EVALUATING THE IMPACTS OF COORDINATED TRAFFIC SIGNAL SYSTEMS

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ABSTRACT

Evaluating the Impacts of Coordinated Traffic Signal Systems

Traffic congestion due to increasing number of vehicles and pedestrians is one of the major problems that need to be tackled especially in urban areas. Numerous methods are available to reduce delays and financial losses and environmental problems caused by road traffic in major cities.

Signalizing is one of the main methods to control traffic at intersections. Most of the signalized junctions in Sri Lanka are isolated fixed-cycle type. Signal coordination is considered as one of the cost effective and successful strategies to reduce congestion problems worldwide. Sri Lankan road development and management agencies are in their initial stage of implementing this system for signalized intersections. However, little has done to quantify the benefits that can be obtained from coordinated traffic signal systems and hardly done studies to recommend a suitable guideline for Sri Lankan context. Therefore, objective of this research is to evaluate the impacts from traffic signal coordination in reducing delay and queue length and propose a guideline, which can be used in signal coordination in Sri Lankan context in optimized manner.

As a case study, closely spaced three signalized junctions are selected at for the analysis. SIDRA, Signalized (and unsignalized) Intersection Design and Research Aid is used to generate the timing plans for each junction. Manual calculations are also done. The system was modeled using PTV VISSIM software and each junction is analyzed considering as a non-coordinated isolated junction and as an individual junction of a coordinated system using that software model. Travel time, delay, effective stop rate and queue length are identified as important parameters to evaluate the benefit/impact of the coordinated system. Data related to above parameters taken from the VISSIM output is used to compare coordinated system and in the isolated system. Using the evaluation results, reduction of delay and reduction of queue length are presented as percentages, as quantified measures of the benefits of the signal coordination. Limitations of signal coordination such as time for pedestrians, longer waiting time to minor street traffic are also identified during the study. Various coordination strategies were modeled as both direction coordination, single direction coordination, multiple cycle times etc. Using the results of the case study, a proper methodology is proposed to optimize the signal coordination in a considered set of junctions.

Keywords: Coordination – Junctions – Peak time

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1 INTRODUCTION

1.1 Background

Traffic congestion is one of the major problems that need to be tackled especially in metropolitan areas due to ever increasing number of vehicles and pedestrians. Numerous methods are available to reduce delays and financial losses as well as environmental problems caused by road traffic in major cities. (C. T. Wannige,D.U.J.Sonnadara, 2008).

Traffic congestion can have an enormous impact on people's personal lives, career, their future and safety. Finding a solution to traffic congestion could mean a vast improvement in the quality of life.

Signalizing is one of the major methods to control traffic at intersections. Most of the signalized junctions Sri Lanka are isolated fixed-cycle type.

Signal coordination is considered as one of the most cost effective and successful strategies to reduce congestion problems worldwide. Sri Lankan road development and management agencies are in their initial stage to implement this system for signalized intersections. However, signal coordination is being implemented in to some extent in traffic signal system in Colombo municipal area.

The goal of coordination is to get the maximum number of vehicles through the system with the fewest stops in a comfortable manner. When traffic signals work together (or are coordinated), they provide a greater opportunity for motorists to travel through adjacent traffic signals without making unnecessary stops (Traffic signal coordination Handbook). This, in turn, reduces fuel use, saves motorists travel time, diminishes wear and tear on vehicles, and cuts vehicular emissions. (Skabardonis, 2000).

1.2 Problem Statement

Coordinated traffic signal systems have been widely implemented for the past few decades in foreign countries because they provide better progression along the major corridors through proper coordination. However, little has been done to quantify the benefits that can be obtained from coordinated traffic signal systems. (Park & Chen, 2010). Although it is important to have quantified measure of the benefits compared to prevailing system, such measure is not available yet in Sri Lankan context. In addition, there is no proper guidance available for coordinating the traffic signals in Sri Lankan context and optimizing the same. In addition, it is necessary to check whether the benefits/impacts of a coordinated system vary depending on the different situations such as time of the day and parameters related to the location.

1.3 Objectives

The main objective of this study is to evaluate the impact from Traffic Signal Coordination to vehicles and pedestrians at peak and off peak time for Sri Lankan urban heavy traffic situations. Using a case study approach to recommend a guideline for signal coordination which can be used for optimizing the future coordination efforts in signalized junctions in Sri Lankan urban areas is an additional objective of the research.

1.4 Research Approach

In order to fulfill the objectives of this research the following approach is followed:

- A comprehensive literature review of previous and current research efforts in the area of signal coordination is conducted at the beginning of the project. The review includes the study of the current practice in signal coordination, its benefits, disadvantages and optimizing methods.
- As a case study, closely spaced three signalized junctions are selected at for the analysis. SIDRA, Signalized (and unsignalized) Intersection Design and Research Aid is used to generate the timing plans for the selected junctions. The timing values obtained are compared with manually calculated values.
- The system is modeled using PTV VISSIM software and each junction is analyzed considering as a non-coordinated isolated junction and as an individual junction of a coordinated system using that software model.

- Important parameters to evaluate the benefit/impact of the coordinated system are identified. Data related to above parameters taken from the VISSIM output is used to compare the travel time and delay of the coordinated system and in the isolated system.
- Using the evaluation results, a quantified measure of the benefits of the signal coordination is presented. Limitations of signal coordination are also identified during the study.
- Various coordination strategies are modeled to compare and find the most suitable strategy to reduce delays for the considered set of junctions. The optimum cycle time is identified for the system at peak time and off peak time by changing the cycle time and comparing delay and queue length results.
- Using the results of the case study, a proper methodology is proposed as a guideline to optimize the signal coordination in a considered set of junctions.

2 LITERATURE SURVEY

2.1 Introduction to Signal Coordination

The ability to synchronize multiple intersections to enhance the operation of one or more directional movements in a system is called traffic signal coordination. (Nesheli & Roshandeh, 2009)

Signal coordination provides a means by which the sequence (begin and end) of green lights is established along a series of traffic signals to allow for the uninterrupted flow of traffic between these traffic signals. Signal coordination is most typically used along heavily traveled arterial streets with a frequent presence of traffic signals. (Signal Timing and Coordination, 2006)

The coordinated operations of adjacent signalized intersections on a main corridor can potentially improve traffic operations and significantly reduce traffic delay. However, developing coordinated traffic signal operation plans through interconnect systems requires careful and detailed analysis that would take into consideration traffic patterns, intersection spacing, communications cost for connecting intersections, as well as possible benefits (i.e., reductions in traffic delay). In general, engineers must balance benefits to the favored movement (main approach) to possible negative impacts on side streets. (Signal Coordination Strategies, 2003)

When intersections are closely spaced and volume on the coordinated arterials is large, the coordinated signal system is preferred to the isolated signal system. The Manual on Uniform Traffic Control Devices (MUTCD) recommends that traffic signals within 800 m (i.e., 0.5 mile) be coordinated under a common cycle length. (Park & Chen,2010)

2.1.1 Benefits of signal Coordination

Traffic signals are coordinated to ensure optimum travel speeds, reduced delays, and minimal stops. The major benefits of properly coordinated signals are listed below.

- Improved mobility and access
- Bolstered local economies
- Reduced vehicular accidents
- Reduced energy and fuel consumption
- Eliminated or delayed street widening needs
- Improved emergency response
- Reduced motorist frustration and road rage

- Reduced vehicle wear
- Increased control of travel speeds
- Reduced diversionary flows in neighborhoods
- Reduced vehicle emissions

(Bhattarai & Marsani, 2015)

2.1.2 Limitations of Signal Coordination

The limitations of signal coordination are mentioned below:

- Increase in travel speeds may have a negative impact in the community
- May attract additional traffic through the corridor
- Maintenance and equipment costs may be high based on the type of hardware and software used.
- Requires qualified staff for maintenance and monitoring of daily operations

(Binayak Bhattarai1, Anil Marsani, 2015)

While traffic signal coordination can reduce stops and travel delays along a particular corridor, travel along a particular street may not completely experience non-stop free-flow conditions due to the following conditions:

Capacity issues as a result of increased traffic caused by growth.

- Complexity of the street system.
- Equipment malfunction.
- Street construction.
- Traffic incidents

2.1.3 Simulation Studies and Software Used Worldwide

Synchro is a software package that evaluates and optimizes traffic signal timing plans based on traffic volume and geometric conditions. It can optimize isolated and coordinated traffic signal systems. Synchro is one of the most widely used tools in the United States. It includes a user friendly graphical interface and various MOEs. (Byungku(Brian) Park, Yin Chen, 2010)

Synchro is a widely adopted engineering tool to evaluate and optimize traffic signal timing plans. However, its validity in replicating field measurements has not been well investigated. (Byungku(Brian) Park, Yin Chen, 2010)

Skabardonis (2001) summarized the benefits of optimizing traffic signal timing plans for coordinated signal control and implementing adaptive signal control. TRANSYT-7F was used in the evaluation in set of junctions in Francisco Bay Area, Los Angeles, San Diego and Orange counties TRANSYT-7F results showed a 7.7 percent reduction in travel time, a 13.8 percent reduction in delays, and a 12.5 percent reduction in stops

Four consecutive intersections about 0.5 miles apart were coordinated to quantify benefits of a coordinated actuated traffic signal system. TRANSYT-7F results showed that the average delay decreased from 68.3 sec/veh to 37.2 sec/veh for morning peak hour and from 65.1 sec/veh to 35.6 sec/veh during evening peak hour (Nesheli et al., 2009)

Zimmerman (2000) indicated that traffic signal coordination across two jurisdictions in Arizona resulted in a 21 percent delay reduction using the INTEGRATION simulation program.

