11-2015

A Two-Stage Fuzzy Logic Model for Urban Traffic Signal Control and Management.

Nada Bakri AlNaser

UAEU

جامعة الإمارات العربيــة المتحدة
United Arab Emirates University

United Arab Emirates University

College of Engineering

Department of Civil and Environmental Engineering

A TWO-STAGE FUZZY LOGIC MODEL FOR URBAN TRAFFIC SIGNAL CONTROL AND MANAGEMENT

Nada Bakri AlNaser

This thesis is submitted in partial fulfilment of the requirements for the degree of Master of Science in Civil Engineering

Under the Supervision of Professor Yaser Hawas

November 2015

Declaration of Original Work

I, Nada Bakri AlNaser, the undersigned, a graduate student at the United Arab Emirates University (UAEU), and the author of this thesis entitled "*A Two-Stage Fuzzy Logic Model for Urban Traffic Signal Control and Management*", hereby, solemnly declare that this thesis is my own original research work that has been done and prepared by me under the supervision of Professor Yaser Hawas, in the College of Engineering at UAEU. This work has not previously been presented or published, or formed the basis for the award of any academic degree, diploma or a similar title at this or any other university. Any materials borrowed from other sources (whether published or unpublished) and relied upon or included in my thesis have been properly cited and acknowledged in accordance with appropriate academic conventions. I further declare that there is no potential conflict of interest with respect to the research, data collection, authorship, presentation and/or publication of this thesis.

Student's Signature: ________________ Date: 15/12/2015

Advisory Committee

1) Advisor: Professor Yaser Hawas

Title: Professor, Department of Civil and Environmental Engineering

Director of Roadway, Transportation and Traffic Safety Research Center

Department of Civil and Environmental Engineering

College of Engineering

2) Co-advisor: Dr. Moza Tahnoon Al Nahyan

Title: Adjunct Assistant Professor

Department of Management

College of Business Administration

Institution: Abu Dhabi University

Approval of the Master Thesis

This Master Thesis is approved by the following Examining Committee Members:

1) Advisor (Committee Chair): Professor Yaser Hawas
   Title: Professor, Director of Roadway, Transportation and Traffic Safety Research Center.
   Department of Civil and Environmental Engineering.
   College of Engineering.

   Signature Yaser Hawas Date 29/11/2015

2) Co-advisor: Dr. Moza Tahnoon Al Nahyan.
   Title: Ph.D., Adjunct Assistant Professor.
   Department of Management.
   College of Business Administration.
   Institution: Abu Dhabi University.

   Signature Moza Bint Tahnoon Date 29/11/2015

3) Member: Dr. Kamran Ahmed.
   Title: Assistant Professor.
   Department of Civil and Environmental Engineering.
   College of Engineering

   Signature Kamran Ahmed Date 29/11/2015

4) For Member (External Examiner): Professor Peter G Furth
   Title: Professor
   Department of Civil and Environmental Engineering.
   Institution: Northeastern University

   Signature ______________ Date 29/11/2015

This Master Thesis is accepted by:

Dean of the College of Engineering: Professor Mohsen Sherif.

Signature Mohsen Sherif Date 15/12/2015

Dean of the College of the Graduate Studies: Professor Nagi T. Wakim

Signature Nagi Wakim Date 17/1/2016

Copy 13 of 14

Abstract

Different traffic signal control systems are applied nowadays. They vary in complexity and approach but mostly aim at improving the intersection level of service and the efficiency of the traffic network. Fuzzy Logic Models (FLM) have been widely regarded as quite appealing for real-time applications, in addition to their explicit considerations for stochasticities or uncertainties of traffic measures. The majority of the FLMs for signal control were developed to handle isolated intersections in specific. Very few of these FLM systems explicitly account for neighbor intersections' traffic impact on the decisions to be made at the underlying intersections.

The aim of this research is to develop a fuzzy logic control system for real time signal control that accounts for various traffic conditions. The system is envisaged to demonstrate signal control settings close to those developed by optimization methodologies.

The literature review highlighted the structure of the existing FLMs for traffic signal control, input and output parameters and testing. The simulation environment (SYNCHRO) was utilized to model and design the traffic signals of an isolated intersection using 289 different traffic configurations and traffic volumes. The cases were carefully selected to cover the domain of different levels of service along the competing approaches. A FLM was developed and calibrated to estimate the cycle time, the green times of the intersection (as an isolated intersection) taking into consideration the traffic congestion status at the downstream side of the intersection.

The model was calibrated to emulate the Highway Capacity Manual (HCM) method for optimal signal control. The general outcome was that the proposed FLM is effective in replicating "optimization" signal control procedures (SYNCHRO).

The devised FLM was thoroughly evaluated against the benchmark solutions of optimal cycle times, green times of the various phases. Further analysis was carried out to validate the devised FLM and to assess its effectiveness if deployed in conditions other than those conditions used model calibration.

The validation results indicated that the FLM is mostly effective for cases of *medium* or *high* downstream congestion and *medium to high* traffic flows.

Keywords: Fuzzy logic control, downstream congestion, signal setting, traffic flow, green time, optimum control setting.

Title and Abstract (in Arabic)

النموذج الضبابي ذو المرحلتين للتحكم في الإشارات الضوئية و إدارة المرور بالمدن

الملخص

تختلف أنظمة التحكم للإشارات المرورية في الوقت الحاضرمن حيث التعقيد والنهج، إلا أن غالبها يهدف إلى تحسين مستوى خدمة وكفاءة التقاطعات المرورية و شبكة المرور. وقد تم اعتبار نماذج المنطق الضبابي (FLM) من النماذج الجذابة جدا لتطبيقات الوقت الحقيقي على نطاق واسع، إضافةً إلى أنها تتخذ في اعتباراها العشوائية أو الشك في التدابير المتبعة لإجراءات المرور.

إن أغلبية نماذج المنطق الضبابي (FLMs) تم تطويرها للتحكم في التقاطعات المعزولة بشكل خاص. إلا أن هناك عدد قليل جدا من هذه الأنظمة) نماذج المنطق الضبابي (FLMs) تأخذ بعين الاعتبار تأثير التقاطعات المرورية المجاورة على القرارات الواجب اتخاذها عند التقاطعات الأساسية.

إن الهدف من هذا البحث هو تطوير نظام مراقبة للتحكم في الإشارات المرورية ذات الوقت الحقيقي باستخدام المنطق الضبابي و التي تأخذ بعين لاعتبار ظروف حركة المرور المختلفة. ومن المتوقع أن يُظهر هذا النظام إعدادات تحكم في إشارة المرور قريبة من تلك التي تم تطويرها باستخدام أفضل المنهجيات.

من خلال الدراسات السابقة فقد تم عرض الهياكل الحالية للنماذج الضبابية (FLMs) المتبعة للتحكم بإشارات المرور، بالاضافة إلى عناصر المدخلات والمخرجات والاختبارات التي تم عملها. وقد تم استخدام برنامج محاكاة البيئة (SYNCHRO) لنمذجة وتصميم إشارات المرور في التقاطعات المرورية المعزولة وذلك باستخدام 289 حالة مختلفة من الاشكال المرورية المختلفة ومختلف كثافة حركة المرور. وقد تم اختيار الحالات بعناية لتشمل مختلف مستويات الخدمة لمختلف النُهج والاتجاهات الأخرى. علاوة على ذلك، تم تصميم ومعايرة نموذج التصميم الضبابي FLM لتقدير الدورة الزمنية للإشارة المرورية وفترات الإشارة الخضراء للتقاطع المروري (كالتقاطعات المرورية المعزولة) مع الأخذ بعين الاعتبار وضع الاختناقات المرورية في الجانب التالي من التقاطع (المَصب). وقد تم معايرة النموذج ليحاكي النظريات المتَبعة في كتيب الطرق السريعة (HCM) للتحكم الأمثل لإشارات المرور. إن النتيجة العامة لهذا البحث

هي أن نموذج التحكم الضبابي المقترح (FLM) كان فعال في تكرار الإجراءات "المُثلى" للتحكم في إشارات المرور (SYNCHRO).

إضافة لذلك، فقد تم تقييم النموذج الضبابي FLM بصورة شاملة لمؤشرات الحلول القياسية المثلى للدورة الزمنية للإشارة المرورية و فترات الإشارة الخضراء لمختلف المراحل. بالإضافة إلى ذلك فقد تم إجراء مزيد من الاختبارات وتحليل النتائج للتحقق من صحة النموذج الضبابي المقترح (FLM) وتقييم فعاليته في حال تم تطبيقه في ظروف غير تلك الظروف التي تم استخدامها سابقا في مرحلة المعايرة.

أشارت نتائج اختبار البحث إلى أن النموذج الضبابي المقترح (FLM) كان فعال في الغالب لحالات متوسطة أو شديدة الازدحام عند التقاطع المجاور (المصب)، و ذات تدفق مروري متوسطة إلى عالية.

مفاهيم البحث الرئيسية: التحكم بواسطة المنطق ضبابي، الازدحام في التقاطع المجاور (المصب)، إعدادات إشارة المرور، تدفق حركة المرور، الوقت الأخضر، إعدادات التحكم الأمثل.

Acknowledgements

This research project would not have been possible without the support of many people.

I wish to express my love to my Father, Mother, and Husband for their endless support, through the duration of my studies

I also wish to express my gratitude to my Supervisor Prof. Yaser Hawas, and co-supervisor Dr. Moza Tahnoon Al Nahyan, who were abundantly helpful and offered invaluable assistance, support and guidance.

Dedication

To my beloved parents and family

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

1.1 Statement of the Problem

Different traffic signal control systems are applied nowadays. They vary in complexity and approach but mostly aim at improving the intersection level of service and the efficiency of the traffic network; mainly reducing both travel and delay times and relatively reducing the negative impact of the fuel consumption on the environment.

Among the most recent approaches applied for traffic management in general and signal control systems in particular are the artificial intelligence approaches as well as the logical systems that accounts for traffic measures uncertainties. Fuzzy Logic Models (FLM) have been widely used in this regard as they seem to be quite appealing for real-time applications, in addition to their explicit considerations for stochasticities or uncertainties of traffic measures. Such FLMs were mostly developed and calibrated based on either experts' opinions. This issue has been widely criticized in literature. To handle the limitations of the expert-based FLMs, researchers have utilized either data collection or simulation to investigate the input/output relations and as such develop the inference engines of the FLMs to emulate such relationships. Tools for system or control modeling based on data include the use of Genetic Algorithms or Neural Networks to train the system/control to function according to the extracted relationships from data.

The majority of the FLMs for signal control were developed to handle isolated intersections in specific. They explicitly account for the upstream conditions of the underlying intersections using few state variables (such as link flows or queues). Very few of these FLM systems explicitly account for neighbor intersections' traffic impact on the decisions to be made at the underlying intersections. In urban traffic networks, and with closely spaced intersections, ignoring such neighboring traffic impact may have significant implications on the effectiveness of the system and the overall network mobility. As an example, it is convincing to note that the traffic states on the downstream links of the intersection would certainly affect the downstream links' remaining capacities, which in turn would affect the total number of vehicles (or the discharge rate) that can be served from the upstream approaches. In case of full blockage of a link, the allocation of green time to an upstream phase that is fully blocked by such downstream link is certainly a waste of time and leads to unnecessary delays. Therefore, accounting for such neighboring intersections effect by the control system is rather essential in urban traffic networks.

As for the "closeness" of all the FLMs to optimal solutions or benchmarks of signal control, it is not really clear how these controllers perform as compared to "optimal" solutions. The majority of these FLMs were developed using intuitions or even training versus some simulation. It is not clear also whether these FLMs would perform favorably in all traffic conditions ranging from free flow to grid locks. Moreover, it is not clear how would they function in a network (not isolated intersection) type of control environment.

1.2 Aim and Objectives of the Research

The aim of this research is to develop a fuzzy logic control system for real time signal control that accounts for various traffic conditions. The system is envisaged to demonstrate signal control settings close to those developed by optimization methodologies.

The main objectives of this research are:

1. To develop a fuzzy logic model for a real time signal control based on optimization conditions, to estimate green time allocations among the competing phases. A simulation environment shall be used to develop various traffic conditions that would be used for the FLM calibration.
2. To develop the inference engine (logic) of the FLM from the simulation-based data covering various traffic conditions
3. To calibrate the proposed developed FLM and to test the closeness of its outputs to optimal signal control settings. The model will be calibrated to account for various network congestion conditions ranging from free flow to grid locks.
4. To account for the network effect, the FLM will be developed as a two-stage process. In the first phase, the FLM is designed to replicate optimal solutions for isolated intersections. In the second stage, the FLM will be developed to explicitly account for the traffic conditions on the downstream links. The "final" green times allocation to a phase will be based on the two stages of control.
5. To validate the developed FLM and assess its effectiveness if deployed in conditions other than those conditions used model calibration.

1.3 Study Approach

This study followed the standard quantitative research approach including the clear statement of the research objectives, literature review, simulation modeling, data extraction from simulation, FLM development and calibration, analyses of the FLM results, validation of the FLM, and finally overall conclusions, discussing model limitations and recommendations for future research.

Related books, articles, and papers were thoroughly and critically reviewed. The review highlighted the structure of the various FLMs, input and output parameters and testing.

The simulation environment (SYNCHRO) was utilized to model and design the traffic signals of an isolated intersection using about 289 different traffic configurations and traffic volumes. The cases were carefully selected to cover the domain of different levels of service along the competing approaches. A FLM was developed and calibrated to estimate the cycle time, the green times of the intersection (as an isolated intersection) taking into consideration the traffic congestion status at the downstream side of the intersection. The model was calibrated to emulate the Highway Capacity Manual (HCM) method for optimal signal control.

The devised FLM was thoroughly evaluated against the benchmark solutions of optimal cycle times, green times of the various phases. Further analysis was carried out to validate the devised FLM and to assess its effectiveness if deployed in conditions other than those conditions used model calibration. Figure 1.1.

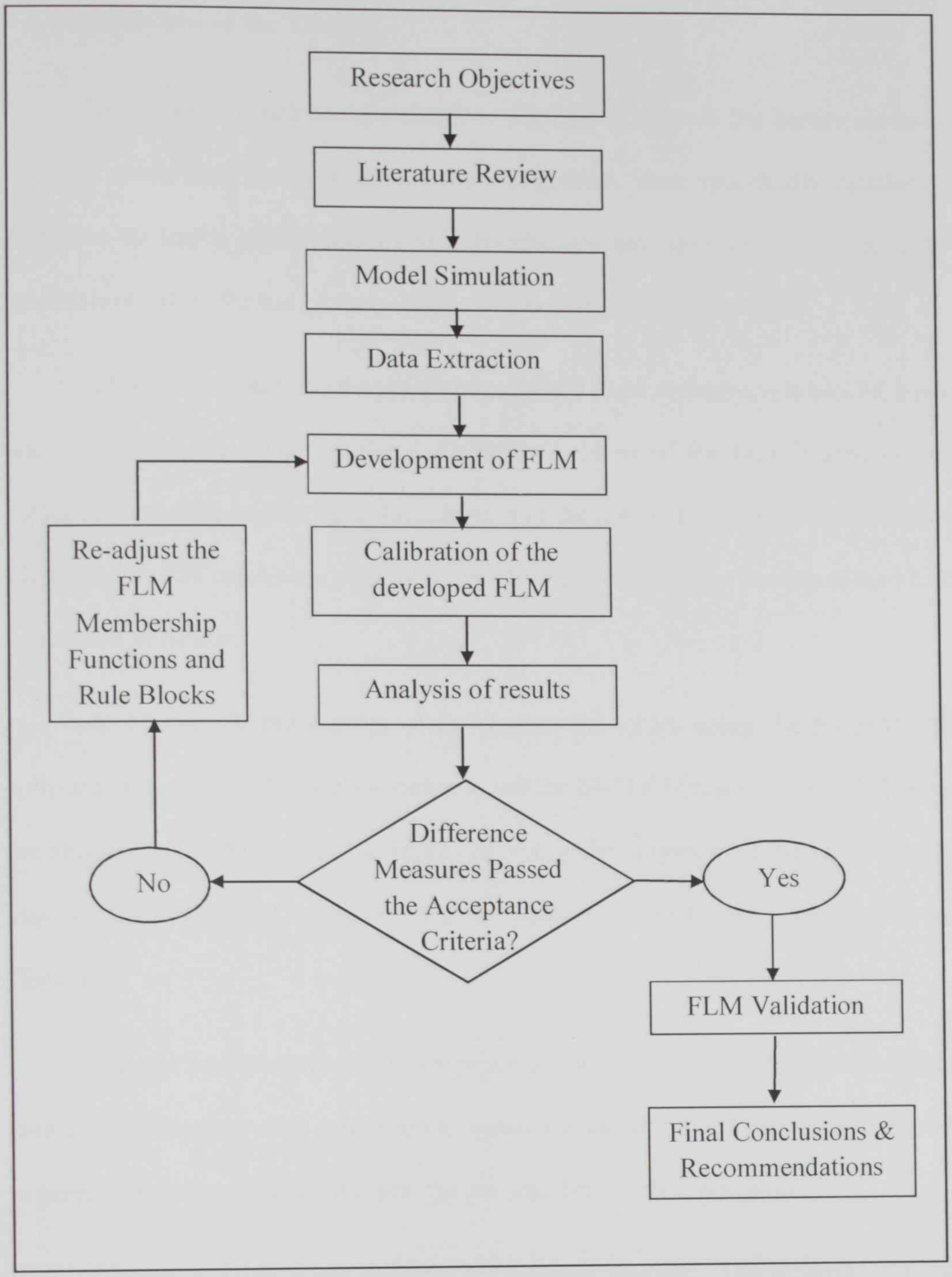


Figure 1.1: Flowchart of the study approach

1.4 Organization of the Thesis

This research includes six chapters. Chapter 2 reviews the earlier research attempts of relevance to traffic management in general. More specifically, articles of relevance to traffic signal control in particular are also reviewed. More specific emphasis is put on the use of fuzzy logic models in traffic signal control.

