration distance is the minimum standards distance needed to properly slow a vehicle down and bring the vehicle to the storage portion of the median opening, or deceleration distance

Table 4-5 Deceleration Distance Required

Design speed of approach Road (km/h)	Length of deceleration D – including diverge taper T										Diverge length Ld3 for lane widths	
	Stop condition1		Design speed of exit curve (km/h) ²									
	0	0	20	30	40	50	60	70	80	90	3.5 m ⁴	3.0 m ⁴
	Comf. 2.5 m/s ²	Max. 3.5 m/s ²	Comfortable average rate of deceleration 2.5m/s ²									
50	40	30	30	25	15	33	27					
60	55	40	50	40	30	15	40	33				
70	75	55	70	60	50	40	20	47	40			
80	100	70	95	85	75	60	45	25	54	44		
90	125	90	120	110	100	85	70	50	25	60	50	
100	155	110	150	140	130	115	100	80	55	30	67	57
110	185	135	180	175	160	150	130	110	90	60	74	62

(Guide to Road Design, Austroads, 2009)

4.4.5 Concentration on public requests

Public involvement when deciding median openings is a very critical factor that needs special attention and consideration. Therefore, it is better if RDA can inform the public (getting access through the highway) regarding the raised centre median and median opening locations in the initial designs stage of the road.

Whenever there is a request regarding the modification to the centre median, the particular request should be accessed through a traffic committee comprised with relevant stakeholders and the decisions regarding the public requests should take cumulatively as committee decisions.

It is better if the road agencies can aware the public about the median construction project, discuss and get the relevant feedback from the public before carrying out any designs on median openings. Most of the time business community having their business premises close to the main road is very keen on these situations.

Therefore, the road authorities must give alternatives to the people and should reduce the impact of the median construction project.

Additionally, the road agencies need to work closely with the institutions like Sri Lanka Traffic Police and get their support for median opening selection process.

4.5 Other considerations

There are several other factors that are needed to be considered when deciding median openings can be listed as follows

4.5.1 “U” turns in advance of a signal

Provision of a “U” turning location before a signalized intersection is very beneficial since it can greatly reduce the delay in the signalized intersection caused due to the vehicles taking “U” turns. However, the median opening should be located avoiding the queuing length of the signalized intersection.

4.5.2 Openings for emergency cases

Even though the demand for the turning vehicles is less, sometimes it may require giving priority to following locations when deciding median openings.

- Hospitals (if private, necessary approvals are required)
- Fire stations
- Police stations