SimTraffic is a microscopic model used to simulate a wide variety of traffic controls, including a network with traffic signals operating on different cycle lengths or operating under fully actuated conditions. SimTraffic also models unsignalized intersections, roundabouts and channelized right turn lanes. (MnDot Traffic Signal Timimg and Coordination Manual, 2013)

LINSIG is a traffic modelling package for the assessment and design of traffic signal intersections, either individually or as a network that comprises of a number of intersections. It is a type of macro-simulation package in which vehicles are represented as a traffic stream or platoon rather than individual identities (Zhang, 2013)

2.2 SIDRA Intersection Software

SIDRA is an advanced micro-analytical traffic evaluation tool. It employs lane-by-lane and vehicle drive-cycle models coupled with an iterative approximation method to provide estimates of capacity and performance statistics of an intersection. SIDRA models can be calibrated for local conditions to capture vehicles lane selection and inter-blocking behavior, which is critical to lane saturation flow rate estimation. (Zhang, 2013)

2.2.1 VISSIM Software

VISSIM is the ideal tool for building a clear and conclusive knowledge basis for decisions for all kinds of traffic engineering questions. The system has been designed for analyzing and modeling transport networks of any size and traffic systems of all types, from individual intersections right up to entire conurbations. (Microscopic traffic simulation with VISSIM, 2014)

VISSIM can simulate the following processes and systems:

- Fixed-time control systems
- Traffic-actuated control systems
- Adaptive network control systems
- Green waves
- Public transport priority schemes
- Rail transport control
- Priority schemes for emergency vehicles
- Ramp metering
- Dynamic speed control signs
- Dynamic lane opening signs

(Microscopic traffic simulation with VISSIM, 2014)

2.2.2 Optimizing the Coordination

To improve the efficiency of a transportation system, signal coordination strategies can be designed to maximize the number of vehicles processed by the network and minimize the travel time of the vehicles in the system. (Rahul Putha, Luca Quadrifoglio & Emily Zechman, 2012)

Optimizing the timing of coordinated traffic signal systems is considered one of the most cost-effective traffic management implementation to reduce delays, stops, fuel consumption and emissions. An optimized traffic signal coordination system will allow for smoother traffic operation that increases capacity, decreases stops, and alleviates high queues. (Michael Mullen, David Holt, Matthew Snead, 2015)

3 METHODOLOGY

For evaluating the impacts of signal coordination, a case study approach will be carried out. Set of junctions will be selected from Colombo and suburbs for the case study and traffic data will be collected for each junction. Timing plans will be generated for each junction and the selected road network will be modeled using VISSIM software using the calculated timing plans. Network will be modeled as coordinated and non coordinated junctions to compare the outcome. Different coordination strategies will be modeled and results will be checked during various times of the day. Results will be compared with non-coordinated system. Parameters such as cycle time will be varied and results will be analyzed in order to optimize the network. Using the results of the software model, recommendations will be given for implementing signal coordination for Sri Lankan signalized junctions

3.1 Summary of the Methodology

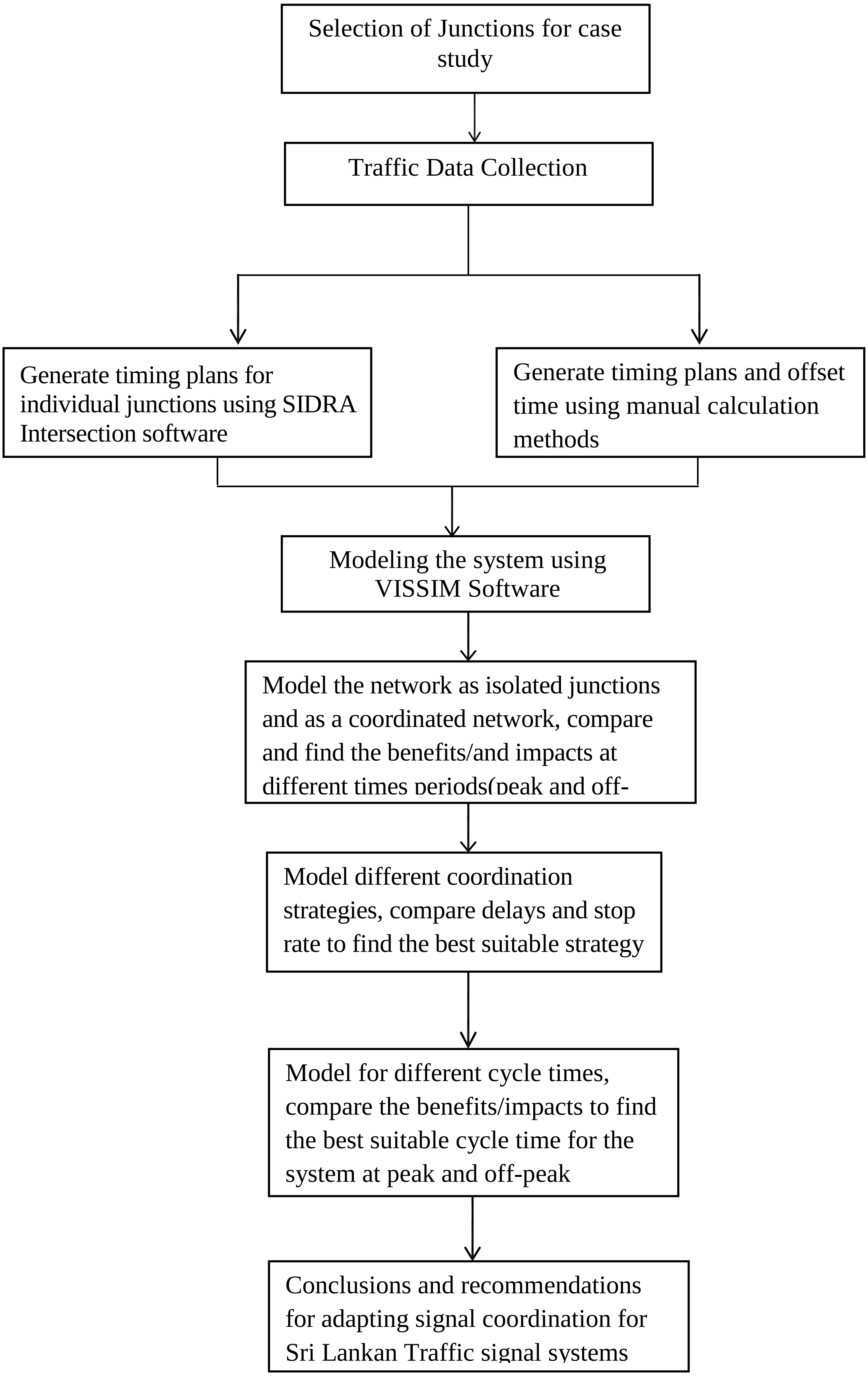


Figure 3-1 :Summery of Methodology

3.2 Selection of Junctions for Case study

Closely spaced set of junctions needed to be selected for the case study to model the coordinated signal system. The distances between the junctions need to be less, disturbance to the traffic flow should be minimum and generated traffic in between the junctions needs to be less.

By considering the signalized junctions within Colombo and suburbs, three junctions in Baseline road Colombo were identified as suitable for the study. The selected junctions are Park Road Junction, Narahenpita Junction and Kirimandala Mawatha Junction in baseline Road.The distance from Park Road Junction to Narahenpita Junction is 360m and from Narahenpita Junction to Kirimandala Mawatha Junction is 200m. Main traffic flow direction is from Kirulapona to Borella in the morning peak hours and it is in the opposite direction in the afternoon peak hours. Park Road Junction and Kirimandala Junction are three leg junctions (T-junctions) and Narahenpita Junction is a four leg Junction.

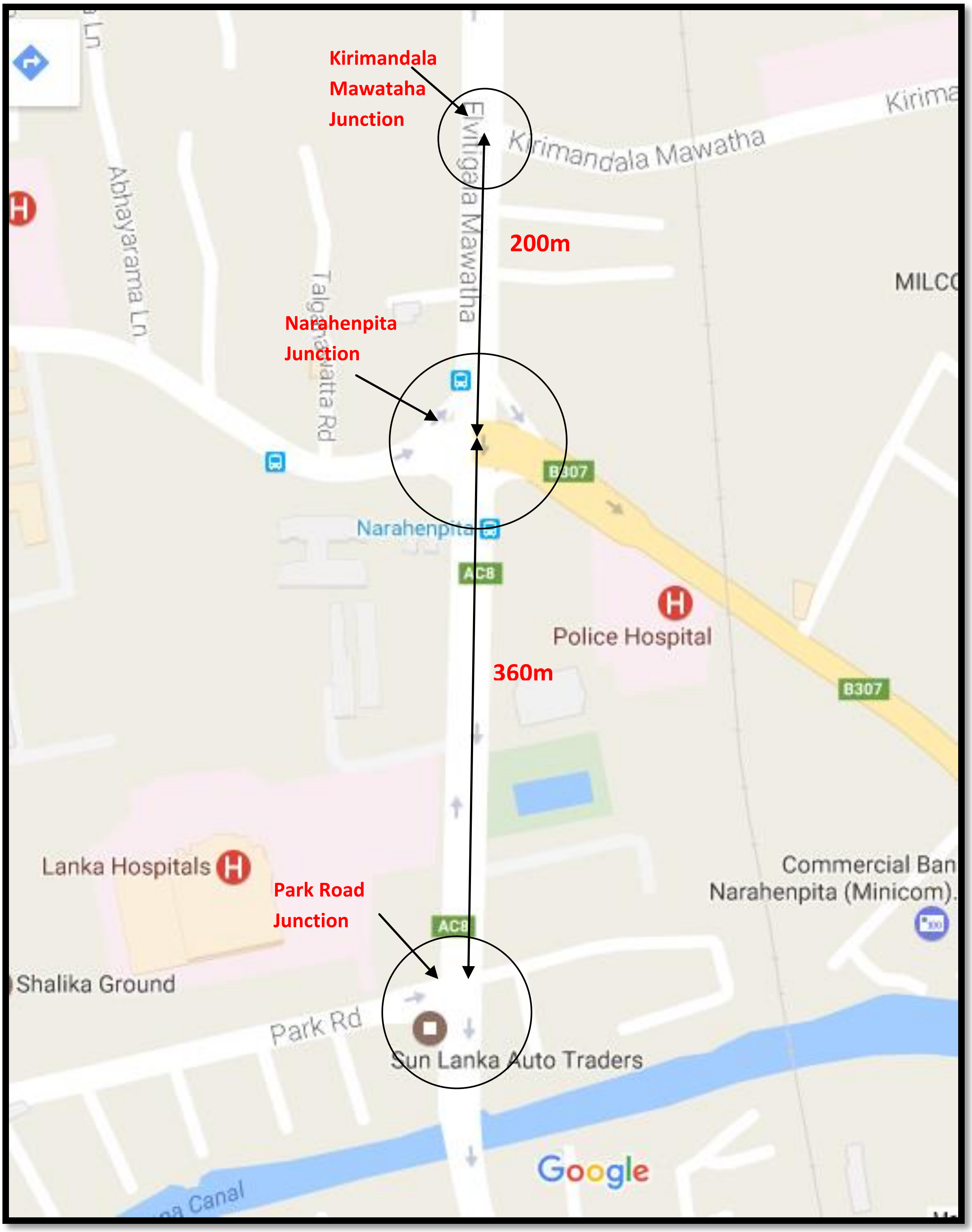
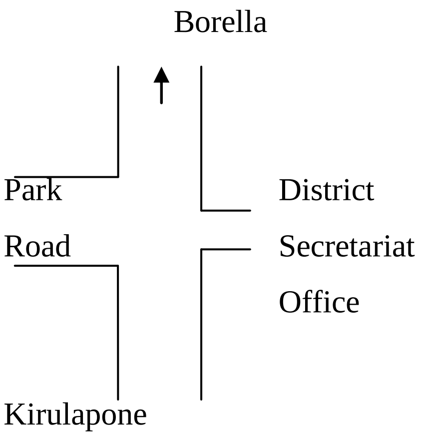


Figure 3-2: Selected Junctions

3.3 Existing Situation

Existing phase arrangement at Park Road Junction is as follows.