Chapter 3 presents the details of the proposed FLM structure, rule blocks, input and output variables. The chapter explains the process of the fuzzification of the various input variables and the defuzzification of the output decision variables. It also highlights the 289 cases simulated by SYNCHRO and explains the process of the FLM calibration in details.

In Chapter 4, the aspects of developing the FLM, using the FuzzyTECH software, are covered. The inputs, outputs, and the IF-THEN rules for the rule blocks are also discussed. Moreover, the results of testing the closeness of the FLM outputs vis-à-vis the SYNCHRO solutions and the calibration results are comprehensively discussed.

Chapter 5 presents the validation process of the proposed FLM for traffic signal control. Various tests were conducted to ensure the validity of the proposed FLM and to assess the extent to which it meets the purpose for which it was built.

Chapter 6 summarizes the primary research findings. The limitation of the research are pointed, and a list of recommendations for further investigations are also discussed.

Chapter 2: Literature Review

This chapter reviews the earlier research attempts of relevance to traffic management in general. More specifically, articles of relevance to traffic signal control in particular are also reviewed. More specific emphasis is put on the use of fuzzy logic models in traffic signal control.

2.1 Traffic Control and Management

The main purpose of traffic management is to enhance the movement of vehicles while increasing the safety and capacity of the offered systems and facilities (Ross, Prassas and Mcshane, 2004). Active traffic management refers to the management and control of traffic demand as well as different transportation facilities based on the application of different operations' strategies such as real time traffic control. Different applied traffic management strategies in Europe and U.S include speed harmonization and variable speed limits signs, queue warning, hard shoulder running and shoulder use for transit, junction control, road pricing, dynamic re-routing, and traveler information (U.S. DoT- FHA, 2010).

Wolshon and Taylor (1999) assessed one of the adaptive traffic signal control, Sydney Coordinated Adaptive Traffic System (SCATS), based on both intersection and approach delay times using a macroscopic simulator. A statistical analysis was conducted, for the obtained results of the simulation, for both intersection and approach total delay times. The main conclusions of this study were; 1) the intersection total delay time was higher with the use of SCATS control system, due to the concept of the SCATS that aims to uniformly distribute the green times among the approaches according to the saturation flows, instead of reducing the delay time of the intersection, and that 2) the delay time was reduced significantly using SCATS control in cases of low traffic flows more than cases of high flows.

Felici et al. (2006) presented a logic programming method for signal traffic control. A micro-simulator was used to assess the developed method. A rule-based logical program which incorporates the traffic information (mainly counts of traffic flows and queues on the approach) was developed. Experience of traffic engineering experts were coded in the form of the logical (If-Then) rules. Comparisons were conducted with other types of controllers such as fixed plan, and dynamic actuated control system. Two performance indicators were used in comparison: 1) detected traffic flow (using cameras or sensors), and 2) number of stops, travelling times and fuel consumptions on segments for some floating probe vehicles. Results indicated that this logical system performs quite well on segments of high traffic flows. At low traffic flow conditions, the actuated dynamic system showed better performance.

Cai, Wong and Heydecker (2009) discussed the use of approximate dynamic programming (ADP) for adaptive traffic signal control, and continuously revising settings for the detected in field parameters (traffic flow and estimated queue length). Numerical tests were conducted using simulator (MATLAB) for an isolated intersection of three sequence stages (three links: A, B, C). Numerical tests were conducted using both fixed plan (pre-timed traffic control) and the ADP for traffic control systems. Results show that the ADP can be used as a real time traffic controller and it has improved the traffic efficiency (it reduces the vehicle delay times).

Saini, Sodhi and Saini (2012) provides a methodology for priority distribution of the green phase based on congestion and the presence of ambulance and/or a VIP vehicles on traffic lanes. It mainly uses the RFID reader to detect vehicles. Green times are estimated taking into consideration the length of the lane, and the speed of vehicles. Congestion is identified when vehicles are not served within the expected time (to reach the downstream point), causing increase of queue. In the case of existing of an ambulance or VIP vehicle, the embedded RFID informs the system about a presence of such a vehicle. Priority levels are considered such that: 1) if two ambulances occur; then the priority will be given to the one closer to the intersection, 2) if an ambulance occur with the presence of a VIP vehicle; then the priority will be given to the ambulance first. Tests were conducted and results show that by using the presented approach, the rate of serving vehicles was increased, the waiting time of an ambulance as well as time difference for two ambulances occurred in two different lanes were reduced significantly.

Skabardonis and Geroliminis (2008) presented analytical model that uses the loop detector data to determine traffic flow and detector occupancy, in addition to the signal settings. This information was used to estimate the travel time as well as the delay time at the intersection. The extended model takes into consideration the delay resulted from long queues, and the queues spillover condition. Another type of model extension (transit signal priority model- TSP) was presented in the paper. By comparing the actual bus time (predicted from the data of automatic transit vehicle location, AVL), and the planned/scheduled bus times; a decision for applying the TSP model is made. In order to reduce the transit delay time, the proposed TSP model considers different parameters such as; cycle time, queue length, offset, and green times. A decision is made to account for the transit by one of the following options; phase insertion- an exclusive signal phase, phase extension- increasing the green phase till the transit is served, or advance phase- the green phase will start before the planned time. Once the transit gets served, the signal controller is reset back to the original mode. This paper considers the priority to transit based on the location of the bus from the intersection. It was important however to account for bus occupancy as well.

Prakash and Tiwari (2011) presented a traffic management scheme for that is based on the communication between the vehicle and a base station that is located at the intersection. The vehicle initially sets the destination of the trip, and once it started to move from the origin and gets close to the intersection, information will be sent to the base station informing. A cost function (of minimum travel time, and fuel consumption and gas emission) is used for route selection. A simulation test was conducted to assess the efficiency of the proposed method. Results indicate that the proposed approach can help reducing the average travel time. The input variables are limited to traffic counts. The methodology does not account for other important parameters such as average link speeds, composition of vehicles in traffic streams, etc. The proposed method can be applied only to GPS-equipped vehicles.

In brief, there are several methods for traffic management that can be used for traffic management. Among the most notable methods are the ones related to traffic intersection control. Such traffic signal control vary widely ranging from simple to complex systems that enable additional functions such as TSP and on-line routing. Logical systems based on experts' opinions were also found to be promising tools for traffic management and may actually outperform dynamic actuated systems. Among these known logical systems are the "fuzzy logic model" (FLM) – based ones. In the following section, the emphasis is put on the use of fuzzy logic models for traffic control and management purposes.

2.2 Fuzzy Logic Models (FLM) for Traffic Control

Traffic signal control and monitoring is among the most commonly known network traffic management schemes. The common types of the traffic signal control are the pre-timed, semi-actuated, and actuated. The application of new technologies mainly the intelligent transportation systems (ITS) had an essential role in the advancement of traffic monitoring and control, especially traffic signal control. Sydney Coordinated Adaptive Traffic System (SCATS), Split Cycle and Offset Optimization Technique (SCOOT), and Fuzzy Signal Control (FUSICO) are among the advanced new traffic signal control systems. Such systems are designed to provide network wide control and as such they are more/or less depend on some optimization logic. Based on the size of the controlled network, huge data inputs may be needed to control the various intersections. Such excessive data needs and corresponding processing times are among the main challenges for online system deployment and real time control. Such excessive data inputs are commonly accompanied with errors and that consequently raises questions on the true effectiveness of such network-wide control systems. Herein, a research question is raised on whether simplified local decentralized logical controllers can be designed to replace the excessive data and time consuming network controllers.

Fuzzy logic modeling is a technique that can be used to model or to control complex systems exhibiting uncertainties in its input/output variables or parameters and decision making. The essence of the FLM is converting the numerical variables into linguistic terms and vice versa (Fuzzification and Defuzzification processes). The principles of the fuzzy logic were initially presented by Lotfi Zadeh in 1965. The introduction of membership functions was proposed as the basis of decision making for uncertainties in variables/information (Ross, 2004).

Teodorovic (1999) presented the basics of FLM and its applications in transportation engineering including; planning and traffic controlling models, incidents analysis, routing models, etc. The paper summarized the main components of the FLM including:

- Fuzzification: numerical data input are converted to fuzzy sets based on a membership function.
- Fuzzy logic rules: mostly in the form of "if-then" statements and commonly based on human experts in pure FLM.
- Inference engine: the initial fuzzy sets are mapped onto other fuzzy sets.
- Defuzzification: some output term is selected and then converted into a numerical value.

Different transportation engineering applications were addressed. FLM were used for OD matrix estimation. Genetic algorithms and fuzzy logic rules are used for trip distribution applications. Travel time and cost of the different modes together with fuzzy rules were used to represent the modal split function. FLMs were used widely for traffic control purposes to reduce the average vehicle delay time, mostly by deciding if green time extension is required based on traffic volumes in both directions. It was concluded that using the FLM actually improves the network as well as the intersection's efficiency (average vehicle delay time reduction).

Trabia, Kaseko and Ande (1999) presented FLM for a traffic signal controller for an isolated intersection with four main approaches. Two types of detectors were used; 1) upstream detector for determining the approach flow, and 2) downstream detector for the left turn movement presence detection. The FLM is used in deciding on the green time extension. The FLM was tested comparatively against the actuated traffic signal controller. Both controllers were assessed using the delay time (average and total), and the percentage of the stopped vehicle. The main input and output parameters were:

- Traffic flow of each approach estimated based on detector counts (input);
- The queue lengths (input/output);
- Vehicle delay time (average and total) (output)
- Number of stopped vehicles on the approach (output).

A mathematical model was developed to estimate the phase queue length, vehicle delay time, and the number of stopped vehicles at time *t*, given the upstream traffic flows, and previous interval's queue length. A FLM was also developed. It uses predicted approach flow and maximum queue length on opposing approaches as input variables. Trapezoidal membership functions were assumed with four fuzzy terms *zero, small, medium,* and *big*.

Results showed that the FLM controller is more effective than the actuated controller in terms of delay and percentage of stopped vehicles. The vehicle's average delay was better by more than 9%, and the % of stopped vehicles was lesser by around 1%. Tests were conducted with various flow levels flow (*high, moderate,* and *low*), and with the use of a simulator program.

This research work by Trabia, Kaseko and Ande (1999) was particularly useful in forming the FLM developed in this thesis. The main limitation is that the FLM was developed mostly in a subjective manner.

Arora and Banga (2012) presented an FLM for signal traffic control of four-leg isolated intersection. The input variables included the arrivals on the serving approaches and queues on the opposite approaches. The FLM rule base was designed based on experience. The FLM makes decisions on green extensions based on the input variables on competing approaches. The FLM does not have any limitations on number of possible of green extensions. The effectiveness of the FLM was not discussed. The presented FLM was limited to two-phase through movement signal operation without left turning vehicles.

Hou et al. (2012) developed a FLM for signal setting based on the upstream and the downstream link flows. The bottleneck problems were taken into consideration in traffic flow data prediction using the mathematical statistics and time series.

Actual filed data were collected. A mathematical statistics and time series model were applied for data correction. Corrected flow data were then used to predict the future traffic flows using the BP neural network. The developed FLM takes into consideration the lane traffic congestion of the green phase of one approach (based on flow ratio) as well as the red phases (based on occupation ratio) of other approaches. The congestion level was indicated by one of five categories; VB: very blocking (0.8-1.0), B: blocking (0.6-0.8), N: normal (0.4-0.6), F: free (0.2-0.4), and VF: very free (0-0.2). The output green time decisions are green time +8, green time +4, invariant green time, green time -8, and green time -4.

The proposed method was tested using VISSIM simulation software. Results indicated significant superiority of the proposed method in low or normal traffic flow conditions. In the case of saturation or oversaturation, the proposed method was slightly better than the typical controller. The presented method was only limited to a specific intersection configuration and it does not account for variant link length, average speed, number of lanes, etc.

Mucsi, Khan, and Ahmadi (2011) presented a FLM to estimate the "Number of Vehicles in a Detection Zone (NVDZ)" based on time occupancy detector data, rather than traffic counts obtained from the detectors. Each lane is assumed to have three time-occupancy detectors. The output of the FLM is a crisp value of the NVDZ. The rule base was built using neuro-fuzzy approach. Training data were generated using VISSIM simulation. The neuro-fuzzy system was developed using the (ANFIS) function of MATLAB.

Different tests were conducted to evaluate the proposed NVDZ method. The tests were conducted using different geometric arrangements (places of detectors), and signal timing (a fixed cycle time signal control was used). Results showed good performance of the proposed method accuracy. Nonetheless, re-tuning the ANFIS is necessarily needed for various signal settings and detector arrangements. This would as such limit the applicability of the model.

Kosonen (2003) presented a new technique of the traffic signal control system using three different levels: real-time simulation, multi-agent control, and FLM. In the first level, and to model the actual real traffic condition, a real-time simulator is used. The simulator is connected with a real time detectors' system. Lane occupancy is the main input to the simulator. The main advantage of the simulator is to keep the drivers updated with the traffic conditions such as the travel times, and queues. Another advantage is its effectiveness in monitoring and controlling the traffic signal.

In the second level, the multi agent control relies on parameters such as; safety (minimum inter-green times between conflicting signals), and equality (each approach will has a chance to get green). This approach adopts a sort of negotiation mechanism among the adjacent intersections, taking into consideration the safety as well as other parameters.

The third FLM level is applied for decision making within the multi-agent control level. The FLM considers the traffic conditions (from the simulator at the first level) as inputs to decide whether to extend the existing green time or to terminate it (as an output). This decision is sent to the multi-agent control.

The logic was implemented in a simulation environment using HUTSIG. The performance of the FLM was compared to the commonly known vehicle actuated control (VA). While the VA showed better performance in cases of low traffic flow, the FLM was better in medium or high traffic flows.

Zaied and Al Othman (2011) developed a FLM for signal control. The inputs include the position of the vehicle from the intersection within the detection zone (8 m away from the intersection, with a length of 100 m), and the phases setting times. Each input/output variable consists of five fuzzy sets: No (N), Semi-Half (SH), Half (H), Semi-Full (SF), and Full (F). The FLM outputs are the modified signal timing setting, cycle time and reducing unused green time. The proposed FLM was modeled and tested using MATLAB. The results indicated better performance (lesser delay) of the FLM as compared to existing intersection's pre-timed control. The FLM does not account for various vehicle types. Other important parameters such as lane length, speed, and number of lanes were not considered. The research is not also clear about the specification of the IF-THEN rules in the inference engine of the FLM.