4.5.3 Issues with the directional opening

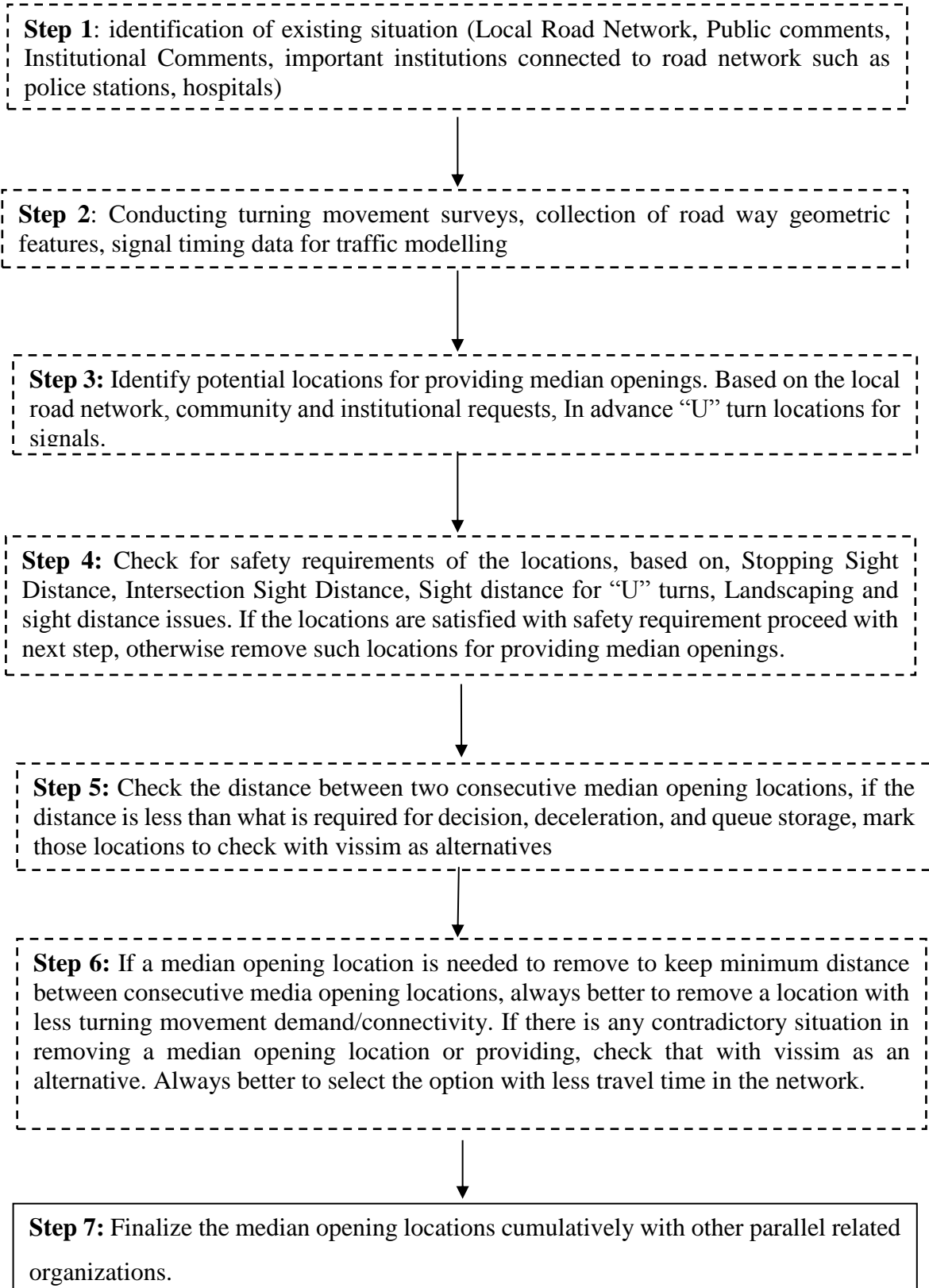
Most of the Sri Lankan urban road medians can be considered as narrow medians without proper storage areas. Most of the time the median width are about 1.5m and due to this narrow width, it is very difficult to provide directional median openings. However, if provided with directional openings on narrow medians, people tend to cross these narrow medians at either direction creating more conflicting situations. Therefore, it is not recommended to provide directional openings on narrow medians. Following is an existing example for a directional opening on narrow median and people tend to turn either direction at these locations creating more congestion situation.