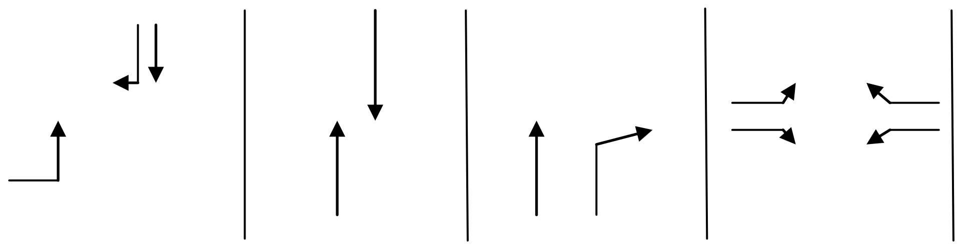
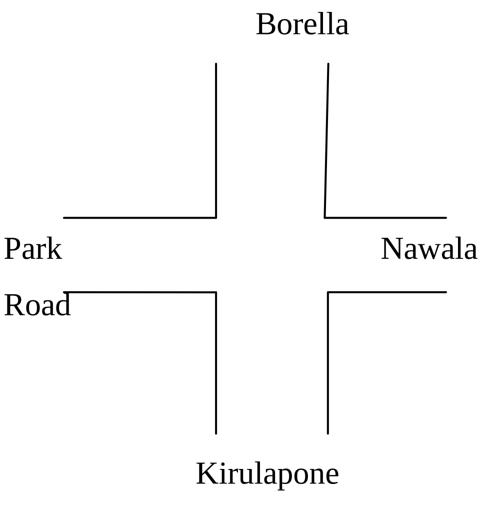


Figure 3-3: Phase arrangement-Park Road

Although this is a three-leg junction, separate turning phases are provided for the entering and leaving vehicles to the District Secretariat Office, Kirulapone. Therefore, according to the prevailing signals, it acts as a four-leg junction. One of the major private hospitals is located close to this junction and currently entering and leaving vehicles to the hospital are also controlled by the signal controller of the Park Road junction. Although green signal is given to the vehicles from park road, vehicles leaving from the rear gate of the hospital to the Park Road disturb the traffic flow.

Existing phase arrangement at Narahenpita Junction is as follows.



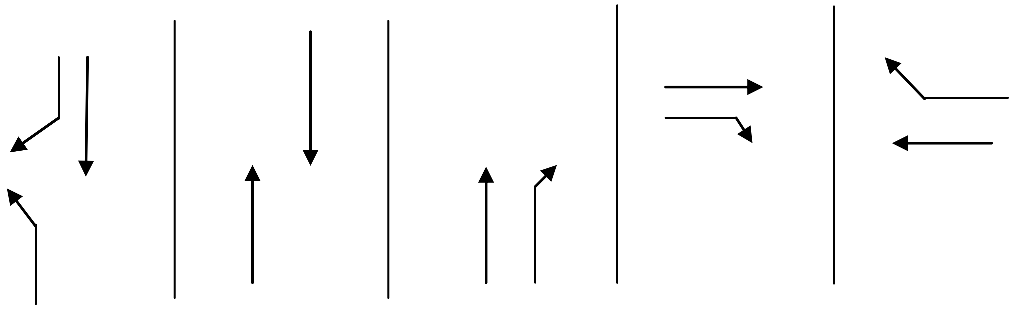
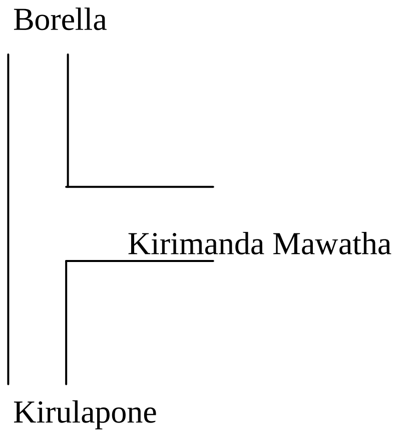


Figure 3-4:Phase Arrangement-Narahenpita

Currently this signalized junction is operated under five phases. Baseline road has three standard lanes. However, at the junction, separate right turn lanes are not provided. As a result, right turning vehicles block the innermost through lane at the junction according to this phase arrangement.

Existing phase arrangement at Kirimandala Mawatha Junction is as follows



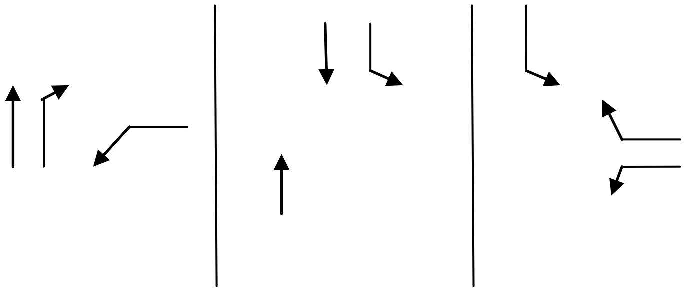


Figure 3-5: Phase Arrangement-Kirimandala

At Kirimandala Mawatha junction, Kirimandala Mawatha is wide enough at the beginning. But it becomes narrow just after the junction. Therefore the vehicles entering to Kirimamdala Mawatha are blocked reducing the number of vehicles passing through the junction.

3.4 Traffic Data Collection

Turning movement data need to be collected for the timing calculations of the selected three junctions. Classified Turning movement data were taken from a traffic survey carried out by Road Development Authority, Sri Lanka on 05/08/2014. Collected data set is attached as Appendix 1.

3.5 Calculation of Signal Timing

For calculation of signal timing, SIDRA (Signalized and Unsignalized Intersection Design and Research Aid) was used. It is an advanced micro-analytical traffic evaluation tool that employs lane by lane and vehicle drive cycle models coupled with an iterative approximation method to provide estimates of capacity and performance statistics (delay, queue length , stop rate, etc.). (SIDRA Intersection User Guide, 2007)

3.5.1 Input Data for SIDRA software

For the SIDRA software wide range of data need to be inputted. Intersection data, Geometry data, Traffic volumes, path data, movement data, priorities, data related to gap acceptance, pedestrian data, phasing and timing data are needed to input to the software.

Intersection data, Geometry Data are collected through observation, traffic volumes and Pedestrian Data are taken from the turning movement data collected. Movement data, Priorities, Gap Acceptance, Phasing and Timing data are collected by observation and by discussions with traffic division of Road Development Authority Sri Lanka.

Following figures shows the input data given to SIDRA software for modeling Park road Junction.

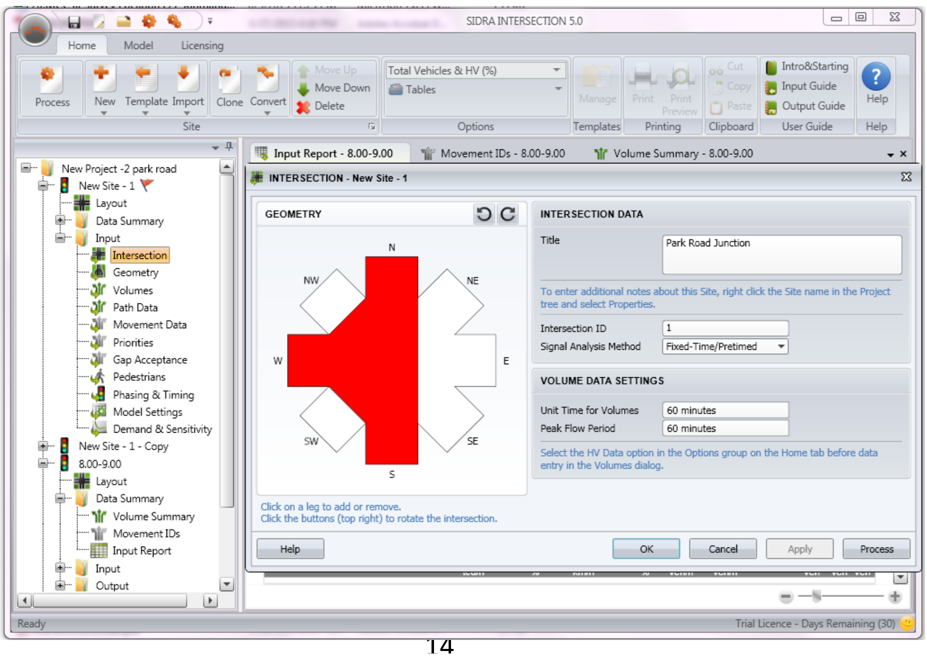


Figure 3-6: Intersection data input for park road Junction

Traffic volumes per every hour for each turning movement were given as an input for the considered time period using the traffic data collected.

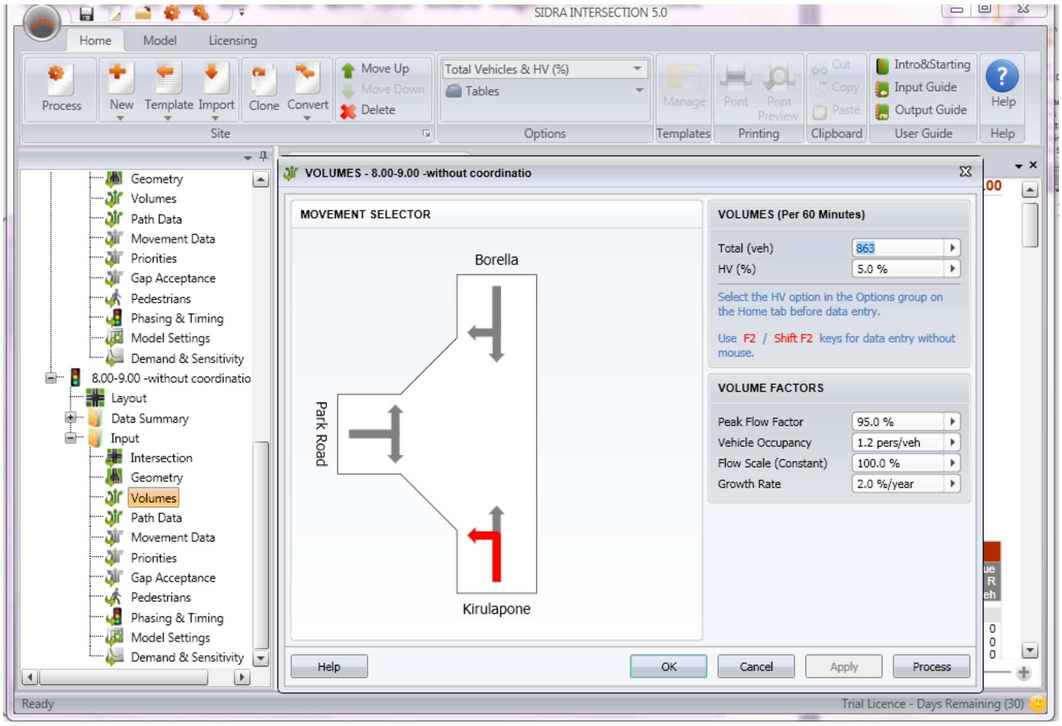


Figure 3-7: Traffic volume input for park road junction

Movement data such as vehicle lengths and queue spacing are given according to the figure below.