Pranevičius and Kraujalis (2012) presented a method for traffic signal control for isolated intersections using fuzzy memberships coupled with expert knowledge system, EKC. Two main inputs are estimated from road detectors; the number of vehicles that were not served during the existing green time phase, and the summation of the arrived vehicles (AV) during the red phases and the remaining vehicles (RV) from the previous green phases. The output of the FLM is the decision whether to extend the existing green by certain time duration, or to terminate it. The queues on the green phase and the red phases are compared and decision is then made on extension or termination of green. Experts' knowledge forms the basis of extension/termination decisions. The EKC was built using the ARENA simulation software. The initial green time is preset to 10 seconds, the extension interval is set to 6 seconds, and the maximum green is preset to 40 seconds.

The proposed EKC control model was tested and compared with two other controllers (FLM, and pre-timed). The results indicated that the proposed model is more efficient than the other two controllers. Much better performance in the case of high traffic flows. The model is particularly applicable to only specific three-leg intersection geometry and phase sequencing.

Mehan (2011) presented a FLM for traffic signal control of four-leg isolated intersections with two through only phases (neglecting the turning movements). The presence of motorcycles was taken into consideration, in addition to passenger cars. Two main inputs were estimated through intersection cameras; the number of arriving vehicles to the current green phase, and current queue on the opposite conflicting phase. The phases are initially set using fixed green time intervals (pre-timed). The FLM then decides whether to increase, decrease, or keep the preset green time interval. The two input variables were set to fuzzy memberships of five terms each, and the output decision is set to three term fuzzy variable. The inference rule base was developed based on human experts.

The FLM was compared to some pre-timed controller in a simulation environment. No details were provided on the comparative performance of both controllers. The FLM is rather limited in the sense that it is only applicable to specific intersection of two through movement phases only. It is particularly useful for urban areas with significant number motorcycle vehicles.

Zarandi and Rezapour (2008) presented a fuzzy signal control System (FSCS) for an isolated signalized intersection. Two main outcome decisions were to be obtained from the proposed FSC System including; a) green time modification (extension or termination of the existing serving phase), and b) the phase sequencing. The proposed model input data are collected from the embedded detectors on: average queue length of the current green phase, average arrival rate of the current green phase, and the average queue length of the competing red phase, A minimum and maximum green time durations are preset for each phase, The decision to extend/terminate the current green phase is deployed only beyond the minimum green with the maximum green constraint. The green extension unit was set to 5 seconds. Upon terminating the current green phase, the "next" green phase is set to the one with highest average queue length among all current feasible red phases.

Trapezoidal membership functions were set for the three input variables. The rule base was formulated initially based on experts' knowledge, and later modified based on simulation data. The proposed model was tested against a pre-timed controller using a simulation software. The results indicated the better performance of the proposed model in comparison to the pre-timed controller, especially in heavy traffic conditions. The model was tested using a three-leg intersection. The model does not account for the various vehicle types that may exist and their influence on the estimates of the PCU on the various approaches. Moreover, the model is lane-based; it does not account for number of lanes served by the various competing phases.

Royani, Haddadnia, and Alipoor (2013) developed a neuro-fuzzy logic using a genetic algorithm approach. Three main inputs were considered; number of vehicle arrivals in the current green interval, number of queued vehicles in current green interval, and number of queued vehicles on current red phase(s). The decision to extend/terminate the green time is bounded by minimum and maximum green time durations of 15 and 30 seconds, respectively.

A five-layer neuro fuzzy logic is developed. The fuzzification process takes place in the first layer. A Gaussian membership function is placed in the second layer. The rule base function is set in the third layer, with a total of 48 rules. The fourth layer estimates and modifies the rule consequents and the weights of each rule through training. The fifth layer handles the defuzzification of the output variable. The Genetic algorithm was applied in the training stage to reduce the squared error of the difference between the estimated output and the corresponding training values.

The proposed model was developed and tested against a pre-timed controller using MATLAB. The model was tested using a two phase traffic signal control of a four-leg intersection with through movements only. The average waiting time was reduced from 330 seconds (using the pre-timed controller) to 178 seconds (using the developed controller).

Murat and Gedizlioglu (2005) presented a **F**uzzy **L**ogic **Mu**lti-phased **Si**gnal **C**ontrol (**FLMuSiC**) for isolated junctions. Two FLM's were developed for signal timing and phase sequencing. Traffic information are collected from two detectors placed 10 and 100 m along each intersection approach. The membership relationships between inputs and outputs were driven by observations (using the mean and standard deviation).

The main inputs of the first signal timing FLM signal are the longest queue length of the red time phases, and the arrivals to junction during green phase. The decision on the currently preset green time phase is driven by the fuzzy output variable of five terms (more decrease, decrease, do not change, increase, and more increase). The main inputs of the phase sequencing FLM are the longest queue length of the red time signal phases, longest vehicle queue of the next phase, and red time of the longest queue. The phase ordering FLM makes the decision on whether to (change/don't change) the sequence. The rule bases of both FLMs were derived using the well-known Generalized Modus Ponens (GMP) concept of logic derivation. A total of 64 and 37 rules were derived for the signal setting and phase sequencing FLMs, respectively.

The proposed controller system was tested in comparison aaSIDRA actuated model and traffic-actuated simulation model. Two signal phase arrangements were tested; three and four phases. Two cases of traffic volumes were considered (equal and unequal). The proposed FLMs resulted in considerable delay time savings in cases of high and variant traffic volumes.

Schmo¨cker, Ahuja, and Bell (2008) developed a FLM for an urban intersection. The FLM accounts for pedestrian delays and vehicle queues. The membership functions (for both inputs and outputs) were optimized using the VISSIM simulator and Genetic Algorithm (GA).

The rule base structure was built based on assumption (degree of belief). The proposed FLM was applied and tested in Marleybone Street, London. The traffic data (vehicle queue length and pedestrian density) were obtained from detectors or using video techniques. The obtained results show good performance of the proposed model, especially in reducing the pedestrian delays.

Askerzade, and Mahmud (2011) proposed a FLM traffic signal controller for estimating green time extension of a pre-timed traffic signal controller. The developed FLM considered five main input variables representing the traffic status (arrivals, queues and travel time) at the underlying intersection as well as the upstream and the downstream ones. The presented FLM is cooperative as it depends on neighboring intersections information.

A test was conducted using MATLAB simulation tool for two cases; single intersection (isolated control) and group of intersections (cooperative control). Results show that considering the group of intersections affects the green time extension. The cooperative type of control can help improving the performance of the intersection signal control especially in urban areas with closely-spaced intersections.

2.3 Discussion

This chapter provided a brief review of the research attempts on traffic signal control management in general and on the use of the fuzzy logic for signal control in particular.

The research attempts on the use of FLM for signal control has been evolving for decades since the establishment of the fuzzy logic principles by Lotfi Zadeh in 1965. The majority of these attempts are what can be categorized as "pure" fuzzy logic, where the rule base or the inference engine of the FLM is merely developed based on human expertise or intuition. Examples of these are those developed by Trabia, Kaseko and Ande (1999), Zarandi and Rezapour (2008), Arora and Banga (2012), Zaied and Al Othman (2011), Pranevičius and Kraujalis (2012), Mehan (2011), Zarandi and Rezapour (2008), Schmo¨cker, Ahuja, and Bell (2008), Askerzade, and Mahmud (2011). These controllers were mostly developed for isolated intersection control, where the controller accounts only for the traffic conditions upstream the underlying intersections. The primary fundamental difference among these pure FLM is the input variables. Some attempts considered only two inputs (e.g. Mehan, 2011; Zaied and Al Othman, 2011; Arora and Banga, 2012), while others may use more (Pranevičius and Kraujalis, 2012). Among the most common input variables are the queues along the red phases, and the expected arrivals along the current green phases. The FLM control decisions are mostly related extension/termination of the current green phases (Zarandi and Rezapour, 2008; Pranevičius and Kraujalis, 2012).

Simulation has been used as the tool for evaluation in virtually all FLM developments. In the majority of these FLM, comparative analysis is conducted against a preset controller (pre-timed phase arrangement). Simulation environment varied from the use of MATLAB (Zaied and Al Othman, 2011), or ARENA (Pranevičius and Kraujalis, 2012) to the use of specific traffic simulators such as VISSIM (Mucsi, Khan, and Ahmadi, 2011; Hou et al., 2012).

To overcome the drawbacks of the intuitive specification of the FLM inference engine, other researches utilized the neuro-fuzzy logic in developing the FLM and calibration of its memberships (Mucsi, Khan, and Ahmadi, 2011; Hou et al., 2012). Other attempts included also the use of Genetic Algorithms in the training (Royani, Haddadnia, and Alipoor, 2013).

Only very few research attempts realized the importance of control provision beyond the isolated intersection. Kosonen (2003) developed a multi-level agent controller that takes into consideration the safety and the equality principles in negotiation among neighboring controllers. Askerzade, and Mahmud (2011) developed a cooperative control that accounts for the traffic conditions on the neighboring intersections. Hou et al. (2012) developed a FLM for signal setting based on the upstream and the downstream link flows. None of these controllers accounts explicitly for the effect of the downstream congestion on the discharge rate of vehicles from the upstream signals. In cases of spillbacks, this discharge rate may dramatically drop (reaching zero) in cases of full downstream blockage. Accounting for this downstream conditions, spillbacks and congestion in specific is critical in developing efficient control systems, especially in urban networks of closely spaced intersections, where isolated control cannot be implemented.

The literature review indicated also the superiority of the FLM to the conventional controllers in in low or normal traffic conditions (Hou et al., 2012). Kosonen (2003) on the other hand indicated that the FLM would perform better in medium to high traffic conditions. Pranevičius and Kraujalis (2012) indicated the better performance of the FLM at high traffic flow conditions. The diversity of these conclusions on what situations would suit mostly the deployment of the FLM makes it necessarily important to devise methodologies that can be deployed to function effectively in all traffic conditions.

It is worth noting that many of these FLM developments were quite limited in terms of the intersection geometry it accounts for or the number of signal phases it can handle. For instance, Mehan (2011) presented a FLM for traffic signal control of four-leg isolated intersections with two through only phases (neglecting the turning movements). The model by Pranevičius and Kraujalis (2012) is particularly applicable to only specific three-leg intersection geometry and phase sequencing. Hou et al. (2012) is only limited to a specific intersection configuration and it does not account for variant link length, average speed, number of lanes, etc. Virtually all the research attempts of relevance to FLM traffic control do not account for traffic composition. The various vehicle types have implications on the traffic measures and consequently the signal control. Moreover, many of these attempts just ignored the turning movements. The FLMs were essentially developed to tackle phases of through movements. It is rather important as such to devise methodologies as such that can handle all traffic congestion levels ranging from free-flow conditions to grid lock ones, traffic compositions that encompasses cars as well as other types of vehicles, intersection geometry (not limited to a specific number of legs or lanes),

As for the "closeness" of all the presented methodologies to optimal solutions or benchmarks of signal control, it is not really clear how would such controllers perform as compared to "optimal" solutions. As indicated, the majority of these FLMs were developed using intuitions or even training versus some simulation. It is not clear also that such methodologies would perform favorably in all traffic conditions ranging from free flow to grid locks. Moreover, it is not clear how would they function in a network (not isolated intersection) type of control environment.

Based on all the above discussion, it was determined that FLM is perhaps a very appealing approach for intersection control as it can handle uncertainties of traffic measures in urban networks. The FLM is also amenable to real time control as it enables quick decision making as compared to conventional optimization techniques. Nonetheless, it is important that such FLMs won't deviate significantly from such benchmark optimization solutions. The primary functional requirements of an ideal FLM based on the extensive literature review can be summarized as follows:

- The FLM should effectively perform and provide solutions close to optimal benchmark solutions
- It should function effectively in all traffic conditions covering all levels of service possibilities and ranging from free flow traffic conditions to grid locks
- It should not be limited to specific network geometry or number of phases
- It should account for all traffic turning movements
- It should not be limited to isolated intersection control. It should incorporate logic to account for the network traffic effect; at least the effect of the neighboring intersection congestion and spill backs. It should be flexible enough to act in both ways as warranted.
- It should not be based on intuitions solely as this may lead to system that is far deviant from optimal solutions. In fact, optimal solutions should be used to derive the inference engine of the FLM.

- Finally, it should be valid for traffic conditions that it was not calibrated for to ensure the generalization of concepts.

Based on the above extensive literature review, this research aims at developing a control system that meets all the above primary functional requirements.

Chapter 3: Methodology and Results

3.1 Introduction

Alternative methods for traffic signal design exist in literature. They range considerably in functional form and methodology. The fuzzy logic based methods are mostly intuitive and are not usually verified against well-known signal control optimization techniques. There is very little research that conducted to look into effectiveness of fuzzy logic based systems vis-à-vis optimization methods. In this research, we attempt to formulate a fuzzy logic system to emulate well known optimization methods. Furthermore, we amend the devised fuzzy logic to add additional capabilities of handling downstream congestion.

Among the main objectives of this research is to study the effect of the downstream congestion on the traffic signal control design (mainly the green times allocations). The majority of the existing traffic light controllers considers the traffic flows conditions upstream the intersection. The effect of the downstream congestion is almost negligible in most of the existing procedures. Some of the existing controllers take into account the propagating effect of congestion along the downstream links.

Hou et al. (2012) presented a fuzzy-logic macroscopic model that considers both upstream and downstream link flows for the estimation of the next interval signal timing. The final decision of the model was set to either increase/decrease the green time of the current green phase by 0, 4 or 8 seconds.

The presented model herein offers better flexibility and wider range of options. The final decision options are not limited to preset time intervals. Furthermore, the fuzzy logic is not intuitive; it is in fact calibrated to emulate optimization based procedures. This will as such give sounder theoretical basis for the model.

3.2 Model Development and Calibration

For the purpose of illustrating how the model is developed and calibrated, we assume a single intersection (as the base intersection). The intersection is modeled by the well-known SYNCHRO model that uses the Highway Capacity Manual formulae in optimizing the traffic signal and estimating the green times of each phase. Some parameters were assumed known and fixed for all modeled operational scenarios.

Among the fixed parameters are:

- Geometric Parameters:
    - Number of lanes: 3 shared lanes
    - Split phase arrangement
    - Link length, L: 500 m
    - Link speed: 60 km/hr
    - Lane width: 3.7 m
    - Saturation flow rate: 1900 veh/hr/lane
    - Passenger car length: 7.6 m
    - Heavy vehicle length: 13.7 m

- Traffic Parameters:
    - Right turn percentage: 30 % of approach volume
    - Through movement percentage: 60 % of approach volume
    - Left turn percentage: 10 % of approach volume

- Peak hour factor (PHF) = 0.92
- Growth factor: 0.95
- Percentage of heavy vehicles: 2%

- Control Parameters:
  - Signal control type: Pre-timed signalized intersection, protected left turn movement, split phase operation.
  - Yellow time: 3 sec
  - All red: 1 sec

The devised fuzzy logic is assumed to operate in field and having access to limited "raw" field data on real time link flows and link queues. Having these field data, the envisaged fuzzy logic will estimate the so-called "green weight" of each phase. The green weight is simply an index to indicate how important it is to allocate the green to this particular phase; the higher the weight, the higher the portion of green that this phase will be allocated (out of the total cycle time). In determining these green weights, the fuzzy logic model was not set arbitrary or intuitively, but rather it was calibrated to more or less produce close values to those that would be estimated by a pure optimization method (such as the Highway Capacity Manual optimization method).

In developing the fuzzy logic model (FLM) system, a specialized software (known by FuzzyTECH) was used. The details and structure of the overall model and its rule blocks are exhibited in Figures 3.1 through 3.5. In brief, the devised FLM has five (5) rule blocks. The various rule blocks are connected all together; that is, the outputs of one block may be inputs to another one, etc. In the following section we highlight the main function of each rule block, we define its input and output variables.

In order to calibrate the devised pure fuzzy logic and instead of just using the intuitive settings of the fuzzy memberships, a more rigorous method was used in calibrating the rule base (IF-THEN) statements and in verifying the devised FLM system. The method of calibrating the FLM can be summarized as follows:

1. Fuzzification of the input variables; namely the approach traffic flow (veh/hr). It is assumed that the only input to this system would be the incoming flows on the various competing approaches. Setting the input variable as a fuzzy term has been conventionally done in literature arbitrary and equally. That is, the fuzzy term ranges are split equal along the domain of potential approach volumes. Herein, we relate the fuzzy terms to specific Levels of Service (LOS). For instance, the "low" term of the approach volume is related to uncongested situations (LOS A through C). The "very high" term corresponds to LOS of F. To do that, one would need to determine the range of approach volumes that will correspond to these LOS's. Herein, we present the simple mathematical formulae that can be used to estimate the numerical ranges of each fuzzy term. This was done using the well-known conventional method and based on the volume to the capacity ratios (v/c) as stated in the Highway Capacity Manual. The details of the fuzzification procedure and the mathematical formulae are explained later in this chapter.
2. Following the development of the membership function of the approach traffic flow, a verification stage was carried out. The rationale is to ascertain the applicability of the fuzzification procedure to various v/c ratios. This was done

by modeling various approach flows in Syncho software. We then compared the estimated v/c from SYNCHRO versus these used in determining the approach flows and the fuzzification of the terms.