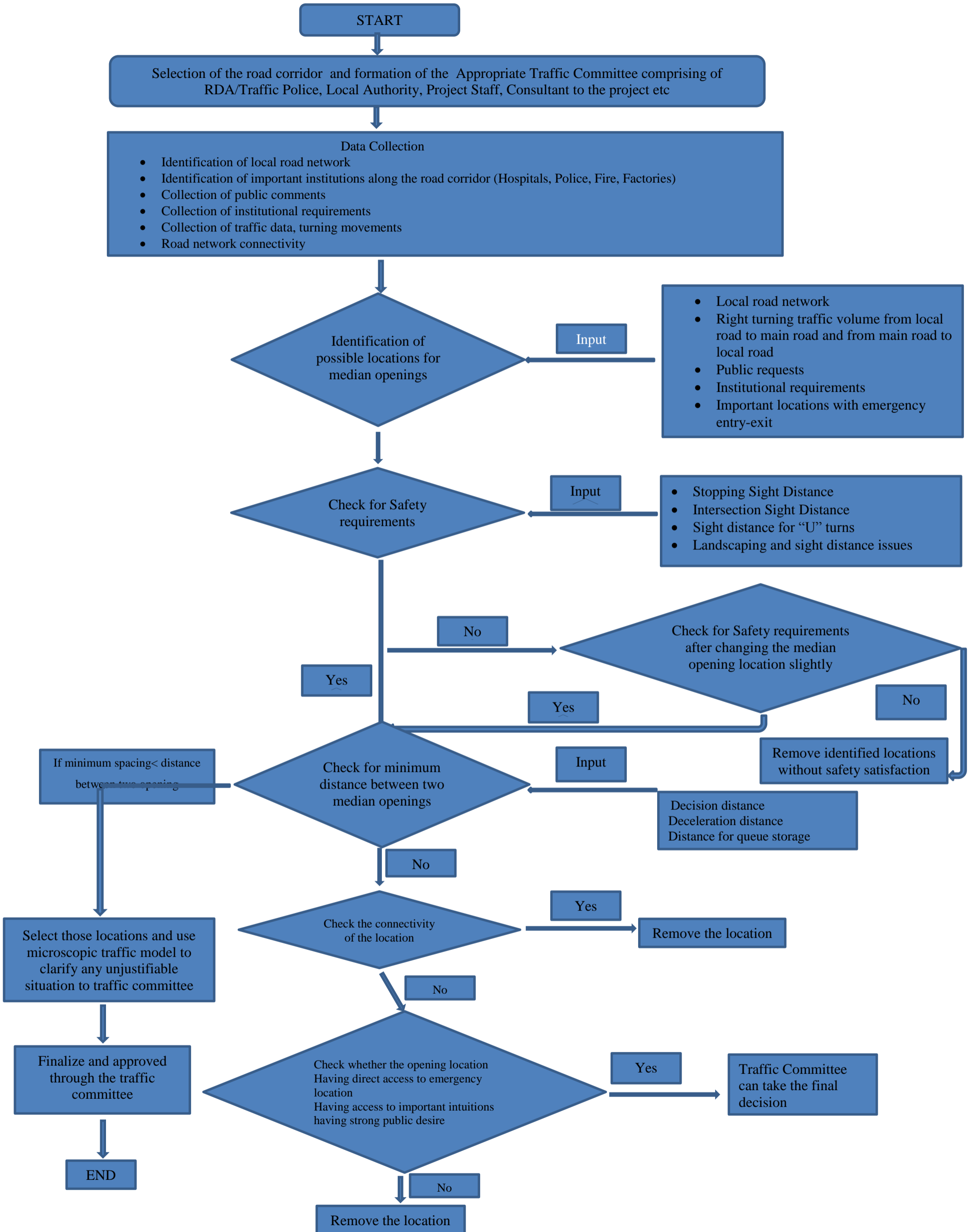
Figure 4-3 Issues at the Direction Openings

5 Development of Framework for Center Median Opening Decision Making

5.1 Framework Development



5.2 Simplified Work Flow Chart for the Centre median opening selection process



5.3 Case Study on Galle Road (From Maliban Junction to Temples road junction)

5.3.1 Roadway, geometric features, traffic volumes, speeds, access density etc.

The road section from Maliban junction to Temples road junction of Galle road was selected as a case study and modelled in VISSIM to get the results. Currently the road section operates as undivided four lane section without a raised centre median. It has recorded high numbers of head on collisions on this road section and as requested by the traffic police and many other parties, it has decided by RDA to install a raised centre median along this road section. Therefore, my case study was to select optimum centre Opening locations From Maliban junction to Temples road junction of Galle Road. In the morning peak times, the average speed of the road section is about 15-25 kmh⁻¹. The general road cross section is as follows,



Figure 5-1 A section of Galle Road

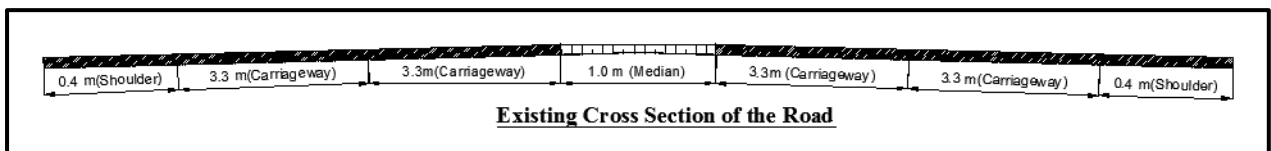


Figure 5-2:Galle road cross section



Figure 5-3: Study Area

5.4 Step 1: identification of existing situation

As the first step, it is needed to identify the following before moving into the step two of the process