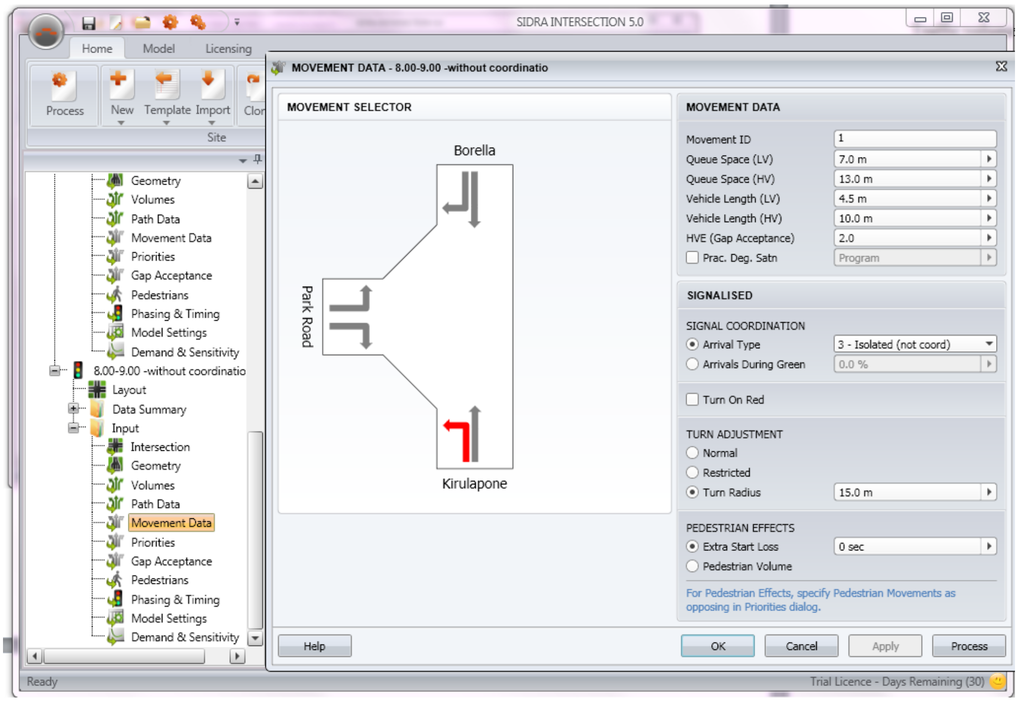


Figure 3-8: Movement data input for Park road junction

Opposing movement for each turning movement were assigned.

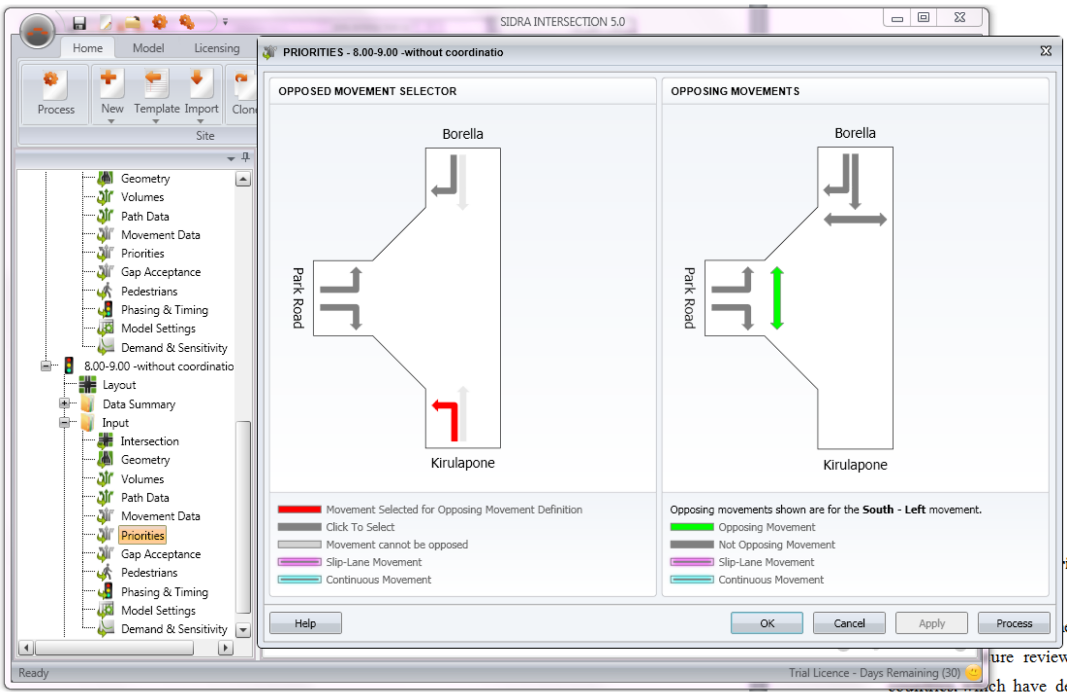


Figure 3-9: Opposing volume data input for Park road junction

Pedestrian volume, speed, queue spacing data were provided for the model as below.

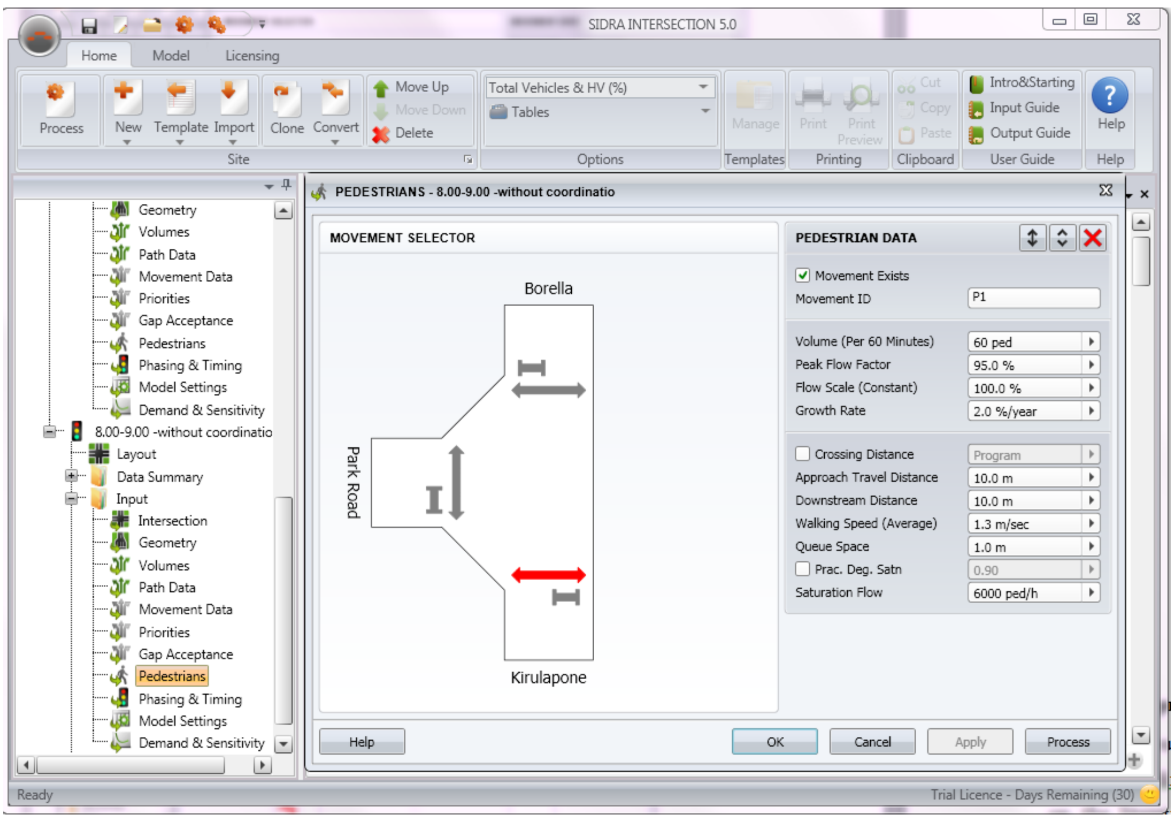


Figure 3-10: Pedestrian data input for Park road junction

Phasing arrangement was given as below.

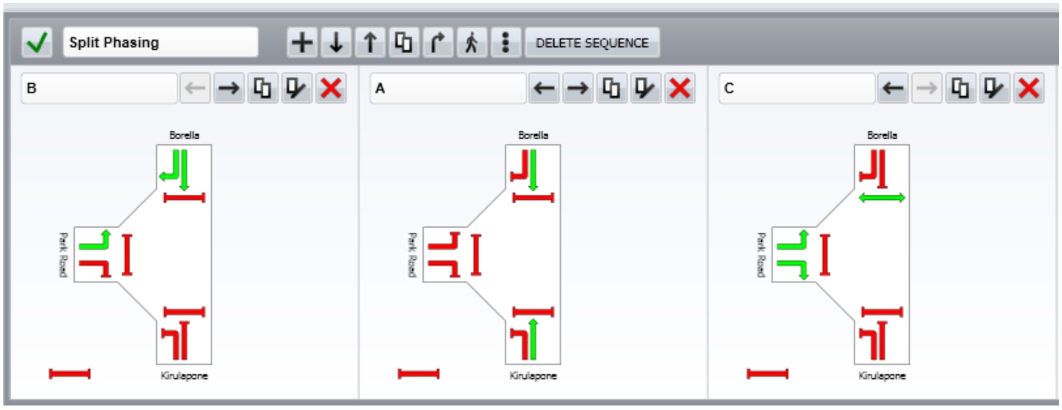


Figure 3-11: Phasing arrangement input for Park Road junction

A detailed output is given from the software after processing. The output includes phasing and timing information, movement capacity and performances, fuel consumption, emission and cost, lane performance, delays and queues, stops, flow rates and demand analysis.