3. The conventional way in literature to calibrate the IF-THEN rules is either by using intuitive experts' opinions or by training using neural nets. Herein we used a different approach that calibrate fuzzy logic to mimic optimization procedures. This is explained in the steps to follow.
4. Design experiments to cover the wide spectrum of approach flows. There are literally infinite number of numerical values for each approach flow. In a four-leg intersection, the possible combinations of link flows are infinity as well. To ease the process, we selected carefully only 289 combinations of link flows. These will fairly cover all possible approach flows ranging from "low" to the "very high" fuzzy levels. Each of the selected combinations is distinct and different from the other ones. The details of these 289 experimental scenarios will be discussed later in this chapter.
5. Use the verified simulator (SYNCHRO) to simulate and optimize the signal settings for the 289 different scenarios. The outputs of these simulation runs are then used to extract three outputs; namely, the 95 percentile queue length, the effective green of each approach and the optimal cycle length. The effective green of each approach and the cycle length were then used to estimate the proportional "green weight" of each approach. The green weight is simply the proportion of the effective green to the total cycle's effective green. The higher the green weight the higher the green time allocation to the approach. It is to be noted here that all of these values correspond to the "optimal" conditions of the signal setting. As such, the use of these information in calibrating the rule base

of the first rule block (Figure 3.1) will result in a fuzzy logic that mimic optimization systems.

6. The fuzzification of the output variables (queue, green weights and optimal cycle time) is done by discretizing these variables to equal ranges for each fuzzy term over the domain of the potential numerical values. The outputs of the 289 simulation scenarios were used to identify the minimum and maximum values for each output variable. The overall domain of each variable (maximum minus minimum values) was then divided into equal number of terms, and the domain of each term was determined.
7. Each of the 289 simulation scenarios was then used in explicitly defining a relationship between the input fuzzy terms and the output variable fuzzy terms. For instance, "low" traffic flows on all four approaches would result in low 95% queue length, "medium" green weight and "low" cycle time. It is worth noting that each of these experimental scenarios is distinctive (not repeated) and as such, each of these scenarios is used to "add" one (IF-THEN) statement to the first rule block of the fuzzy logic.
8. The queue on each link as an output of the simulation is also used to estimate a congestion index to reflect on the congestion on the downstream approach of any signal phase. This will imply the downstream blockage and will as such be used to modify the signal settings. For instance, based on the *high* upstream approach flow, its specific phase might be given a *high* green weight. Nonetheless, if the downstream approach of this phase is blocked, the green weight is modified to minimize the green time allocation of this phase. The consideration of the downstream congestion index and the modification of the initially calculated green weight to a "final" green weight is exhibited in the 2nd

through the 5^{th} rule blocks (Figures 3.2 – 3.5) and will be explained later in the chapter.

Details on each of the above steps will follow afterwards.

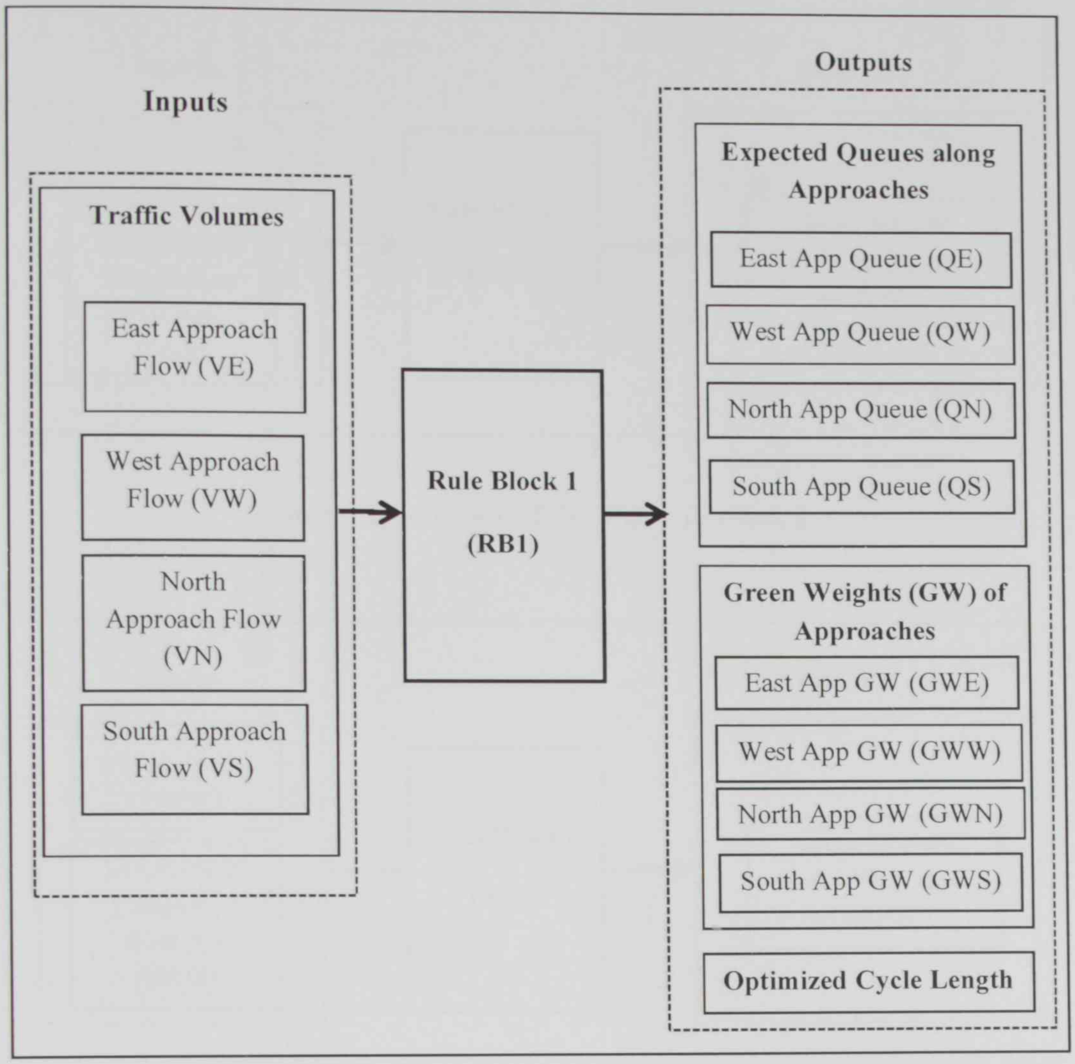


Figure 3.1: Structure of the FLM rule block 1

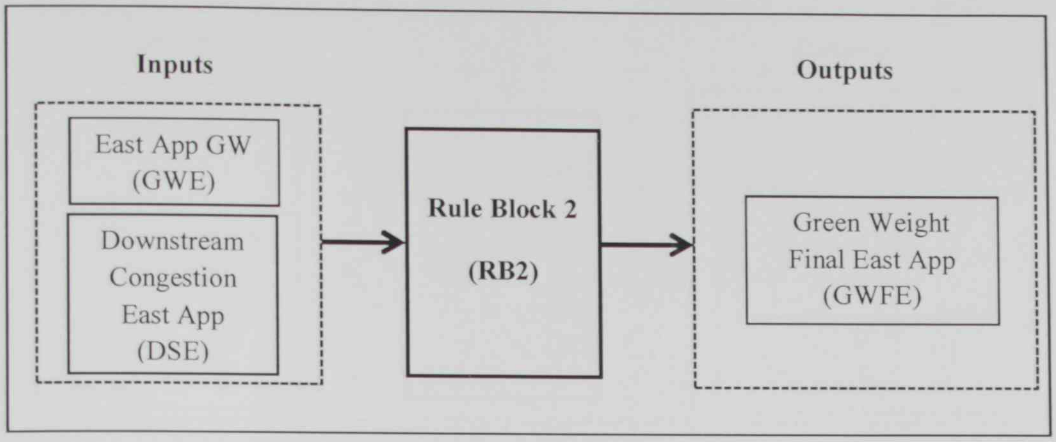


Figure 3.2: Structure of the FLM rule block 2

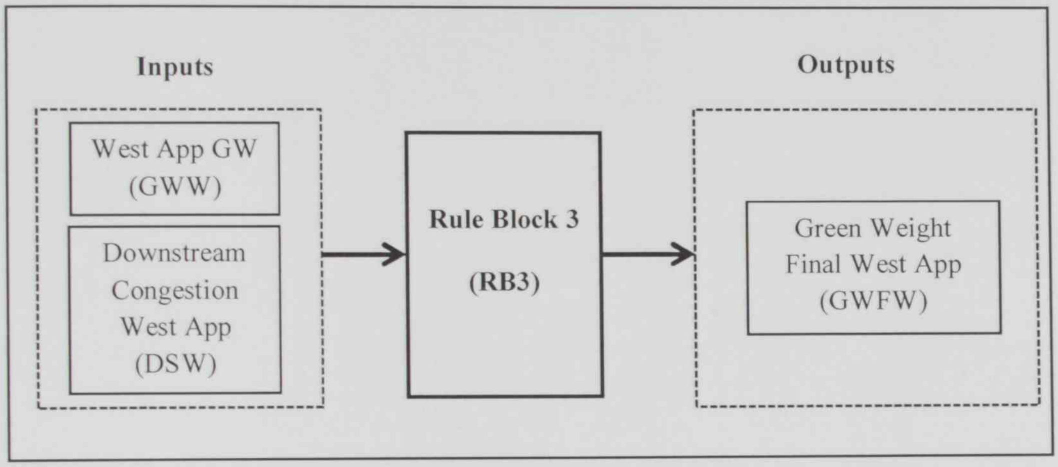


Figure 3.3: Structure of the FLM rule block 3

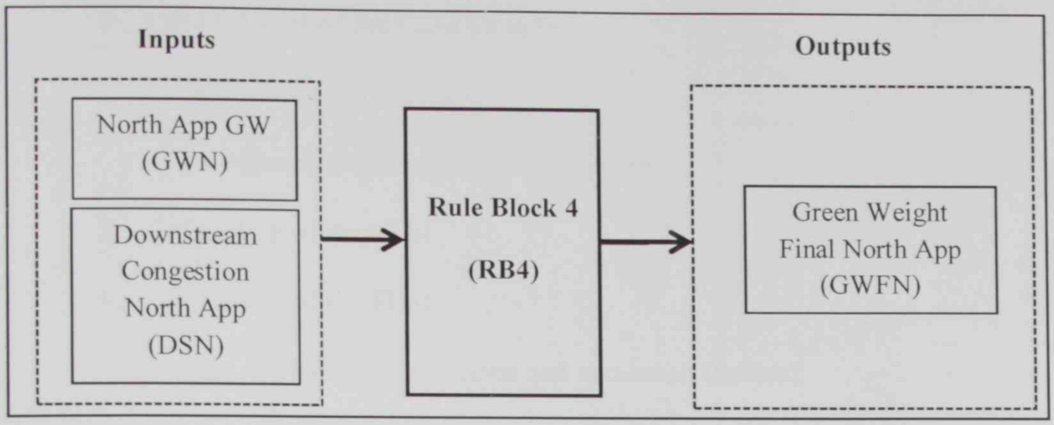


Figure 3.4: Structure of the FLM rule block 4

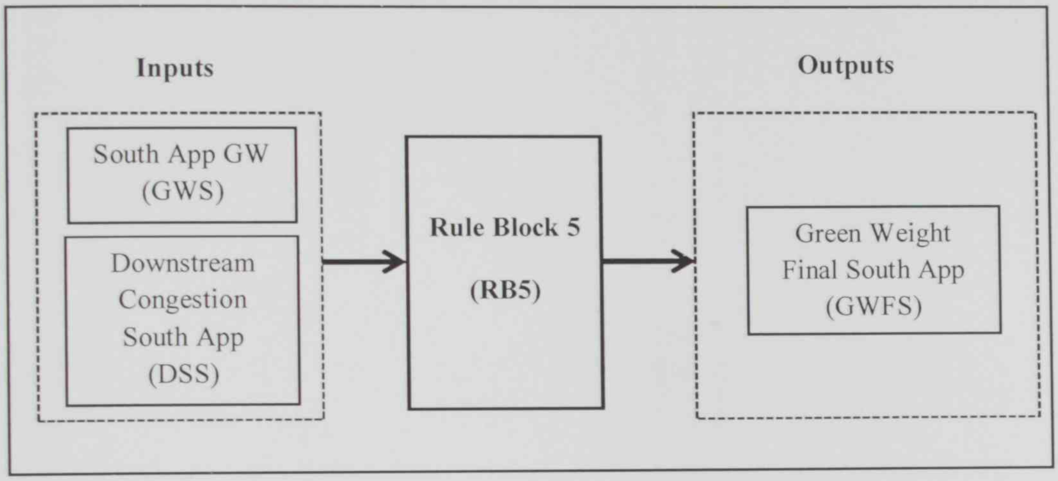


Figure 3.5: Structure of the FLM rule block 5

The main stages which were followed in this research were as follows;

1. Design of experiments to cover the wide spectrum of approach flows (around 289 combinations of traffic flows were selected).
2. Model a single intersection using SYNCHRO to simulate and optimize the signal settings for the selected scenarios.
3. Data extraction from SYNCHRO, mainly the 95 percentile queue, the actual green times, and the cycle length.

4. Development of the FLM including;

   a. Fuzzification process

   b. Membership function development.

5. Calibration of the FLM.

6. Validation of the FLM.

7. Finally, listing all conclusions and recommendations.

A flow chart diagram represent the procedure sequence followed in Model developing and calibration. Figure 3.6

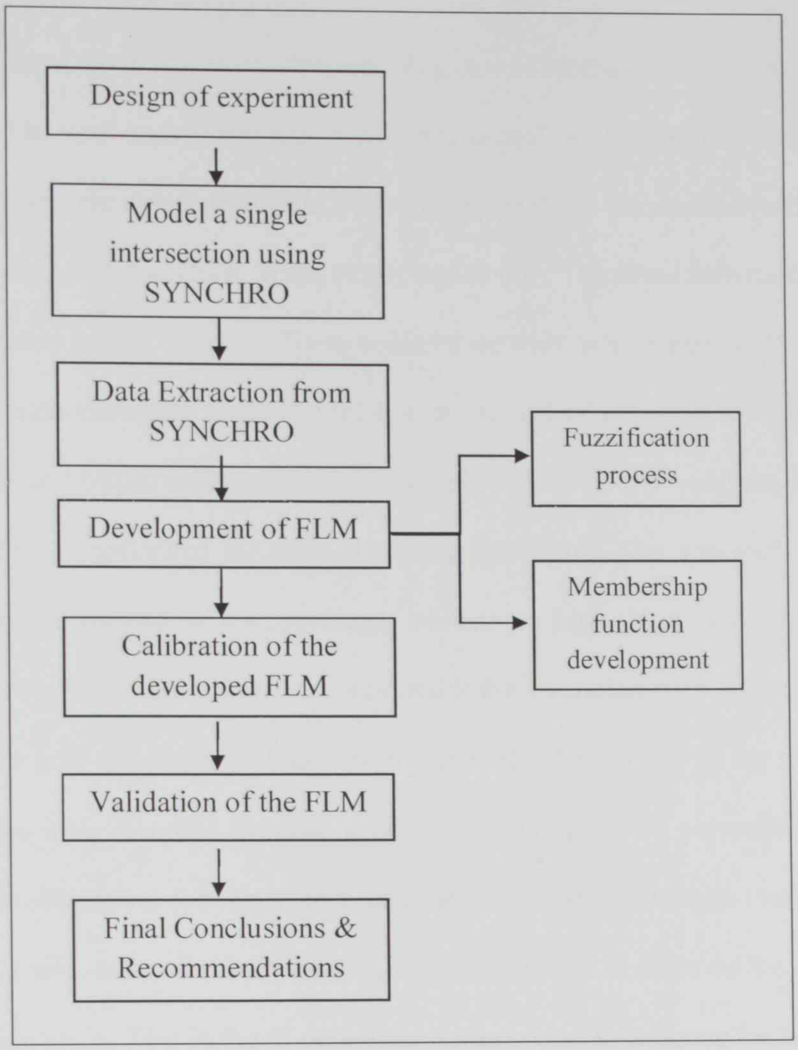


Figure 3.6: Flowchart of the study approach.