- Identification of local road network, its connectivity and land use patterns along the road corridor
- Identification of important institutions, hospitals, schools, police stations and any other important land use development which get access from the selected road corridor.
- Get the public comments and suggestions on median opening/closure at different locations specially from the business community along the road corridor.
- Get the relevant institutional comments regarding the raised median construction and their suggestions for median opening and closure.
- At this situation I received some of the comments from the traffic police and suggestions from the Dehiwala / Mt lavinia road safety committee meeting.

The identified by roads from the From Maliban junction to Temples Road junction can be listed as follows.

1. Sri Sumanagala Road
2. Sri Dhammadara road
3. Sri Dharmarama road
4. Chakindarama road
5. De silva place road
6. Park road
7. Bandaranayake Mawatha
8. William place road
9. Piriwena road
10. St Rita's road
11. Hena Road
12. St Mary's road

5.5 Step 2: carryout necessary surveys for traffic modelling and investigations

Turning Movements Surveys were carried out at each local road intersecting with the main road. The traffic volumes on the main road and the turning movements of Maliban and Temples toad junctions were extracted from the existing data. Existing signal timing data was used to model the junctions.

5.6 Step 3: Identify potential locations for providing median openings

Identification of potential locations for providing medians opening were carried out based on the following factors. However, it is important to provide median openings at by road intersecting locations with the main road rather than providing them at other locations.

- Functional requirements (Decision/Deceleration/queuing)
- In advance “U” turn locations before signalized junctions.
- Any important institutional locations for providing median openings.
- Community and institutional considerations
- By road turning volume densities

5.6.1 Minimum spacing as per the functional requirements

The requirements for minimum spacing between two adjacent centre median openings were calculated based on the Austroads guidelines. A 15 m queue storage area was considered and that satisfies to store two vehicles at a time.

- Considering 70 km/h approach speed (even though the speed limit is 50km/h, at night time vehicles can travel faster)
 - Decision distance – 20 m for urban
 - Deceleration distance – 75 m
 - For queue storage – 15 m
- Total minimum spacing requirement – 110 m

(Guide to Road Design, Austroads, 2009)

In the potential opening selection, the Sri Sumangala road was not provided with a median opening, since it was located less than 110 m from the Maliban junction opening. Moreover the William place road also not provided with a opening, since it had few right turning vehicles in the morning time and was located very close to the Pirivena road junction. However as requested by the police road safety committee meetings, Sri Lanka Transport Board, bus depot and Mt.Lavinia police station was provided with mediana openings. However the openings provided for the Bandarainayake Mawatha can use for the entrance /exit purposes of police vehicles. The SLTB Depot can modify their entrance to use the opening given at Pirivena road.



Figure 5-4: Potential Opening locations and Spacings

5.7 Step 4: Check for safety requirements

It is necessary to check the potential opening locations are visible for the drivers and are not located in any hazardous locations in the road network. As described in the literature review following sight distance requirements were checked.

- Stopping Sight Distance
- Intersection Sight Distance
- Sight distance for “U” turns
- Landscaping and sight distance issues

Since the selected road section of the Galle road is almost straight, no sight distance issues were encountered.

5.8 Step 5: Model the corridor using VISSIM

As described in the literature review and methodology, the PTV VISSIM software was used to model the selected road segment with potential opening locations. In this scenario, a hypothetical raised centre median was constructed in the model. The previously calibrated driver behaviour parameters were used as modified driver behaviour for the Galle road section. Morning peak (7am- 8am) and evening peak (6pm-7pm) times were modelled separately as two scenarios to check the situation in both morning and evening peak times. Travel time and total delay of the road network was considered as parameters to optimize the selected opening locations.