The timing outputs given for the considered junctions are given below.

PHASING SUMMARY

Park Road Junction
Signals - Fixed Time   Cycle Time = 150 seconds (Practical Cycle Time)

Phase times determined by the program
Sequence: Split Phasing
Input Sequence: B, A, C
Output Sequence: B, A, C

Phase Timing Results

Phase	B	A	C
Green Time (sec)	67	35	33
Yellow Time (sec)	3	3	3
All-Red Time (sec)	2	2	2
Phase Time (sec)	72	40	38
Phase Split	48 %	27 %	25 %

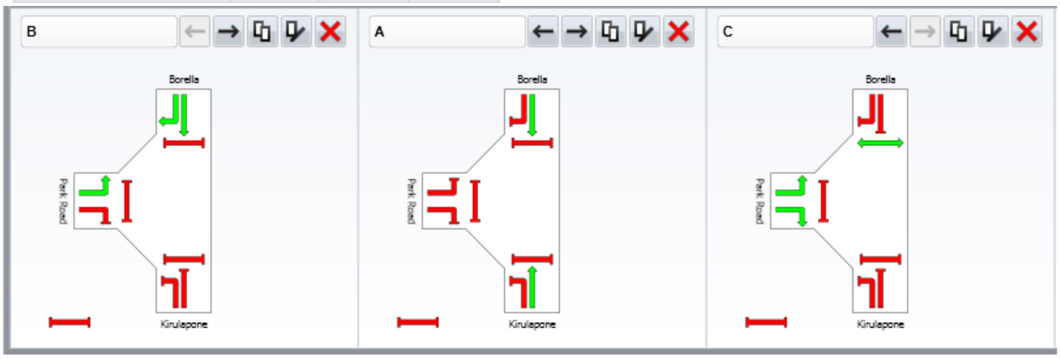


Figure 3-12: Timing Output for Park road junction

PHASING SUMMARY

Narahenpita Junction
Signals - Fixed Time   Cycle Time = 150 seconds (Practical Cycle Time)

Phase times determined by the program
Sequence: Split Phasing
Input Sequence: B, A, C, D
Output Sequence: B, A, C, D

Figure 3-13: Timing output for Narahenpita junction

PHASING SUMMARY

New Site
Signals - Fixed Time   Cycle Time = 150 seconds (Practical Cycle Time)

Phase times determined by the program
Sequence: Split Phasing
Input Sequence: A, B, C
Output Sequence: A, B, C

Phase Timing Results

Phase	A	B	C
Green Time (sec)	62	37	36
Yellow Time (sec)	3	3	3
All-Red Time (sec)	2	2	2
Phase Time (sec)	67	42	41
Phase Split	45 %	28 %	27 %

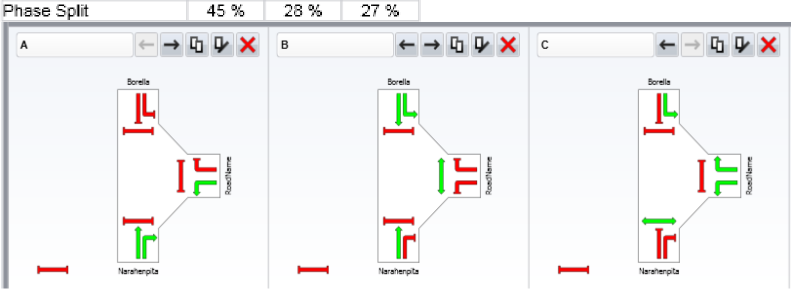


Figure 3-1: Timing output for Kirimandala junction

According to the output from SIDRA software, the cycle time was given as 150s for all junctions.

3.5.2 Manual Calculation

According to the MUTCD-part 4 Highway Traffic Signals, 2003 signal timing calculations were carried out for the above junctions manually. According to the calculation, all three junctions are in saturated condition at peak period. (Summery of the calculation is given below in table).Therefore maximum cycle time need to be used for all junctions at peak period.

At off peak, cycle time for Park Road junction is 115s and other two junctions are saturated. Therefore maximum cycle time need to be used.

According to the traffic flow variation, almost all the time Narahenpita Junction was at Saturated condition.

Summary of the Manual Calculation-8 to 9 am (peak period)

Table 3-1-Summery of manual Calculations-8 to 9am

Junction	TCL	Cycle Time
Park Road Junction	2228	Maximum cycle time(since TCL> saturation flow)
Narahenpita Junction	2425	Maximum cycle time
Kirimandala Junction	2402	Maximum cycle time

Table 3-2 Summery of manual Calculations-off peak

Junction	TCL	Cycle Time
Park Road Junction	1592	115s(using 2200 as saturation flow)
Narahenpita Junction	2033	Maximum cycle time
Kirimandala Junction	2271	Maximum cycle time

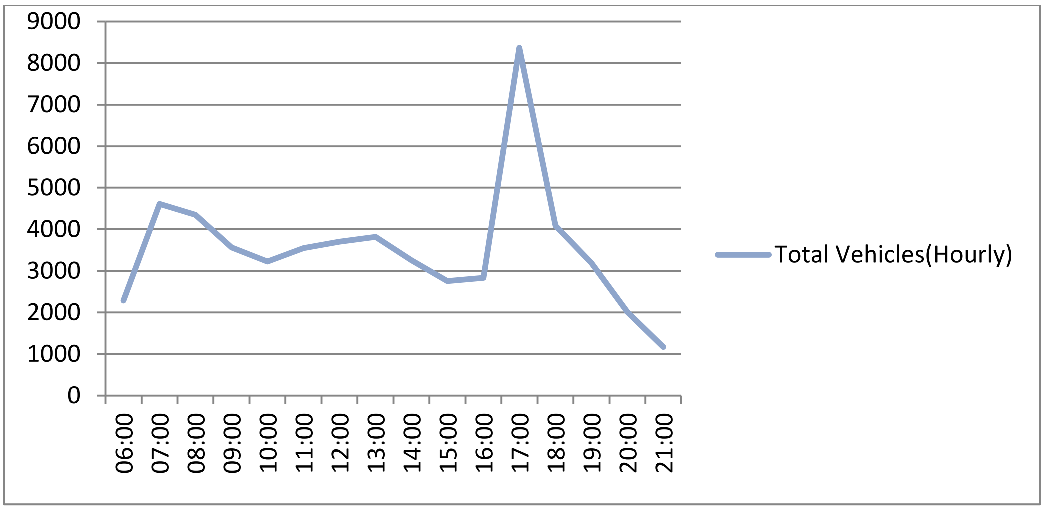


Figure 3-15: Hourly Traffic Variation at Park Road Junction-all directions

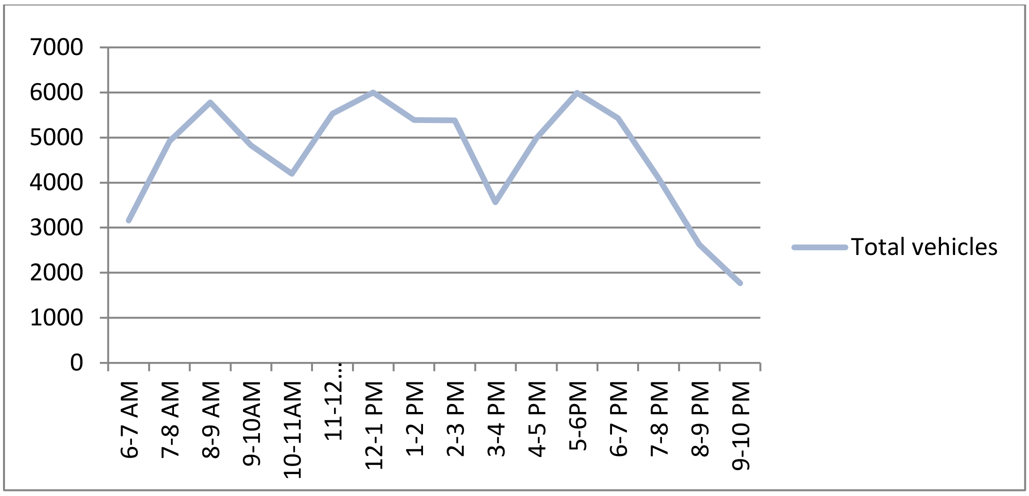


Figure 3-162 Hourly Traffic Variation of Narahenpita Junction-all directions

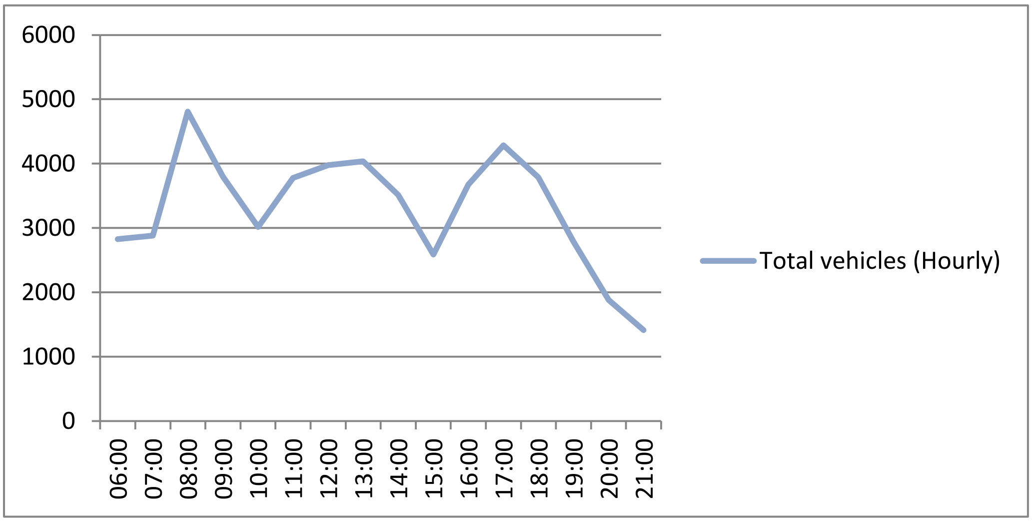


Figure 3-17 Hourly Traffic variation of Kirimandala Mawatha Junction-all directions

3.6 Calculation of Offset Time

time is the time that the green phase at an intersection begins after the beginning of green of the major control intersection or the reference signal.