3.3 Definition of Rule Blocks

The rule block is a database of IF-THEN statements that defines the relationship between the inputs and the rule block outputs. The inputs incorporate the traffic information (herein the approach traffic flows and its queues). The rule blocks are commonly developed based on the experience of traffic engineering experts to end up with a logic decision for the traffic controller (Felici a et al, 2006).

3.3.1 Rule Block 1 (RB1)

The rules of the RB1 was constructed using data collected through a simulation environment. The well-known simulation software model (SYNCHRO) was used to model and optimize the signal settings of a pre-timed signalized intersection (with split phasing) of four approaches (East, West, North, and South). The simulation model was run for preselected hourly volumes. These volumes are then used as inputs of RB1.

The simulation/optimization model is used instead of field data collection to capture the various traffic measures associated with various hourly volumes, in case the traffic signal is optimized for these particular conditions. The approach hourly volumes were categorized as low, medium, medium to high, high, and very high according to the value of the volume as compared to the saturation flow. Section 3.2.1 below explains how the traffic volumes were selected. The outputs of the multiple simulation runs were recorded for each approach including the 95 percentile queue length (m), the effective green times (sec), and the optimized cycle length (sec).

These traffic measures from the simulation were used to calibrate the outputs of the fuzzy rule block. That is, the 95 percentile queue is used to calibrate the "Queue" variable of each approach. Similarly, the effective green times were used to estimate the "green weight" of each approach as will be explained later. The "Optimum" cycle time output of the fuzzy rule block was similarly calibrated using the "optimum" cycle times estimated from the SYNCHRO model.

3.3.2 Rule Blocks 2 to 5 (RB2-RB5)

RB2 through RB5 are applied for the four approaches in parallel; each approach traffic data feed into one specific rule block. RB2 is used for the East approach, RB3 for West, RB4 for North and BR5 for the South. The inputs to any of these rule locks includes the so-called "green weight" of each approach; which is the estimated output of RB1 for this particular approach. The inputs also include the so-called "downstream congestion" estimated from the SYNCHRO traffic measures. Further description of these inputs will follow later in section 3.2.5.

The outputs of these rule blocks were calibrated intuitively using a logical relationship between the two input variables of the approach rule block. The output variable of rule block is denoted by the "final green weight", and it is a sort of index that can be used to indicate how important it is to allocate green to the approach in the current cycle; the higher the weight, the higher is the green time allocation of the phase.

3.4 Fuzzy Logic Structure

As mentioned earlier in Chapter 2, the four main components of the fuzzy logic system are the Fuzzification (the conversion of the numerical data input into fuzzy terms based on a predefined membership function), the fuzzy logic rules (the IF-THEN statements that defines the relationship between the inputs and output fuzzy terms and it is conventionally calibrated intuitively based on human experience. Herein, the rule blocks are calibrated using the data derived from the simulation/optimization environment. The third component of the fuzzy system is the Defuzzification (the process of converting the resulting fuzzy terms into numeric values. The final component is the result that combines the outputs of the various rules in specific result (TeodorovicÂ, 1999).

The following sections present in more details the main fuzzy logic components and the proposed model parameters.

3.4.1 Fuzzification of the approach hourly volume

Field data collection is commonly considered a major and essential stage in designing traffic models. In this research, a pure fuzzy logic model (FLM) was developed based on data developed through simulation/optimization environment in addition to some intuitive logical settings based upon expert's knowledge.

To develop a FLM that is applicable to all potential traffic conditions, it was necessary to consider the various levels of approach traffic flows (hourly volumes) and to design the FLM to provide optimal signal setting solutions that correspond to the various flow levels. Due to the limitation of resources (time, tools, and human resources) and in order to cover possible variations of the traffic situations (congested and non-congested traffic), a simulation environment was considered (using the well-known SYNCHRO software). Different combinations of the traffic flows (ranging from low to very high flows) along the four approaches (East, West, North, and South) were considered, applied and tested.

In brief, in calibrating the FLM, a total of 289 simulation scenarios (or cases) reflecting various flow levels on the competing four approaches of the intersection. The resulting traffic measures of the 95 percentile queue length on each approach, the effective green times for the competing split phases, and the optimum cycle time were recorded for each simulation scenario, and were later used in developing the rule base of the first rule block of the FLM.

In order to set the membership function of the first input variable (approach hourly volume), the minimum and maximum volume values for each fuzzy term were determined to correspond to some specific level(s) of service (LOS). For instance, the

LOS of A as defined by the Highway Capacity Manual (Transportation Research Board, Highway Capacity Manual, Special Report 209, Washington, D.C., 1994) is one that corresponds to a v/c (volume to capacity ratio) of 0.6 or less. The LOS of B corresponds to v/c [0.6-0.69], and LOS of C corresponds to v/c [0.7-0.79] as shown in Table 3.1.

Level of service	Interpretation	v/c ratio
A	Uncongested operations; all queues clear in a single signal cycle.	Less than 0.60
B	Very light congestion; an occasional approach phase is fully utilizes.	0.60 to 0.69
C	Light congestion; occasional backups on critical approaches.	0.70 to 0.79
D	Significant congestion on critical approaches, but intersection functional. Cars required to wait through more than one cycle during short peaks. No long-standing queues formed.	0.80 to 0.89
E	Severe congestion with some long-standing queues on critical approaches. Blockage of intersection may occur if traffic signal does not provide for protected turning movements. Traffic queues may block nearby intersection(s) upstream of critical approach (es).	0.90 to 0.99
F	Total breakdown, stop-and-go operation	1.00 and Greater

Table 3.1: Intersection Level of Service (LOS) Definitions (source: HCM, 1994)

For any specific intersection, it is expected that the approach's volume that corresponds to a specific LOS would vary, based on many factors among which is the intersection geometry, lane width and number of lanes. In order to obtain the approach's hourly volume range that corresponds to the different LOS, the v/c ratios as indicated in Table 3.1 were used.

Assuming the lane saturation flow rate "s" to be 1900 (veh/hr/lane), each approach has three (3) lanes, and four lane groups (or split phasing approaches), the hourly volume range corresponding to the various LOS was calculated using the following formulae;

$$Saturation\ flow\ rate\ of\ lane\ group\ i,\ \left(\frac{veh}{hr}\right) =$$

$$Lane\ saturation\ flow\ rate\ "s_i"\left(\frac{\frac{veh}{hr}}{\text{lane}}\right) x\ Number\ of\ lanes(\text{lanes}) \qquad (3.1)$$

Where s_i was assumed to be 1900 (veh/hr/lane) for urban intersections. For the purpose of demonstrating how the FLM is developed, all approaches were assumed to have three (3) lanes. If the number of lanes is different, one would expect applying same methodology with some additional simulation scenarios. Herein, the number of lanes of any lane group (approach) is set to three (3). Therefore;

$$Saturation\ flow\ rate\ of\ lane\ group\ i = 1900\left(\frac{\frac{veh}{hr}}{\text{lane}}\right) x\ 3(\text{lanes}) = 5700\ \left(\frac{veh}{hr}\right) \qquad (3.2)$$

For a split phasing, each approach will be represented by the lane group. For a lane group i, the saturation flow rate was assumed to be equals to the lane group capacity (5700 pcu/hr).The intersection's v/c ratio is estimated as the sum of the individual approaches v/c's as indicated in Eq. (3.3)

$$Intersection\ v/c\ = \frac{\sum_{i=1}^{4} v_i}{5700} \qquad (3.3)$$

If all the lane groups are of equal volume, then

$$Intersection\ v/c\ = \frac{4 \times v_i}{5700} \tag{3.4}$$

Equation (3.4) is applicable only if the traffic stream constitutes only through movements. In case of right and/or left turning movements, one would expect a further reduction in the resulting interaction's *v/c* due to the accompanied turning factors effect. That is, the turning traffic has higher passenger car unit equivalency values (higher approach PCU values) as compared to the through traffic. As such, mixed traffic streams would result in higher intersection *v/c* values, as compared to the case of the traffic stream constituting only through movement.

Herein, each lane group (or approach) was assumed to constitute a 30% RT and 10% LT. Simulation experiments were conducted to estimate the so-called "reduction factor" to account for the RT and LT traffic components. It was found that a reduction factor of 35% would result in close estimates of the overall intersection's *v/c* ratio (as estimated by SYNCHRO). That is, this 35% reduction factor of the intersection's *v/c* ratio was considered due to the 10% left and the 30% right turning movements. Therefore, Eq. (3.5) can be used to estimate the traffic flow (hourly volume) of any lane group (approach) "v_i".

$$Traffic\ flow\ for\ lane\ group\ (approach), v_i\ \left(\frac{veh}{hr}\right) =$$

$$(1 - 0.35) \times\ Intersection\ v/c\ \times \frac{5700(\frac{veh}{hr})}{4} \tag{3.5}$$

Using the above equations and the suggested v/c ratios of the various LOS by the Highway Capacity Manual, the approach hourly volume as an input fuzzy variable was assumed to have five (5) terms (*Low, Medium, Medium High, High and Very High*) as shown in Table 3.2 and Figure 3.7. Each of these terms corresponds to a range of approach volumes and as such a range of LOS. For instance, the *Low* traffic volume term covers the range of traffic volumes from zero to *b* as shown in Figure 3.7. The reverse estimation of the volume range for the *Low* term indicates that this term is likely to result in intersection LOS of A through C (as indicated in the 2nd column of Table 3.2). Using SYNCHRO to estimate the LOS using the *Low* term volumes results in LOS of A and B as shown in the third column of Table 3.2. The remaining columns of Table 3.2 are self-explanatory. The expected volume range for each fuzzy term is used to estimate the expected range of the intersection's v/c ratio, the reduction factor and the resulting average approach's volume.

The estimated approach volumes (of the various terms as shown in the last column of table 3.2) were then used to construct the 289 simulation scenarios that were used to estimate the resulting queues, and optimal signal settings. It is worth mentioning that these 289 scenarios were carefully selected to cover almost all possible traffic congestion scenarios ranging from low to very high congested situations.

In brief, the HCM's *v/c* values for the various LOS can be used to estimate the traffic volume ranges of the various fuzzy terms. This is known by the process of "fuzzification". Conventionally, in almost all reviewed FLM's in literature, the fuzzification is done arbitrary and almost equally. That is, the terms numerical ranges are distributed equally over the entire domain of the possible numerical values. Herein, the fuzzification and the setting of the membership function of the fuzzy terms is done logically and in relation to the various LOS's using the above explained systematic procedure.

Traffic Flow Input Fuzzy Terms	Fuzzy Term's LOS Interval	Resulting Simulation LOS's	v/c ratio (TRB-HCM Report 209)	Average Interval *v/c*	*Total intersection volume* v = Average Interval v/c * 5700 (veh/hr)	Reduction = (35% * v) (veh/hr)	Approach volume, *vi* = (Intersection Volume, v - Reduction)/ 4 (veh/hr)
Low	A-C	A&B	0-0.7	0.35	1995	698.25	324
Medium	B-D	C	0.7-0.8	0.75	4275	1496.25	695
Medium High	C-E	D	0.8-0.9	0.85	4845	1695.75	787
High	D-E	E	0.9-0.99	0.95	5415	1895.25	880
Very High	F	F	>1	1.2	6840	2394	1112

Table 3.2: Definition of the FLM Traffic Flow (Hourly Volume) Input Variable Fuzzy Terms

In Figure 3.7, the hourly volume is divided into five (5) fuzzy terms. The range of the numerical value for a specific term were determined using the procedure explained earlier. For instance, the "*min*" value in the figure corresponds to the value of 324. The b value corresponds to 695, the d value corresponds to 787, the f value corresponds to 880, and the "*max*" value corresponds to 1112, as determined in the last column of Table 3.2. The points of intersect between the various terms (a, c, e, g) are determined through geometric calculations.

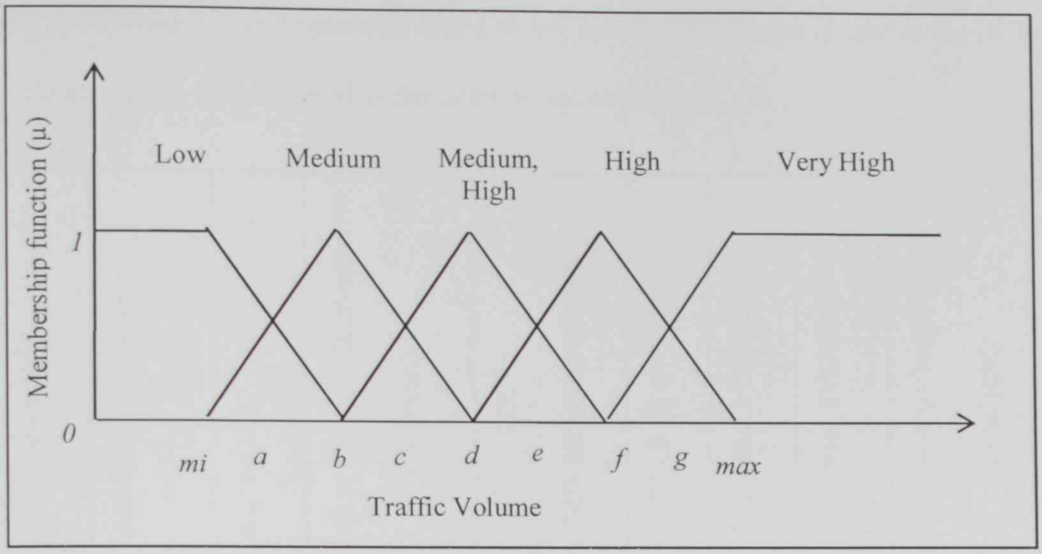


Figure 3.7: The membership function of the input (traffic volume) – Fuzzification

3.4.2 Verifying the fuzzification of the approach hourly volume

Following the estimation of the numerical ranges of the various fuzzy terms, and prior to running various simulation scenarios needed for the calibration of the rule base, a test was done to verify the set values of the various terms (the traffic flows per approach). In this test, different values of traffic flows were coded in SYNCHRO. For each traffic flow input and run, the intersection capacity utilization (ICU), the ICU LOS as well as Intersection delay-based LOS were recorded, in addition to the ICU value and the *v/c* ratio from SYNCHRO output as shown in Table 3.3 (columns 6, 7, 8 and 9). These SYNCHRO -based outputs were compared with the initial v/c value (column 1) and the LOS estimated by the HCM in column 5 (TRB- HCM Report 209). Table 3.3 shows the comparison between the SYNCHRO estimated LOS's based on the applied formulae for approach volume (as estimated in column 4) and the HCM based on the applied v/c ratio (column 1). The 5th and the 6th columns show almost identical results and LOS's. Note here that the SYNCHRO LOS estimated based on the ICU (which is itself estimated based on v/c ratios) gives closer results to the HCM estimated LOS, as compared to the delay-based estimated LOS.