In the potential opening selection, the provision of median opening at St.Ritas road and the opening at Sri Dharmadara road was doubtful due to following reasons.

- Since the Sri Dharmadara road was located very close to the Maliban junction, the opening at this location could interfere the smooth signal functioning at Maliban junction. Therefore, it has modelled two separate scenarios (with and without opening at the location) in vissim to check the suitability of providing a median opening for Sri Dharmadara
- Due to the provision of a median opening at St.Ritas road, the distances to nearest median opening locations were recorded as 133 m and 117 m. However this situation needed to clarify in vissim since, in the morning time St.Ritas road was very busy with lot of vehicle movements and located with closer spacings to other openings. Therefore

it has modelled two separate scenarios (with and without opening at the location) in vissim to check the suitability of providing a median opening for St.Ritas road.

Table 5-1 Travel Time of Galle Road with/without considering the opening at Sri Dharmadara road

Time Period	Direction	Travel Time (s)
EP with opening	1: from Maliban to Temples road junction	273
	2: from Temples junction to Maliban junction	457
EP without opening	1: from Maliban to Temples road junction	283
	2: from Temples junction to Maliban junction	444
MP without opening	1: from Maliban to Temples road junction	736
	2: from Temples junction to Maliban junction	336
MP with opening	1: from Maliban to Temples road junction	815
	2: from Temples junction to Maliban junction	349