Calculation of offset times for signal coordination for the selected junctions was carried out using Traffic Signals: Capacity and Timing Analysis by (R.Akcelik).

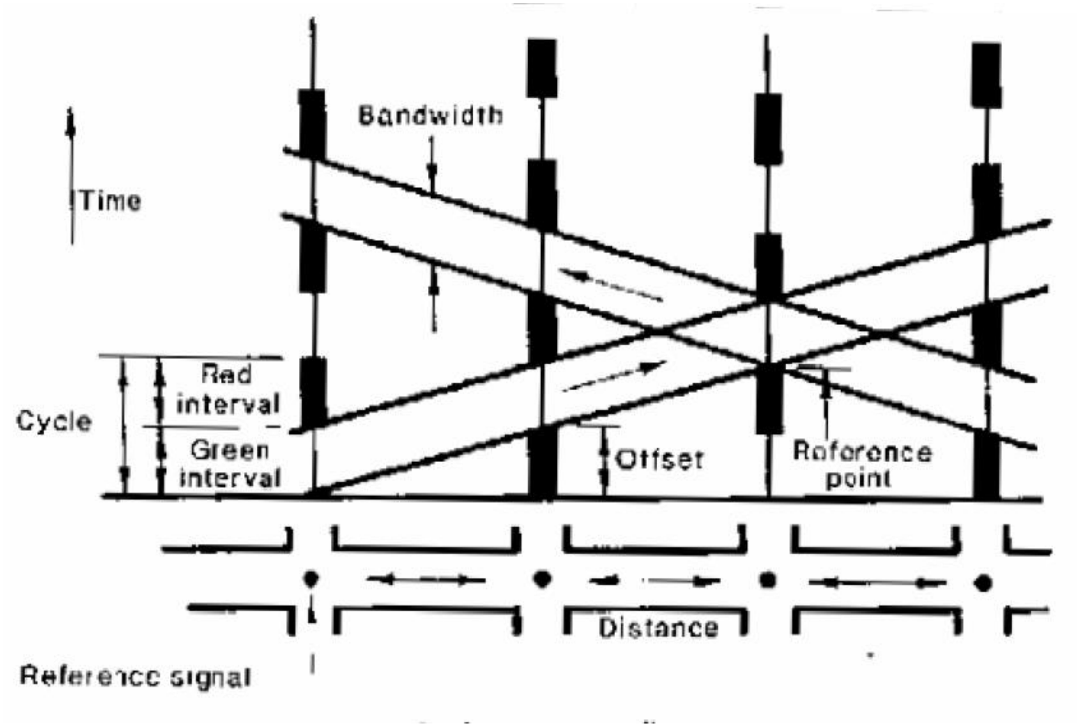


Figure 3-18: Green wave concept in signal coordination

The Offset, which is the difference between the starting times of the upstream and downstream green periods, which provides a reasonable progression for a platoon of vehicles can be calculated from

$$O=Tc+(Gu-Gd)/2$$

Where Tc is average cruising (uninterrupted travel) time and gu,gd are the upstream and downstream green times(all parameters are in seconds)

Distance from Park road Junction to Narahenpita Junction (l) = 360m

From observations,

Average platoon Speed (v) =30km/h

Average cruising time Tc =3.6x distance/speed

=3.6*360/30

=43.2 s

Offset(O)-

O =Tc+(Gu-Gd)/2

Tc-Average cruising time

Gu, Gd-Upstream and downstream green periods

therefore

$$\text{Offset O} = 43.2+(67-50)/2$$

$$= 51.7 \text{ s}$$

Therefore Green period of Narahenpita Junction must start 51.7s after starting the green period of park Road junction

According to the same calculation procedure, offset time in between Narahenpita junction to Kirimandala Junction is calculated as 18s.

These offset time values were used in modeling the coordinated system using VISSIM software.

3.7 Modeling the System Using VISSIM Software

PTV VISSIM Software was used to model the coordinated traffic light system. Road network at selected junctions were drawn and vehicle composition, vehicle volumes taken from the traffic count and average speed determined by observation were inputted.

The road network built using the software is shown below.

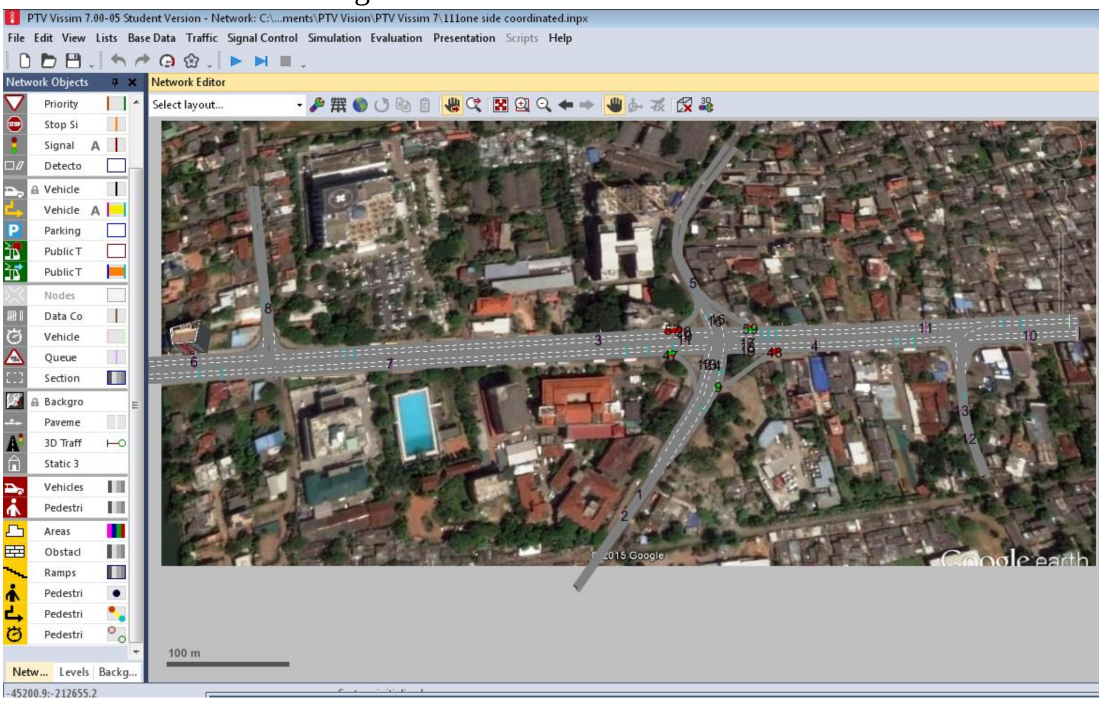


Figure 3-3:Modeled road network in VISSIM interface

Vehicle routes were defined to account for turning movements and relative flow values were given for each turning movement. Signals were added to the network. Following coordination strategies were modeled using the built network.

1. Single direction coordination (main Traffic flow direction)

2. Coordinating the both direction (main traffic flow direction and opposite direction)

3. Coordination using equal cycle times for all junctions

4. Coordination using multiples of cycle times

3.7.1 Single direction coordination (main traffic flow direction)

At morning peak hours main traffic flow direction is from Kirulapone to Borella.(north bound traffic)

Traffic signals were coordinated by changing the offset times to above calculated values (according to the figure 3-17)And using the cycle time as 150s for all junctions in the direction from Kirulapona to Borella. (Using the result from SIDRA intersection software).Delay and stop rate outputs were taken after running the VISSIM model. (Results are shown in figure 4-1 and 4-2)

3.7.2 Coordinating the both direction (main traffic flow direction and opposite direction)

At morning peak hour, traffic signals were coordinated in main traffic flow direction and opposite direction by adjusting the green period of the relevant direction using the offset values calculated above. Delay and stop rate values were taken from the VISSIM output.

3.7.3 Coordination Using Equal Cycle Times/Multiple cycle times

The above stated coordination strategies were modeled using the same cycle time (150s) for all three junctions and also using multiple cycle times (75s for Park Road Junction and 150s for other three junctions) and the delay and stop rate values were taken. Cycle times were selected this way because park road junction has a less traffic volume compared other two junctions.

The above coordination strategies were modeled for afternoon peak also.

3.8 Finding the Most Suitable Cycle Time

According to the manual calculations and SIDRA results, two of the considered junctions are in saturated condition. For finding the best suitable cycle time for the system, at first Narahenpita Junction was considered. Because it is the most congested junction with regarding to the traffic flow.

At first Narahenpita junction was modeled using 120s as the cycle time. For this condition delay and queue length values were taken using the VISSIM model. After that cycle time for that junction was increased in increments of 5s and variation of the total delay was observed to select a most suitable cycle time. (summery of the results are shown in table 4-1)

After finding the best suitable cycle time for Narahenpita Junction, that value was used to model the coordinated network and delay and queue length values were checked and compared with the previous values.(Results are shown in chapter 4)

Cycle time for coordinated network was changed from 115s to 150s in 5s increments and delay and queue length values were taken for each situation. The results were plotted against the cycle time and optimum cycle time which is giving the minimum delay and queue length was selected from the graph.(results are shown in table 4-2)

This procedure was repeated for the morning peak, evening peak and off peak periods for finding the best suitable cycle time for optimizing the coordinated signal network at each time of the day.

3.9 Comparison of Delay

Optimized cycle times for individual junctions were found with respect to delay. For this purpose, cycle time was changed in 5s increments and delay outputs observed to find the cycle time which gives the minimum delay output. This cycle time was selected as the optimum cycle time. This procedure was repeated for each junction to find the optimum cycle times of each junction.

Delay output values of individually optimized junctions were compared with delay of the coordinated optimized network. This comparison helped to find out the most advantageous optimization method.

4 RESULTS AND DISCUSSION

This chapter includes the simulation results obtained by VISSIM software model. The results are used to identify the benefits/drawbacks of coordinated network compared to individual operation of the signalized junctions. In addition, these results are used to develop a guideline to optimize the signal coordination within Sri Lankan signalized junctions (discussed in section 5.5).

4.1 Benefits/Drawbacks of Single Direction Coordination

By signal coordination in major street in the direction where traffic flow is high with 150s cycle time, following figures show the total delay and queue length results.