Tested V/C	*Intersection v* (veh/hr) = = v/c * 5700	Reduction=(35%* Intersection *v*)	Approach *v* (veh/hr) = (Intersection *v*- Reduction)/4	LOS- (TRB- HCM Report 209)	ICU LOS (SYNCHRO)	ICU value SYNCHRO	V/C ratio- SYNCHRO	Intersection delay based LOS - SYNCHRO
0.3	1710	599	278	A	A	0.38	0.32	C
0.6	3420	1197	556	B	B	0.6	0.63	C
0.65	3705	1297	602	B	B	0.63	0.69	C
0.7	3990	1397	648	C	C	0.67	0.74	D
0.75	4275	1496	695	C	C	0.7	0.79	D
0.8	4560	1596	741	D	D	0.74	0.84	D
0.85	4845	1696	787	D	D	0.77	0.9	D
0.9	5130	1796	834	E	D	0.81	0.94	D
0.92	5244	1835	852	E	E	0.83	0.96	E
0.95	5415	1895	880	E	E	0.85	0.99	E
0.99	5643	1975	917	E	E	0.88	1.05	E
1	5700	1995	926	F	E	0.88	1.06	E
1.1	6270	2195	1019	F	F	0.95	1.15	F
1.2	6840	2394	1112	F	G	1.03	1.25	F
1.4	7980	2793	1297	F	H	1.17	1.46	F

Table 3.3: Comparison between LOS Values Estimated by SYNCHRO and Suggested Calculations

3.4.3 Simulation scenarios for data collection

Following the verification of the methodology suggested to estimate the approach flows that correspond to a specific *v/c* and HCM LOS, a total of 289 simulation experiments were determined necessary to cover all possible flow combinations along the various approaches of the tested intersection. The scenarios are carefully selected to cover all the possible "fuzzy" terms of the approach hourly volume (*Low, Medium, Medium to High, High,* and *Very High*) among the four approaches (East, West, North and South). These scenarios will serve as the replicates of the field data collection associated with optimal signal settings. The scenarios are used to measure the corresponding queues and the green times resulting from signal optimization. The measured values of each scenario will be then used to estimate the so-called green weight of each approach and then form a single (IF-THEN) rule in the first rule block. In this way, the derived fuzzy logic and its rule base will result in close to optimum solutions of the signal. Table 3.4 shows only a sample of the 289 simulation runs used to estimate the measures needed to calibrate the fuzzy logic rule base. Table A.1 in Appendix A shows the whole 289 simulation runs derived from the SYNCHRO simulation software. Following the conclusion of all the 289 simulation runs, the Minimum and Maximum values were estimated for each of the output variables, and were used to estimate the numerical domain to be split the fuzzy sets of these variables (fuzzification).

Approach Flow Fuzzy Term				Modeled Approach Flow (veh/hr)				The 95 Percentile Queue Length (m)				Green Times (sec)				Cycle length (sec)
E	W	N	S	E	W	N	S	E	W	N	S	E	W	N	S	
Low	low	low	low	324	324	324	324	24.4	24.4	24.4	24.4	16	16	16	16	80
Low	low	low	med	324	324	324	695	24.4	24.4	24.4	51.6	16	16	16	16	80
Low	low	low	med high	324	324	324	787	24.4	24.4	24.4	66.1	16	16	16	16	80
Low	low	low	high	324	324	324	880	24.4	24.4	24.4	78.2	16	16	16	16	80
med	low	low	low	695	324	324	324	51.6	24.4	24.4	24.4	16	16	16	16	80
med	low	low	med	695	324	324	695	51.6	24.4	24.4	51.6	16	16	16	16	80
med	low	med	low	695	324	695	324	51.6	24.4	51.6	24.4	16	16	16	16	80
med high	low	med	low	787	324	695	324	66.1	24.4	51.6	24.4	16	16	16	16	80
med high	low	med	med	787	324	695	695	66.1	24.4	51.6	51.6	16	16	16	16	80
med high	med	med	low	787	695	695	324	66.1	51.6	51.6	24.4	16	16	16	16	80
med high	med high	low	med high	787	787	324	787	66.1	66.1	24.4	66.1	16	16	16	16	80
med high	med high	low	high	787	787	324	880	66.1	66.1	24.4	78.2	16	16	16	16	80
med high	high	med	low	787	880	695	324	66.1	78.2	51.6	24.4	16	16	16	16	80
med high	high	med	med	787	880	695	695	66.1	78.2	51.6	51.6	16	16	16	16	80
high	med high	med	low	880	787	695	324	78.2	66.1	51.6	24.4	16	16	16	16	80
high	high	med high	med	880	880	787	695	69.5	82.2	75.7	65.6	22	19	17	16	90
high	high	med high	med high	880	880	787	787	75	82.2	75.7	75.7	21	19	17	17	90
high	high	med high	high	880	880	787	880	75	85.7	75.7	85.7	21	18	17	18	90
high	high	high	low	880	880	880	324	78.6	82.2	82.2	27.9	20	19	19	16	90
high	high	high	med	880	880	880	695	78.6	82.2	82.2	65.6	20	19	19	16	90
very high	low	very high	med	1112	324	1112	695	108.3	27.9	108.3	65.6	21	16	21	16	90
very high	low	very high	med high	1112	324	1112	787	108.3	27.9	108.3	79.3	21	16	21	16	90
very high	med	very high	med	1112	695	1112	695	108.3	65.6	108.3	65.6	21	16	21	16	90
very high	high	very high	med	1112	880	1112	695	104.7	92.9	111.9	65.6	22	16	20	16	90
very high	very high	very high	low	1112	1112	1112	324	126.4	126.4	126.4	34.5	26	26	26	16	110
very high	very high	very high	very high	1112	1112	1112	1112	179.1	179.1	179.1	179.1	36	36	36	36	160

Table 3.4: Sample of SYNCHRO Calibration Runs.

3.4.4 Fuzzification of the 95 percentile link queue variable

The minimum and maximum values of the 95 percentile queue length (m) on each approach were obtained for the 289 runs as shown in Table 3.5 below. The obtained values (minimum and maximum) were then used in estimating the domain for each of the fuzzy logic variable sets (the values of the fuzzy logic membership function) as exhibited in Figure 3.8. The fuzzy variable sets were spread equally along the domain estimated by the difference between the maximum and minimum values. The queue variable is divided into three terms; *low*, *medium* and *high*.

	95 percentile queue length (m)			
	East	West	North	South
Minimum	24.3	24.4	24.4	24.4
Maximum	179.1	179.1	179.1	179.1
Minimum of all approaches	24.3			
Maximum of all approaches	179.1			
Mean (Default)	58.33	57.70	62.69	58.71

Table 3.5: The Minimum and Maximum Values of the 95 Percentile Queue Length (m) for the 289 SYNCHRO Simulation Scenarios

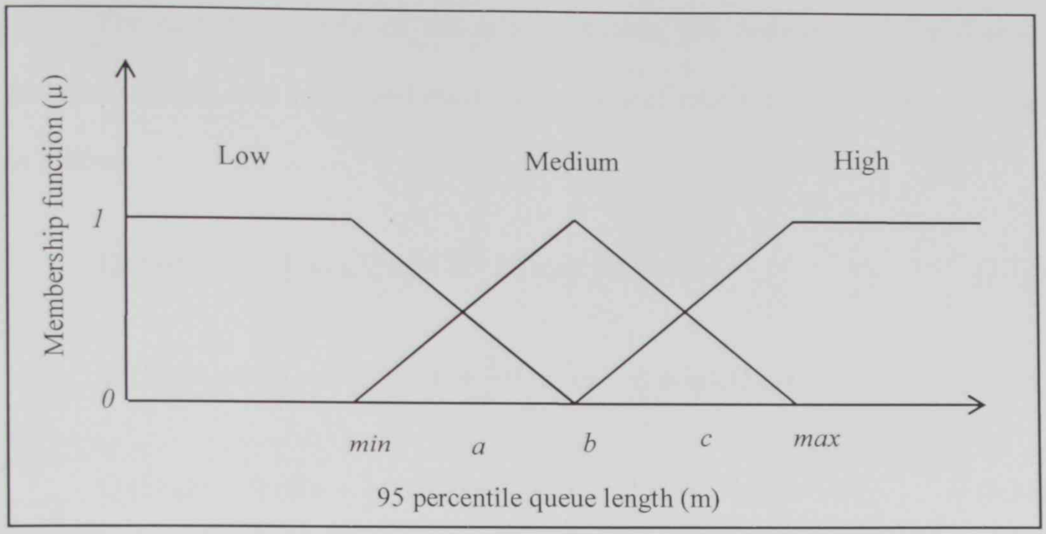


Figure 3.8: The membership function of the 95 percentile queue length (Fuzzification).

The estimation of the *a*, *b*, and *c* values in Figure 3.8 is done using Eqs (3.6-3.8)

$$a = Q\min + \frac{1}{4}\,(Q\max - Q\min) \tag{3.6}$$

$$b = Q\min + \frac{2}{4}\,(Q\max - Q\min) \tag{3.7}$$

$$c = Q\min + \frac{3}{4}\,(Q\max - Q\min) \tag{3.8}$$

The calculated values of *a*, *b*, and *c* were 63, 102, and 140 (m), respectively. The following "If-Then" statements were then applied for the fuzzification of the 95 percentile queue length (i.e. converting the numerical values into linguistic fuzzy terms).

If Q <= "*a*" → Q is *low "L"* (3.9)

If "*a*"< Q <= "c" → Q is *medium "M"* (3.10)

If Q > "*c*" → Q is *high "H"* (3.11)

For each fuzzy term of the queue variable, the definition of the domain {minimum value, mid value, and maximum value} of each fuzzy term was estimated as follows:

$$\text{Q (Low)}: \{0,\ \text{Q min}, \text{Q min} + \tfrac{2}{4}(\text{Q max} - \text{Q min})\} \tag{3.12}$$

$$\text{Q (Medium)}: \{\text{Q min}, \text{Q min} + \tfrac{2}{4}(\text{Q max} - \text{Q min}), \text{Q max}\} \tag{3.13}$$

$$\text{Q (High)}: \{\text{Q min} + \tfrac{2}{4}(\text{Q max} - \text{Q min}),\ \text{Q max},\ \text{Q max} +\} \tag{3.14}$$

3.4.5 Fuzzification of green weight variable

For each of the 289 simulation scenarios, the resulting green times for each of the competing split phases and the optimal cycle time were recorded, and were used to estimate the "green weight" (GW) of each phase as follows:

$$Green\ wight\ (GW) = \frac{Green\ time\ (sec)}{Totl\ green\ time\ (sec)} \tag{3.15}$$

$$Total\ Green\ time\ (sec) = Cycle\ time\ (sec) - no.of\ phases\ [All\ red\ (sec) + Yellow\ time\ (sec)] \tag{3.16}$$

In all simulation runs, the number of phases is 4, the all red time is 3 (sec) and the yellow time is 1 (sec).

The minimum and maximum values of GW for each approach were obtained for the 289 simulation scenarios as shown in Table 3.6. The minimum and maximum values were then used in estimating the domain for each of the GW fuzzy logic variable sets (the values of the fuzzy logic membership function) as exhibited in Figure 3.9. The fuzzy variable sets were spread equally along the domain estimated by the difference between the maximum and minimum values. The GW variable is divided into three terms; *low*, *medium* and *high*.

	Green Times (sec)				Green weights = Green time (sec)/Total Green time (sec)			
	East	West	North	South	East	West	North	South
Minimum	16	16	16	16	0.23	0.22	0.22	0.17
Maximum	36	36	36	36	0.30	0.28	0.31	0.31
Minimum of all approaches	16				0.170			
Maximum of all approaches	36				0.311			
Mean (Default)	17.2	16.6	17.0	16.5	0.25	0.25	0.25	0.25

Table 3.6: The Minimum and Maximum Values of the Green Times (sec) and Estimated Green Weights (GW) for the 289 SYNCHRO Simulation Scenarios

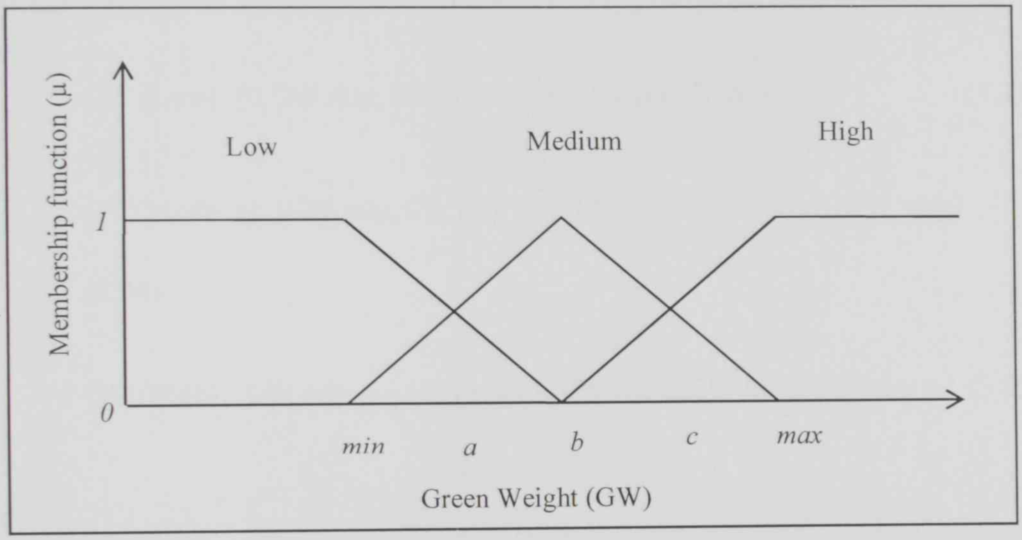


Figure 3.9: The membership function of the calculated green weights-(Fuzzification).

The estimation of the a, b, and c values of the GW variable in Figure 3.9 is done using Eqs (3.17-3.19)

$$a = GW\ min + \frac{1}{4}\ (GW\ max - GW\ min) \tag{3.17}$$

$$b = GW\ min + \frac{2}{4}\ (GW\ max - GW\ min) \tag{3.18}$$

$$c = GW\ min + \frac{3}{4}\ (GW\ max - GW\ min) \tag{3.19}$$

The calculated values of a, b, and c were 0.205, 0.241, and 0.276 respectively. The following "If-Then" statements were then applied for the fuzzification of the green weight (GW) variable (i.e. converting the numerical values into linguistic fuzzy terms).

If GW <= "*a*" → GW is *low "L"* (3.20)

If "*a*"< GW <= "*c*" → GW is *medium "M"* (3.21)

If GW > "*c*" → GW is *high "H"* (3.22)

For each fuzzy term of the GW variable, the definition of the domain {minimum value, mid value, and maximum value} of each fuzzy term was estimated as follows:

$$\text{GW (Low)}: \{0, \text{GW min}, \text{GW min} + \frac{2}{4}(\text{GW max} - \text{GW min})\} \tag{3.23}$$

$$\text{GW(Medium)}: \{\text{GW min}, \text{GW min} + \frac{2}{4}(\text{GW max} - \text{GW min}), \text{GW max}\}$$

(3.24)

$$\text{GW(High)}: \{\text{GW min} + \frac{2}{4}(\text{GW max} - \text{GW min}), \text{GW max}, \text{GW max} +\} \tag{3.25}$$

3.4.6 Fuzzification of cycle time variable

The minimum and maximum cycle time length were estimated from the results of the 289 simulation scenarios as shown in Table 3.7.

The minimum and maximum values were then used in estimating the domain for each of the cycle time (C) fuzzy logic variable sets (the values of the fuzzy logic membership function) as exhibited in Figure 3.10. The fuzzy variable sets were spread equally along the domain estimated by the difference between the maximum and minimum values. The C variable is divided into five terms; *low*, *low medium, medium, medium high* and *high*. The variable is split into five terms (instead of three as in the case of the queue and the GW) because the FLM performance is expected to be quite sensitive to the cycle time value, and as such more discretization of the output term would result in more accurate system.

	Cycle length (sec)
Minimum	80
Maximum	160
Mean (Default)	83.39

Table 3.7: The Minimum and Maximum Values of the Cycle Time (sec) for the 289 SYNCHRO Simulation Scenarios

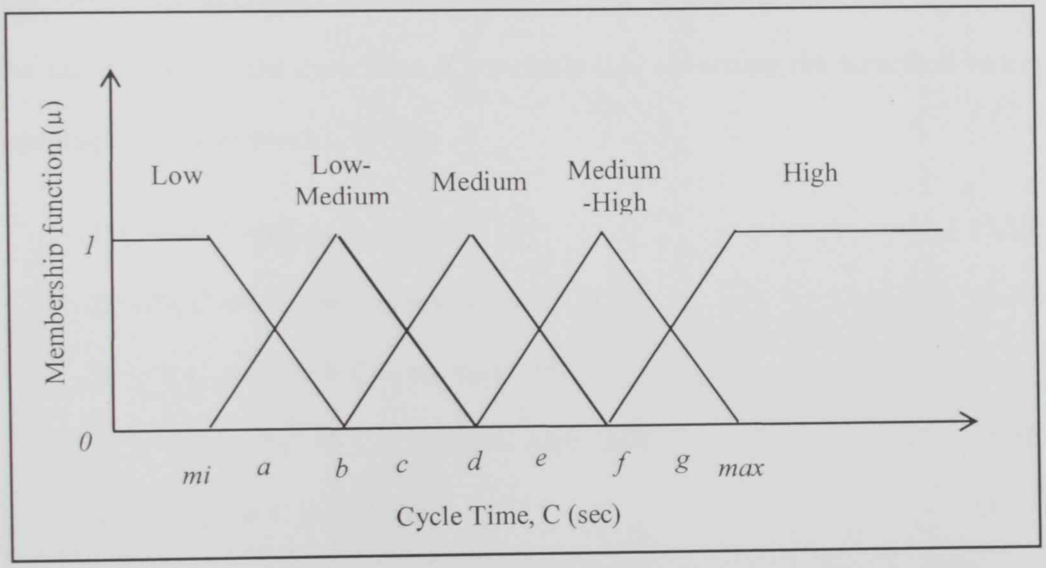


Figure 3.10: The membership function of the cycle time (C), (Fuzzification).