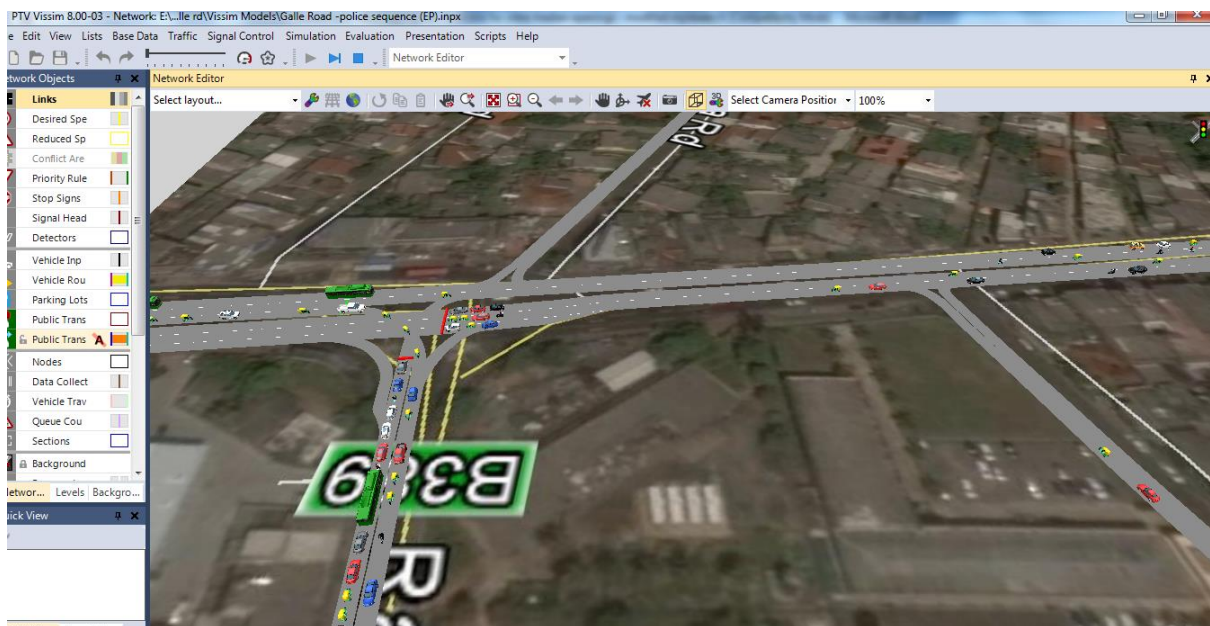


Figure 5-5: Road Network Model in VISSIM

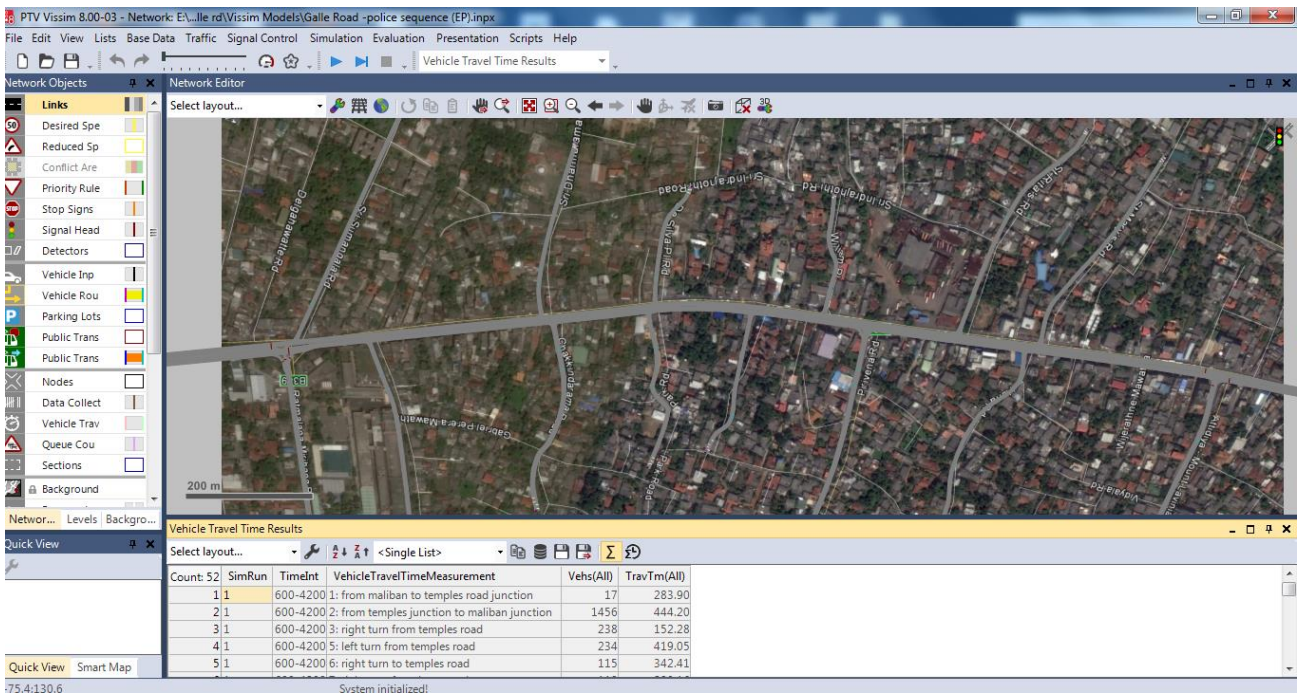


Figure 5-6: Road Network Model in VISSIM

As per the travel times obtained from the two scenarios, it cannot identify a major difference in the travel time in evening peak time, with and without opening at Sri Dharmadara road. However, in the morning peak times, there can identify a huge difference between the travel time from Maliban junction to temples road junction with and without opening at the location. If we provide an opening at this location, that can result to increase the travel time of the road

Table 5-2 Travel Time of Galle Road with/without considering the opening at St Ritas road

Time Period	Direction	Travel Time (s)
MP without opening	1: from maliban to temples road junction	782
	2: from temples junction to maliban junction	337
MP with opening	1: from maliban to temples road junction	736
	2: from temples junction to maliban junction	335
EP without opening	1: from maliban to temples road junction	277
	2: from temples junction to maliban junction	469
EP with opening	1: from maliban to temples road junction	277
	2: from temples junction to maliban junction	446

As per the above analysis through the vissim simulation, it can clearly understand that providing an extra median opening location at St.Ritas road reduces the travel time of the Galle road , in peak time and evening times as well.