Delay Results

Select layout... <Single List>

Count: 108	SimRun	TimeInt	DelayMeasurement	StopDelay(All)	Stops(All)	VehDelay(All)	Vehs(All)	PersDelay(All)	Pers(All)
1	1	0-600	1: Borella direction	175.12	3.55	225.78	22	225.78	22
2	1	0-600	2: Kirulapona direction	59.37	1.51	82.09	105	82.09	105
3	1	0-600	3	79.42	1.87	106.98	127	106.98	127
4	1	600-1200	1: Borella direction						
5	1	600-1200	2: Kirulapona direction						

Figure 4-1: Delay Result-Coordination towards Borella Direction-Morning Peak

Queue Results

Select layout... <Single List>

Count: 216	SimRun	TimeInt	QueueCounter	QLen	QLenMax	QStops
1	1	0-600	3: At Parkrd Jun	76.33	102.73	323
2	1	0-600	4: At NArahenpita Jn	14.29	45.46	64
3	1	0-600	5: At KiriM Jn	7.69	37.68	47
4	1	0-600	6	67.69	162.45	228
5	1	0-600	7	149.76	278.15	350

Figure 4-2: Queue length Result-Coordination towards Borella Direction-Morning Peak

Following tables shows the delays at each junction for the above situation without coordinating the signals.

Delay Results

Select layout... <Single List>

Count: 18	SimRun	TimeInt	DelayMeasurement	StopDelay(All)	Stops(All)	VehDelay(All)	Vehs(All)	PersDelay(All)	Pers(All)
1	1	0-600	1: Borella direction	190.76	3.24	232.15	25	232.15	25
2	1	0-600	2: Kirulapona direction	132.79	2.98	166.29	86	166.29	86
3	1	0-600	3	145.85	3.04	181.12	111	181.12	111
4	1	600-1200	1: Borella direction						
5	1	600-1200	2: Kirulapona direction						

Figure 4-3: Delay Result-Without Coordination-Morning Peak

Queue Results

Select layout... <Single List>

Count: 36	SimRun	TimeInt	QueueCounter	QLen	QLenMax	QStops
1	1	0-600	3: at park rd jn	75.23	102.70	344
2	1	0-600	4: at Narahenpita Jn	39.34	88.41	138
3	1	0-600	5: At KiriM JN	29.58	114.52	148
4	1	0-600	6	57.40	151.02	195
5	1	0-600	7	148.35	278.09	337
6	1	0-600	8	53.16	88.62	165

Figure 4-4:Queue Length Result-Without Coordination-Morning Peak

According to the above results, delay has reduced by 5% and queue length has reduced by 31% by coordinating the signals.

4.2 Coordinating the both direction (main traffic flow direction and opposite direction)

By signal coordination in Major Street in both directions, following table shows the total delay results for major street traffic. (Baseline Road)

Delay Results

Select layout... <Single List>

Count: 18	SimRun	TimeInt	DelayMeasurement	StopDelay(All)	Stops(All)	VehDelay(All)	Vehs(All)	PersDelay(All)	Pers(All)
1	1	0-600	1: nort	142.68	2.72	179.86	29	179.86	29
2	1	0-600	2: south	44.28	1.27	63.89	103	63.89	103
3	1	0-600	3	65.89	1.59	89.37	132	89.37	132
4	1	600-1200	1: nort						
5	1	600-1200	2: south						

Figure 4-5Delay Result-both direction coordination Coordination-Morning Peak

Queue Results

Count: 36	SimRun	TimeInt	QueueCounter	QLen	QLenMax	QStops
1	1	0-600	3: At Parkrd Jun	69.86	97.36	30
2	1	0-600	4: At NArahenpita Jn	8.29	43.78	5
3	1	0-600	5: At KiriM Jn	6.86	36.70	4
4	1	0-600	6	70.65	180.19	30
5	1	0-600	7	150.45	277.66	37
6	1	0-600	8	56.13	83.23	17

Figure 4-6: Queue length Result-Both direction coordination-Morning Peak

According to the above results, delay has reduced by 20% and queue length has reduced by 13% by both side coordination, compared to single direction coordination.

4.3 Coordination using equal cycle times for all junctions

By signal coordination using equal cycle times(150s) all three junctions, following table shows the total delay results for major street traffic. (Baseline Road)

Delay Results

Count: 108	SimRun	TimeInt	DelayMeasurement	StopDelay(All)	Stops(All)	VehDelay(All)	Vehs(All)	PersDelay(All)	Pers(All)
1	1	0-600	1: Borella direction	175.12	3.55	225.78	22	225.78	22
2	1	0-600	2: Kirulapona direction	59.37	1.51	82.09	105	82.09	105
3	1	0-600	3	79.42	1.87	106.98	127	106.98	127
4	1	600-1200	1: Borella direction						
5	1	600-1200	2: Kirulapona direction						

Figure 4-7: Delay Result-Coordination using equal cycle times-Morning Peak

Queue Results

Count: 36	SimRun	TimeInt	QueueCounter	QLen	QLenMax	QStops
1	1	0-600	3: at park rd jn	75.23	102.70	344
2	1	0-600	4: at Narahenpita Jn	39.34	88.41	138
3	1	0-600	5: At KiriM JN	29.58	114.52	148

Figure 4-8: Queue length Result-Coordination using equal cycle times-Morning Peak

4.4 Coordination Using Multiples of cycle Times

Since considered junctions are close to saturated condition and the cycle times do not differ much from one another, using half or double of the cycle time of one junction as the cycle time for other junctions (multiple cycle times) is not suitable for the selected network.

4.5 Selection of the Proper Cycle Length

The natural cycle length for each intersection within the considered corridor may vary greatly, so choosing a proper cycle length may have great impact on the performance of the coordinated signal system. A shorter cycle length may result in poor progression while a longer cycle length may result in queue blockage problems.

4.6 Variation of Delay with respect to Cycle time-Narahenpita Junction

Following table and chart show the variation of delay with respect to cycle time at morning peak for Narahenpita Junction (taken from VISSIM output).

Table 4-1: variation of delay with cycle time in Narahenpita Junction

Time of the day	Cycle time(s)	Delay(s)
8 to 9 am	115	96.57
	120	96.04
	125	101
	130	100.9
	135	114.39

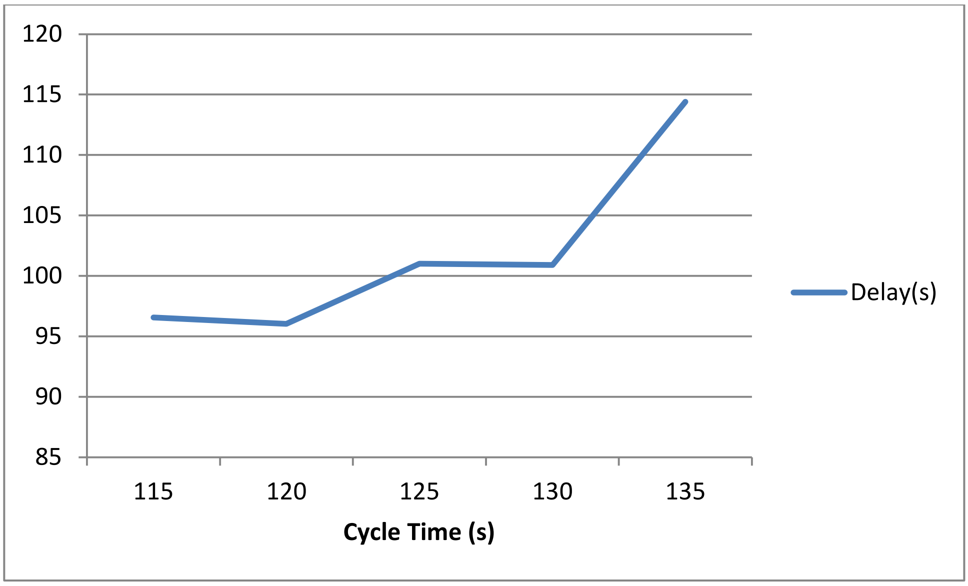


Figure 4-9: variation of Delay with respect to cycle time-Narahenpita junction

According to the above results, delay values are minimum at 120s. Therefore 120s can be considered as the optimum cycle time for Narahenpita Junction at morning peak.

4.7 Variation of Delay with respect to cycle time of Coordinated Network at Morning Peak

Following table and chart show the variation of delay and queue length (taken from VISSIM output) with respect to cycle time at morning peak for coordinated network.

Table 4-2: variation of delay and queue length of coordinated network at morning peak

Time of the day	Cycle time(s)	Delay(s)	Queue Length(m)
8 to 9 am	115	201.15	98.42
	120	248.99	113.43
	125	203.05	113.24
	130	162.88	99.8
	135	224.46	103.89
	140	202.13	99.65
	145	242.89	98.73
	150	225.78	98.31

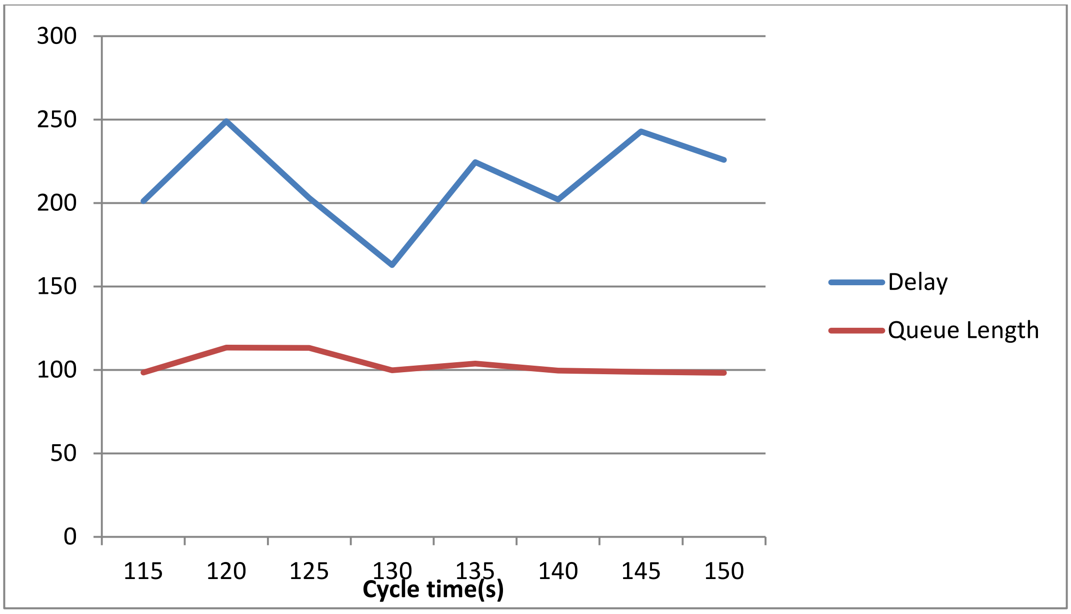


Figure 4-10: variation of delay and queue length of coordinated network at morning peak

According to the above results, delay and queue length values are minimum at 130s. Therefore 130s can be considered as the optimum cycle time for coordinated system at morning peak

4.8 Variation of Delay with respect to cycle time of coordinated network at Evening Peak

Following table and chart show the variation of delay and queue length (taken from VISSIM output) with respect to cycle time at evening peak for coordinated network.