The estimation of the *a, b, c, d, e, f* and *g* values of the cycle time (C) variable in Figure 3.10 is done using Eqs (3.26-3.32)

$$a = C\,min + \frac{1}{8}\,(C\,max - C\,min) \quad (3.26)$$

$$b = C\,min + \frac{2}{8}\,(C\,max - C\,min) \quad (3.27)$$

$$c = C\,min + \frac{3}{8}\,(C\,max - C\,min) \quad (3.28)$$

$$d = C\,min + \frac{4}{8}\,(C\,max - C\,min) \quad (3.29)$$

$$e = C\,min + \frac{5}{8}\,(C\,max - C\,min) \quad (3.30)$$

$$f = C\,min + \frac{6}{8}\,(C\,max - C\,min) \quad (3.31)$$

$$g = C\,min + \frac{7}{8}\,(C\,max - C\,min) \quad (3.32)$$

The calculated values of *a, b, c, d, e, f,* and *g* were 90, 100, 110, 120, 130, 140, and 150 (sec), respectively. The following "If-Then" statements were then applied for the fuzzification of the cycle time (C) variable (i.e. converting the numerical values into linguistic fuzzy terms).

If C <= "*a*" → C is *low "L"* (3.33)

If "*a*"< C <= "*c*" → C is *low- medium "LM"* (3.34)

If "*c*"< C <= "*e*" → C is *medium "M"* (3.35)

If "*e*"< C <= "*g*" → C is *medium- high "MH"* (3.36)

If C > "*g*" → C is *high "H"* (3.37)

For each fuzzy term of the C variable, the definition of the domain {minimum value, mid value, and maximum value} of each fuzzy term was estimated as follows:

$$\text{C (Low)}: \{0, \text{C min}, \text{C min} + \frac{2}{8}(\text{C max} - \text{C min})\} \quad (3.38)$$

$$\text{C (Low-Medium)}: \{\text{C min}, \text{C min} + \frac{2}{8}(\text{C max} - \text{C min}), \text{C min} + \frac{4}{8}(\text{C max} - \text{C min})\} \quad (3.39)$$

$$\text{C (Medium)}: \{\text{C min} + \frac{2}{8}(C_{max} - C_{min}), \text{C min} + \frac{4}{8}(\text{C max} - \text{C min}), \text{C min} + \frac{6}{8}(\text{C max} - \text{C min})\} \quad (3.40)$$

$$\text{C (Medium-High)}: \{\text{C min} + \frac{4}{8}(\text{C max} - \text{C min}), \text{C min} + \frac{6}{8}(\text{C max} - \text{C min}), \text{C max}\} \quad (3.41)$$

$$\text{C, High}: \{\text{C min} + \frac{6}{8}(\text{C max} - \text{C min}), \text{C max}, \text{C max} +\} \quad (3.42)$$

3.4.7 Fuzzification of the downstream congestion, DSC

The downstream congestion variable (DSC) is estimated to reflect on the degree of the blockage of on the downstream approach of a specific signal phase or lane group. Eq. (3.43) is used to estimate the DSC numerical value. For any specific link, its congestion index is simply the proportion of the queue length (m) to the link length. For any specific phase, the blockage on the downstream link to which this phase feeds vehicles play important role in effectiveness of its green time allocation. If the link is fully blocked, it is advisable to entirely stop sending more cars to this link, even if the phase upstream approach has high (GW) allocation based on the competing upstream link flows. The inclusion of the DSC variable is very important and enhances the devised signal logic significantly. By including the variable, the logic can be regarded as a quasi-network control instead of only isolated signal control. That is, by accounting for the status of congestion on the downstream approaches, the signal control would now consider the upstream approach flows in estimating the green weights (GW), and then use the status of congestion on the downstream links in "readjusting" these green weights into more reasonable final ones (GWF). If there is no blockage on the downstream links, the estimated final green weights (GWF) would simply match the initially estimated ones (GW).

$$Downstream\ Congestion\ Index\ (\%), DSC = 100\ x\ \frac{Queue\ length\ (m)}{Link\ length(m)} \quad (3.43)$$

The minimum and maximum downstream congestion values were estimated from the results of the 289 simulation scenarios as shown in Table 3.8. These values were then used in estimating the domain for each of the downstream congestion (DSC) fuzzy logic variable sets (the values of the fuzzy logic membership function) as exhibited in Figure 3.11. The fuzzy variable sets were spread equally along the domain estimated by the difference between the maximum and minimum values. The DSC variable is divided into three terms; *low, medium* and *high*.

	Downstream Congestion Index, DSC = (Queue Length /L) *100			
	East	West	North	South
Minimum	4.86	4.88	4.88	4.88
Maximum	35.82	35.82	35.82	35.82
Minimum of all approaches	4.860			
Maximum of all approaches	35.820			
Mean (Default)	11.67	11.54	12.54	11.74

Table 3.8: The Minimum and Maximum Values of the Downstream Congestion Index for the 289 SYNCHRO Simulation Scenarios.

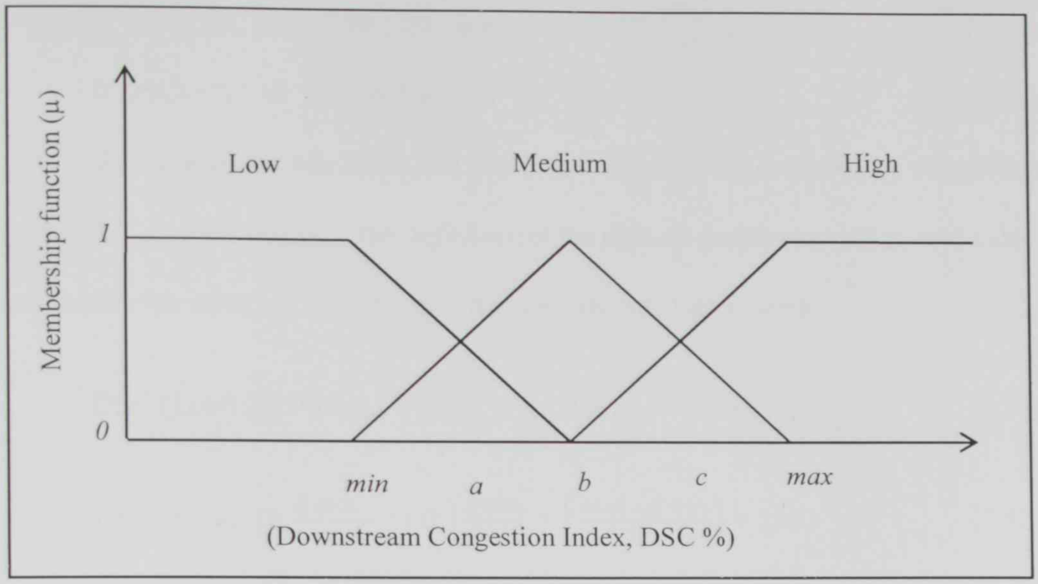


Figure 3.11: The membership function of the downstream congestion index (DSC).

The estimation of the *a, b* and *c* values of the downstream congestion index (DSC) variable in Figure 3.11 is done using Eqs (3.44-3.47)

$$a= \frac{Q\,min}{L} * 100 + \frac{1}{4}\left(\frac{Q\,max - Q\,min}{L}\right) * 100 \quad (3.44)$$

$$b= \frac{Q\,min}{L} * 100 + \frac{2}{4}\left(\frac{Q\,max - Q\,min}{L}\right) * 100 \quad (3.45)$$

$$c= \frac{Q\,min}{L} * 100 + \frac{3}{4}\left(\frac{Q\,max - Q\,min}{L}\right) * 100 \quad (3.46)$$

$$DSC_{Min} = \frac{Q_{min}}{L} * 100, DSC_{Max} = \frac{Q_{max}}{L} * 100 \quad (3.47)$$

The calculated values of *a, b* and *c* were 12.6, 20.34 and 28.08, respectively. Moreover, both DSC_{Min} and DSC_{Max} were estimated as 4.86, and 35.82, respectively. The following "If-Then" statements were then applied for the fuzzification of the downstream congestion index (DSC) variable (i.e. converting the numerical values into linguistic fuzzy terms).

If DSC <= "*a*" → DSC is *low "L"* (3.48)

If "*a*"< DSC <= "*c*" → DSC is *medium "M"* (3.49)

If DSC > "*c*" → DSC is *high "H"* (3.50)

By knowing the minimum and maximum values of the downstream congestion index: DSC_{Min}, and DSC_{Max}, the definition of the domain {minimum value, mid value, and maximum value} of each fuzzy term was estimated as follows:

$$\text{DSC (Low):}\{0, DSC_{Min}, DSC_{Min} + \frac{2}{4}(DSC_{Max} - DSC_{Min})\} \quad (3.51)$$

$$\text{DSC (Low): }\{0, \frac{Q\,min}{L} * 100, \left(\frac{Q\,min}{L} + \frac{Q\max - Q\,min}{2L}\right) * 100\} \quad (3.52)$$

$$\text{DSC (Medium):}\{DSC_{Min}, DSC_{Min} + \frac{2}{4}(DSC_{Max} - DSC_{Min}),\ DSC_{Max}\}$$

(3.53)

$$\text{DSC (Medium): }\{\frac{Q\,min}{L} * 100, \left(\frac{Q\,min}{L} + \frac{Q\max - Q\,min}{2L}\right) * 100, \frac{Q\,max}{L} * 100\}$$

(3.54)

$$\text{DSC (High): }\left\{DSC_{Min} + \frac{2}{4}(DSC_{Max} - DSC_{Min}), DSC_{Max}, DSC_{Max} +\right\}$$

(3.55)

$$\text{DSC (High): }\{\ \left(\frac{Q\,min}{L} + \frac{Q\max - Q\,min}{2L}\right) * 100, \frac{Q\,max}{L} * 100, \frac{Q\,max+}{L} * 100\}$$

(3.56)

3.4.8 Fuzzification of the final green weight

The final green weight "GWF" of any approach is set intuitively based on two main input variables; namely the green weight (GW) of the (upstream) approach (the lane group) as well as the congestion index of the downstream link (DSC) to which the lane group feeds vehicles. The rule blocks 2, 3, 4 and 5 operate the same logic (as shown in Figures 3.2 through 3.5) - one for each lane group (or approach). Each of these rule blocks employs the IF-THEN statements shown in Table 3.9. The rationale behind the logic is to set the final green weight similar to the initially estimated green weight (using the upstream flow estimates). As the congestion on the downstream approach increases, the "final" green weight is decreased and it reaches its lowest value when the downstream approach congestion index reaches its maximum value.

By applying the rules in Table 3.9 to the traffic conditions (green weights and congestion status on downstream links) depicted any of the simulation scenarios, the initially estimated green weights were readjusted. Table 3.10 shows a sample of the 289 scenarios with modified final green weights.

IF			Then
Green Weight of approach, *i "GWi"*	and	Congestion Index of Downstream Approach "DSC"	Final Green Weight for approach, i *"GWFi"*
Low "L"	and	*Low "L"*	*Low "L"*
Medium "M"	and	*Low "L"*	*Medium "M"*
High "H"	and	*Low "L"*	*High "H"*
Low "L"	and	*Medium "M"*	*Low "L"*
Medium "M"	and	*Medium "M"*	*Low "L"*
High "H"	and	*Medium "M"*	*Medium "M"*
Low "L"	and	*High "H"*	*Low "L"*
Medium "M"	and	*High "H"*	*Low "L"*
High "H"	and	*High "H"*	*Low "L"*

Table 3.9: The IF-THEN Statements of the Rule Block of the Final Green Weight Variable Estimation

Green weights variables				Downstream Congestion variables, DSC variables				Green Weight Final, "GWF" (sec)			
East	West	North	South	East	West	North	South	East	West	North	South
M	M	M	M	L	L	L	L	M	M	M	M
M	M	M	M	L	L	L	L	M	M	M	M
M	M	M	M	M	M	M	L	L	L	L	M
M	M	M	M	M	M	M	M	L	L	L	L
M	M	M	M	M	M	M	M	L	L	L	L
H	M	H	M	M	L	M	M	M	M	M	L
H	M	H	M	M	M	M	M	M	L	M	L
H	M	H	M	M	M	M	M	M	L	M	L
H	M	H	M	M	M	M	M	M	L	M	L
H	M	M	M	M	M	M	L	M	L	L	M
H	M	M	M	M	M	M	M	M	L	L	L
H	M	H	L	M	M	M	M	M	L	M	L
H	M	H	M	M	M	M	M	M	L	M	L
H	H	H	L	M	M	M	L	M	M	M	L
H	M	M	L	H	H	H	M	L	L	L	L
M	M	M	L	H	H	H	M	L	L	L	L
M	M	M	M	H	H	H	M	L	L	L	L
M	M	M	M	H	H	H	H	L	L	L	L

Table 3.10: Final Green Weight (GWF) Estimates on a Sample of the 289 Scenarios

This chapter has reviewed the suggested methodology in the fuzzification process of all the FLM variables. All memberships were defined and all the numerical value ranges were determined. Following the application of these fuzzy membership functions, and the selection of the 289 simulation scenarios, the simulation/optimization process (SYNCHRO) was carried out to map the input and output variables (of the first rule block).

Once the first rule block is calibrated, all five blocks were coded as one integrated FLM using a specialized software (FuzzyTECH) for testing and verification of the devised logic effectiveness. The application of the FuzzyTECH software, the calibration of the IF-THEN statements in the first rule block will be discussed in more details in Chapter 4.

3.5 Phase Sequencing Concept

This section address the concept of phase sequencing. Implementing such concept in real-time environment requires the use of link detectors to extract the FLM inputs. In principle, phase sequencing is essentially implemented by selecting the phase of highest final green weight. For instance; if the current green phase is the East bound phase, then the next phase would be the one which has the highest final green weight among the other three competing phases (West, North, and South). As the signal timing would be updated each cycle, the phase sequence could be changed each cycle.

In summary, the phase sequencing starts by comparing the final green weights of the competing phases following the current green phase. The arrangement of the phases would be based on serving the highest first, then the second highest, etc.

Chapter 4: Calibration of the Proposed Fuzzy Logic Model

4.1 Introduction

This chapter covers the aspects of the development of the FLM using the FuzzyTECH software. It covers the specification of all model inputs, outputs as well as the specification of the IF-THEN rules of the various rule blocks. Furthermore, it presents the results of testing the FLM and the closeness of its outputs vis-à-vis the SYNCHRO solutions.

4.2 The proposed Fuzzy logic Model (FLM)

Using the FuzzyTECH software, the proposed model was built, fuzzy rules were defined for all blocks, and the membership functions of all variables (inputs and outputs) were defined as well, based on the specifications of all variables discussed in Chapter 3.

Figure 4.1 shows the structure of the proposed fuzzy logic model (FLM). The FLM has five main rule blocks. The first one (seen on Figure 4.1 in two parts) is responsible for estimating the green weight (GW), the estimation of the queue length on each incoming approach, and the estimation of the Cycle length (C). The inputs to this rule block includes only the incoming approaches flow rates. The second rule block estimates the final green weight for the East bound approach using the estimated green weight (GW) of the first rule block as well as the estimates of the downstream congestion index (DSC). The output of this rule block is the final green weight for the East approach. Similarly, the third, fourth, and fifth rule blocks are identical to the second rule block and for the other competing approaches.

The input variables' membership functions are shown in Figures 4.2 and 4.3. Figures 4.4, 4.5, 4.6, 4.7, and 4.8 show the fuzzy logic rule for the various rule blocks.