Figure 5-7 Finalized Opening Locations and Spacings

Recommended Median opening Locations

1. Sri Dharmadara road (signalize –coordinate /evening peak only)
2. Sri Dharmarama road/ Chakindarama road
3. De silva place road/Park Road
4. Bandaranayake Mawatha /Mt.Lavinia Police
5. Piriwena road/ CTB Depot
6. St Rita's Road
7. Hena Road / St Mary's road

6 Conclusions

Most of the time, median opening closure will result to increase the delay to by road traffic largely and cannot expect a significant travel time reduction in the main road since the unavailability of turning/storage areas and due to weaving movements. However, this situation can change in some situations with the traffic signals operations. Since decision making on median opening selection is somewhat complex in nature, it is recommended to use outputs of a simulation model before finalizing the opening locations. Through the simulation results, it was clear that the removal of media opening for important local road location will increase the delay to the overall road users.

Since median opening location acts as an intersection point on a road network, it is desirable to have proper storage bays for right turning movements. If we close the media opening locations, the additional weaving and merging conflict will result to increase the delay of the road network. However, the absence of proper turning storage areas will worsen the situation in median opening locations. Hence it is recommended to provide median opening locations where there is a requirement for right turning vehicles. However, it is mandatory to consider the safety of the location and minimum distance between adjacent median opening locations before finalizing the locations.

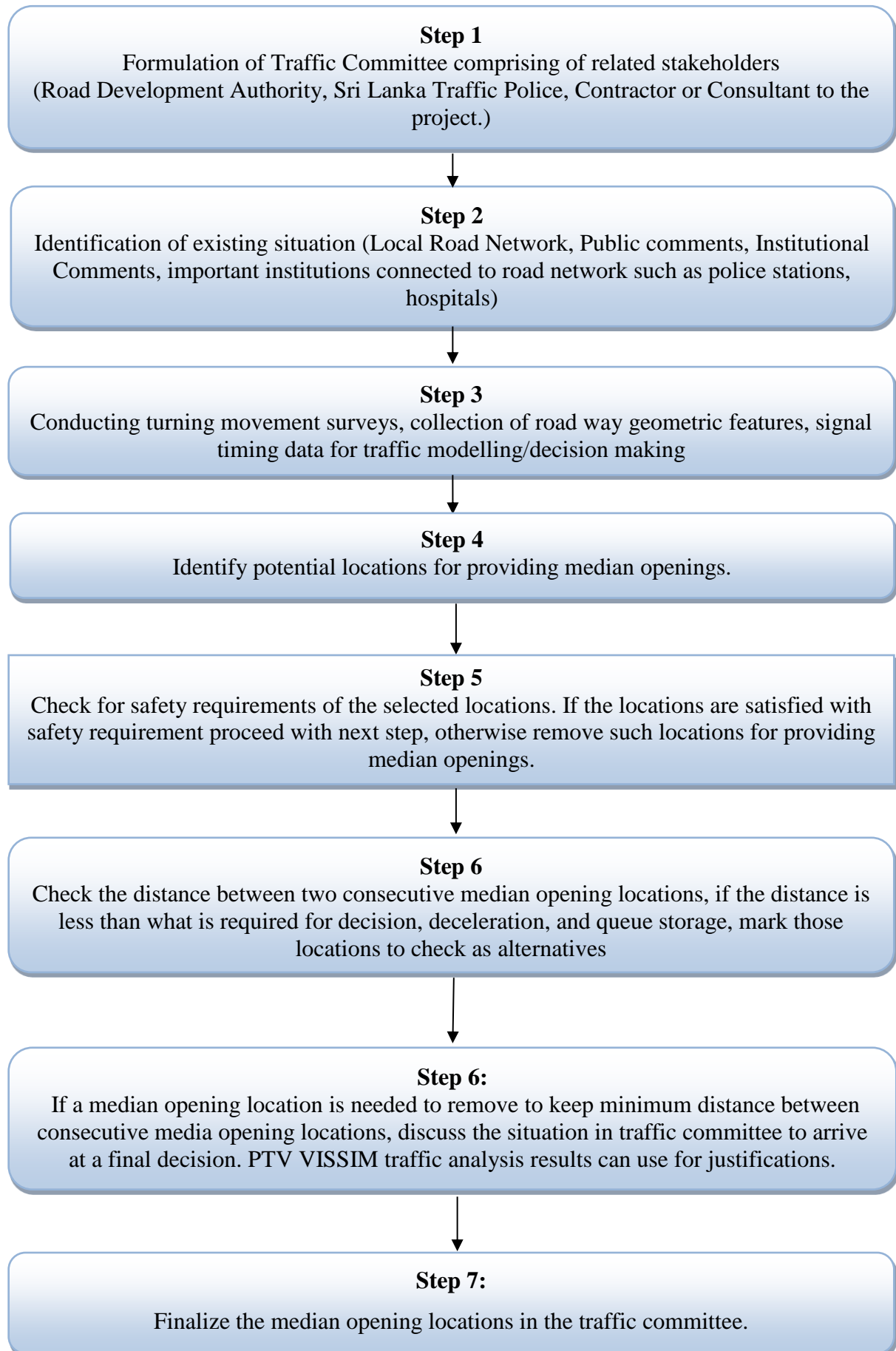
Public comments, desires and institutional requirements needed to be accessed in a committee comprising of relevant stake holders like Traffic Police, Local Authorities of the area before finalizing the median opening locations. Since the introduction of new centre median can restrict vehicle movements to great extent, naturally public will oppose to such situations. Therefore, median opening location selection process needed to be carried out wisely and proper coordination with relevant stake holders. Otherwise unnecessary influences will result to ad hoc decision-making situation and finally public will not receive the proper benefit of raised median construction.