Table 4-3:Variation of delay and queue length of coordinated network at evening peak

Time of the day	Cycle time	Delay	Queue Length
5 to 6 pm	**115**	187.4	55.02
	120	**217.37**	**54.16**
	125	**149.17**	**58.88**
	130	134.2	71.3
	135	129.57	58.50
	140	147.32	59.93
	145	**119.79**	**60.87**
	150	**180.4**	**74.75**

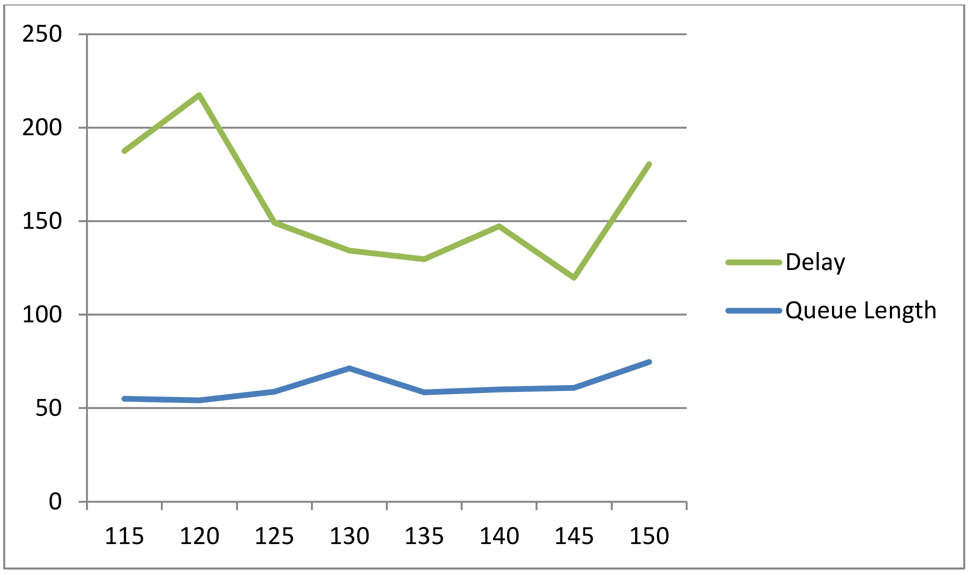


Figure 4-11:variation of delay and queue length of coordinated network at evening peak

According to the above results, delay and queue length values are minimized at 135s and at 145s. 145s was selected as the optimum cycle time for coordinated system at evening peak.

4.9 Variation of Delay with respect to Cycle Time of Coordinated Network at Off-Peak

Following table and chart show the variation of delay and queue length (taken from VISSIM output) with respect to cycle time at off peak for coordinated network.

Table 4-4: variation of delay and queue length of coordinated network at off peak

Time of the day	Cycle time(s)	Delay(s)	Queue Length(m)
10 to 11 am	**115**	**112.56**	**100.82**
	120	**248.99**	**113.43**
	125	**116.46**	**43.4**
	130	121.35	40.52
	135	176.99	40.77
	140	175.93	44.95
	145	**172.64**	**43.52**
	150	**157.04**	**44.66**

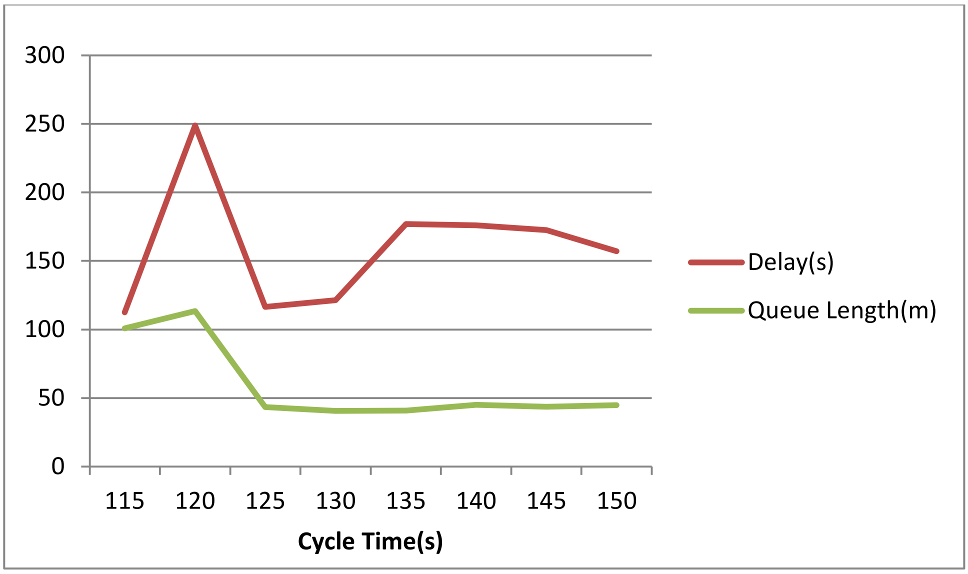


Figure 4-12: variation of delay and queue length of coordinated network at off peak

According to the above results, delay and queue length values are minimum at 125s. Therefore 125s can be considered as the optimum cycle time for coordinated system at off peak.

4.10 Delay comparison Results

4.10.1 Variation of Delay with respect to Cycle Time-Park Road Junction

Following table and chart show the variation of delay with respect to cycle time at morning peak for Park Road Junction (taken from VISSIM output).

Table 4-53: variation of delay with cycle time in Park Road Junction

Time of the day	Cycle time	Delay
8 to 9 am	**100**	**110.95**
	105	96
	110	95.6
	115	89.32
	120	98.5
	125	110
	130	120.7

According to the above table, minimum delay occurs when the cycle time is 115s. Therefore optimum cycle time for park road junction can be considered as 115s.

4.10.2 Variation of Delay with respect to Cycle time- Narahenpita Junction

Following table and chart show the variation of delay with respect to cycle time at morning peak for Narahenpita Junction (taken from VISSIM output).

Table 4-64: variation of delay with cycle time in Narahenpita Junction

Time of the day	Cycle time(s)	Delay(s)
8 to 9 am	115	96.57
	120	96.04
	125	101
	130	100.9
	135	114.39

According to the above table, minimum delay occurs when the cycle time is 120s. Therefore optimum cycle time for Narahenpita junction can be considered as 120s.

4.10.3 Variation of Delay with respect to Cycle time-Kirimandala Mawatha Junction

Following table and chart show the variation of delay with respect to cycle time at morning peak for Kiriamandala Mawatha Junction (taken from VISSIM output).

Table 4-75: variation of delay with cycle time in Kirimandala Mawatha Junction

Time of the day	Cycle time	Delay
8 to 9 am	100	142.2
	105	120
	110	106.8
	115	102
	120	98.5
	125	100.8
	130	118.5

According to the above table, minimum delay occurs when the cycle time is 120s. Therefore optimum cycle time for Kirimandala Mawatha junction can be considered as 120s.

According to the above table 4-2, minimum delay at optimum cycle time is 162.88s for morning peak. If the junctions are individually optimized using above selected optimum cycle times, total delay at all three junctions would be 283.86s. It is considerably larger than coordinated optimized system delay. As such, optimized signal coordination is much advantageous than optimization at individual junctions.

5 Conclusions and Recommendations

5.1 Benefits and Drawbacks of Signal Coordination

Although signal coordination achieves significant benefits, there are some negative impacts. Traffic flow and delays must be balanced throughout the system. Therefore there should always be a compromise between those.

Signal coordination requires that each intersection have the same cycle length or be multiples of the same cycle length. Usually, few critical intersections require a particular cycle length to accommodate the traffic and pedestrian demands, while others within the system must be operated accordingly to allow coordination. This can sometimes result in a longer wait at certain locations, than expected.

A main objective of signal coordination is to efficiently move the majority of vehicles through the system with fewer stops and reduced travel time. In traffic signal coordination, the busiest traffic movements are given priority over the smaller traffic movements. This means that side street traffic often experiences a slightly longer wait time. However, once on the main street, motorists generally experience better flowing traffic conditions.

5.2 Recommendations for Coordination of Traffic Signals in Sri Lanka

Signal coordination results in reduction in delay and queue length of major street traffic flow. However, it is disadvantageous for the traffic from minor roads (by roads).Therefore this should be taken into consideration in future coordination projects. Sometimes according to the site condition, there may be situations where the traffic flow from minor road should be given precedence. (Roads leading to a major hospital etc). In such situations, signal coordination is not advisable to implement.

According to the results of the analysis, coordination in both direction of major road is advantageous to the traffic flow regarding delay and travel time compared to coordination in single direction. Therefore, it is advisable to coordinate the signals in both direction of the major street whenever possible.

During future coordination projects if the traffic volume permits, using multiples of cycle times can be advantageous to ease the traffic congestion since it allows more number of traffic to pass through the network.

Selecting the best suitable cycle time for the coordinated network is an effective optimizing strategy for a coordinated network. It contributes in reducing delay and queue length in a considerable amount. This is done by simulating the road network with junctions by varying the cycle time and comparing the outputs. (delay and queue length). First an approximate cycle time to begin with need to be found. This can be found by manual calculation of cycle time for the each junction. It is the best to use a guideline prepared for Sri Lankan context for manually calculating the cycle times for junctions in Sri Lanka. Otherwise MUTCD (2003) guideline can be used for this purpose.

Then the junction which requires the maximum cycle time need to be selected. It is the critical junction of the considered set of junctions. Optimum cycle time for that junction can be found by varying the cycle time in 5s increments/decrements around the calculated value and comparing the delay and queue length results. After that, all considered junctions should be modeled as coordinated network using the above selected cycle time for all junctions or in multiples of the same.

To find the optimum cycle time for the coordinated junction network, the cycle time of the network need to be varied in small increments or decrements around the above selected value and the results need to be compared for each cycle time.

The cycle time which gives the minimum delay and queue length can be selected as the optimum cycle time for coordination of considered set of junctions. This need to be repeated for morning peak, evening peak and off peak period.

Individual optimization and coordinated optimization can be compared with respect to delay and most suitable strategy can be selected.

The above stated methodology will give better results in implementing signal coordination in Sri Lankan signalized junctions and will contribute to optimize the same.

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