The final decisions on median opening locations should be taken cumulatively in the traffic committee as discusses above. Any public complain regarding a median opening locations or request for new median opening locations should be evaluated in the above formulated traffic committee. The committee should be responsible for the decisions that they have taken and should represent the committee decision in any forum and instance. It is better to find suitable ways to communicate with the public whose get affected due to centre median construction before starting the process for selection suitable locations for median openengs.

6.1 Summary of the research study methodology and findings

As per the research carried out, the following generalized methodology can be recommended to decision makers to follow in centre median opening selection process. Before starting the centre median opening selection process, it is mandatory to appoint a traffic committee to carry out this task.

Selection of appropriate locations for centre median openings is always challenging and therefore having a sound methodology for decision makers is very important. Therefore, throughout this research, a suitable, simple methodology and framework was developed for the use of engineers and decision makers. However, the practical knowledge is essential to apply the following developed framework in the field. Public awareness and sound communication with relevant stakeholders are very important for success implementation of the developed methodology.



6.2 Further studies needed

The entry/exit vehicles to/from road side developments are needed to be encountered when deciding median opening locations. Sometimes the number of turning movements taken for a road side development like supermarkets, shopping centres may need to evaluate separately while selecting locations for median openings. However, this need to be considered very wisely hence the providing a separate median opening location for private establishments (like supermarket) may negatively impact the median opening selection process. Providing a separate median opening location for individual development may result for lot of public request for median openings and the situation would be very difficult to handle.

Therefore, the appointed committee can consider taking a policy decision in providing median opening locations for individual developments as discussed above. As per the Sri Lankan condition it is wise to avoid providing individual median opening locations for commercial establishments.

Further research is needed to develop a comprehensive guideline for selection suitable locations for centre median opening. However, the developed frame work for median opening section can use as the basis for the development of the guideline. In the guideline it can recommend a minimum right turning traffic value to provide median opening for a location based on the access density, main road traffic and functionality of the road.

7 References

- (2004). *Access Management for Kentucky*. Kentucky Transportation Centre.
- (2011). *Access Management Guidelines, City of Tucson*. Arizona: Tucson Department of Transportation.
- (2012). *Access Management Manual*. Mississippi Department of Transportation.
- Eisele, W. L. (2004). Estimating the impacts of access management with access management. Kansas City, Missouri.
- (2014). *Florida Median Handbook*. Florida Department of Transportation.
- (1998). *Geometric Design Standards of Roads*. Road Development Authority.
- (2009). *Guide to Road Design, Austroads*. Austroads.
- (1992). *NCHRP Report 348*.
- (2003). *TRB Access Management Manual*. Transportation Research Board.