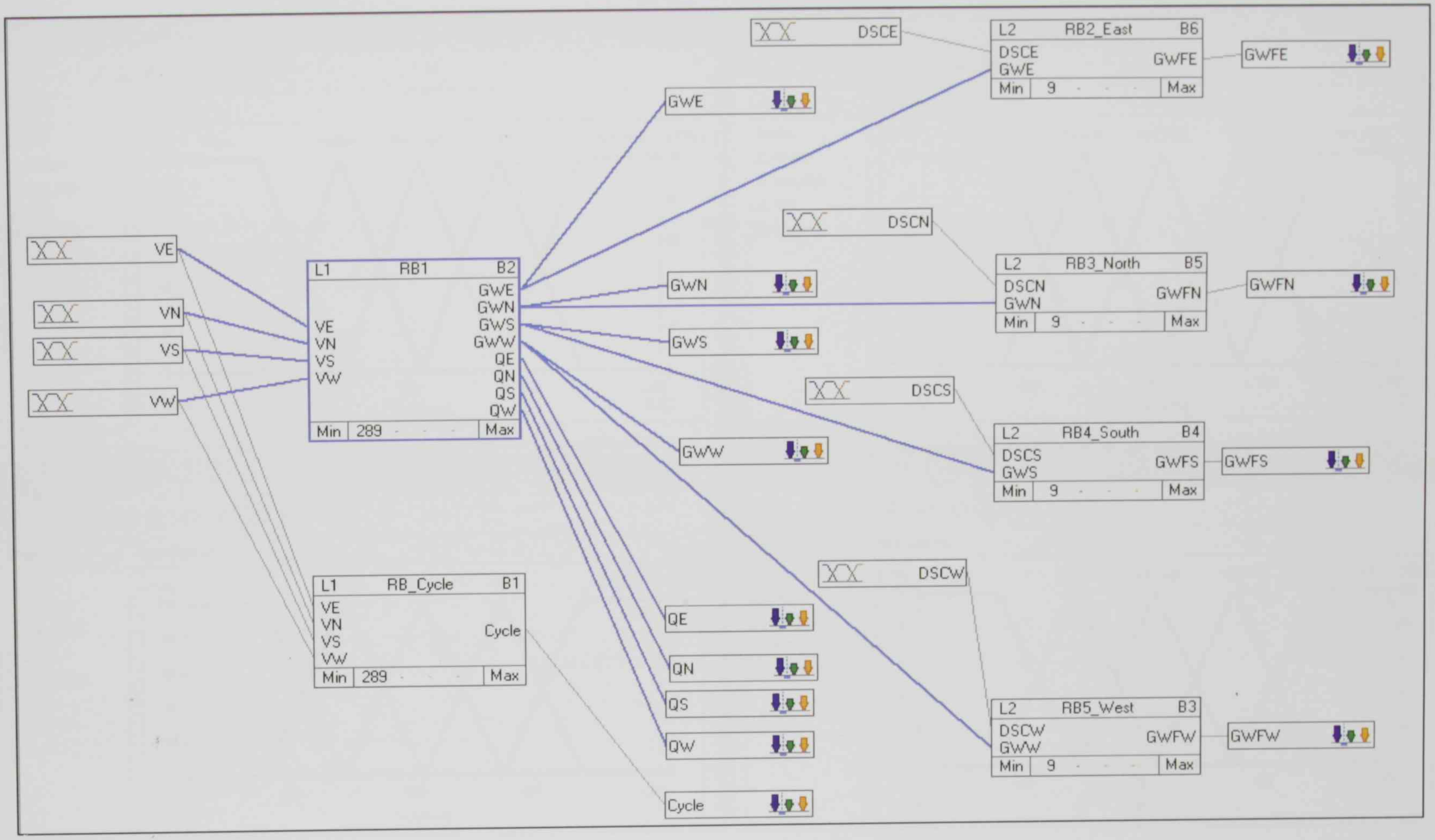


Figure 4.1: Fuzzy logic model (FLM) structure

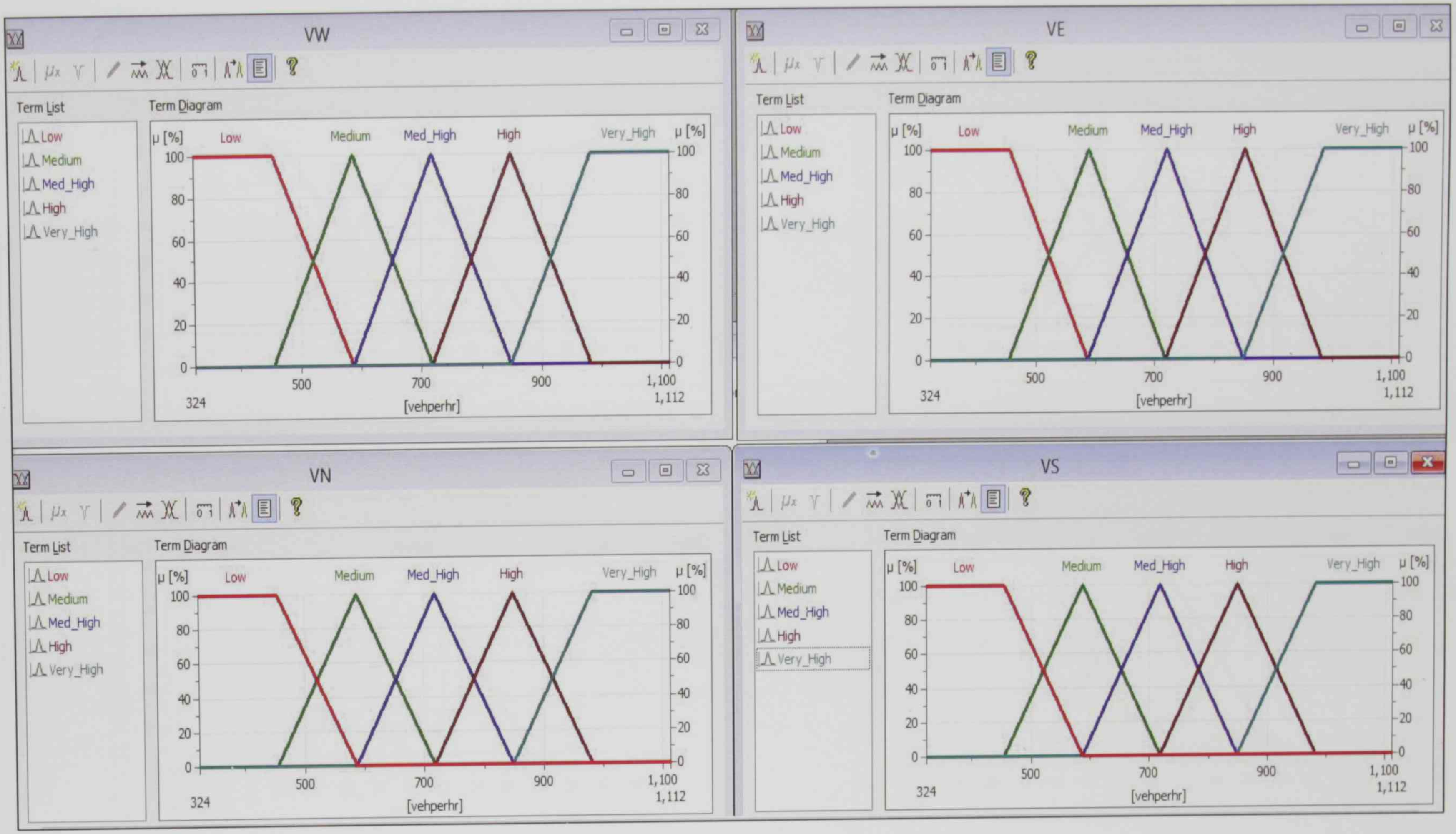


Figure 4.2: Membership functions of the approaches' traffic volumes input variables

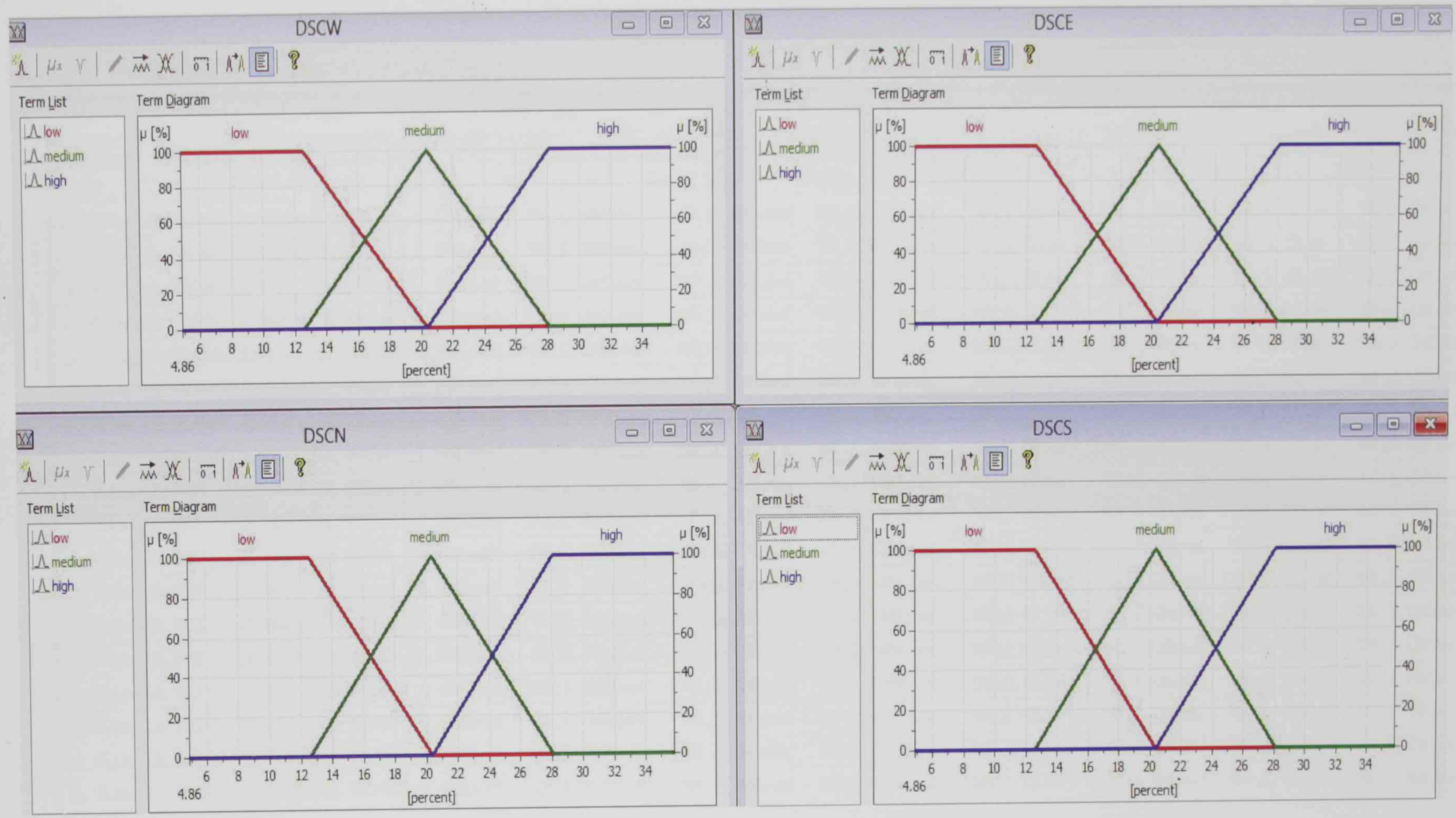
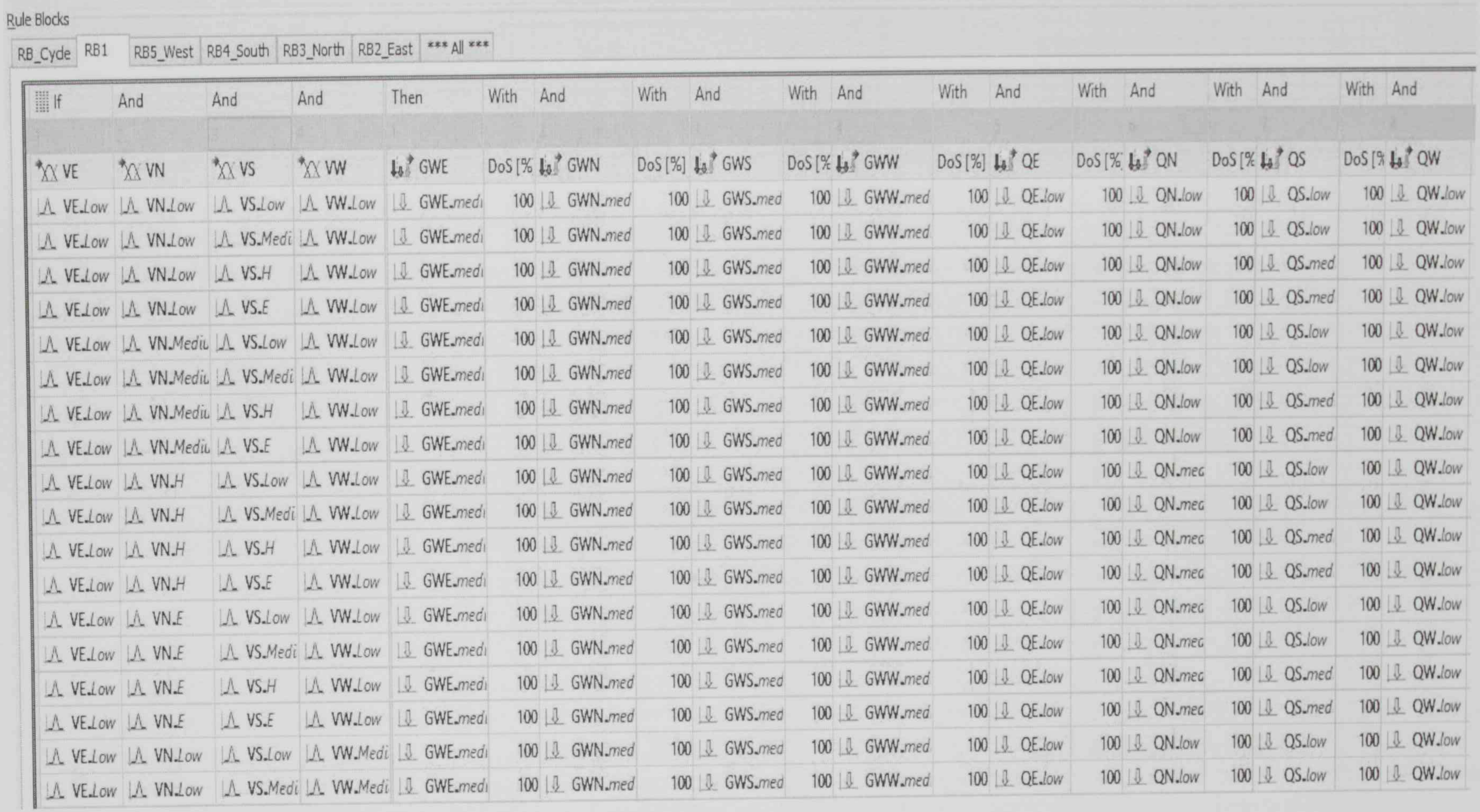


Figure 4.3: Membership functions of the downstream congestion input variables



Rule Blocks

RB_Cycle | RB1 | RB5_West | RB4_South | RB3_North | RB2_East | *** All ***

If	And	And	And	Then	With	And	With	And	With	And	With	And	With	And	With	And	With	And
VE	VN	VS	VW	GWE	DoS [%	GWN	DoS [%]	GWS	DoS [%	GWW	DoS [%]	QE	DoS [%	QN	DoS [%	QS	DoS [%	QW
VE.Low	VN.Low	VS.Low	VW.Low	GWE.medi	100	GWN.med	100	GWS.med	100	GWW.med	100	QE.low	100	QN.low	100	QS.low	100	QW.low
VE.Low	VN.Low	VS.Medi	VW.Low	GWE.medi	100	GWN.med	100	GWS.med	100	GWW.med	100	QE.low	100	QN.low	100	QS.low	100	QW.low
VE.Low	VN.Low	VS.H	VW.Low	GWE.medi	100	GWN.med	100	GWS.med	100	GWW.med	100	QE.low	100	QN.low	100	QS.med	100	QW.low
VE.Low	VN.Low	VS.E	VW.Low	GWE.medi	100	GWN.med	100	GWS.med	100	GWW.med	100	QE.low	100	QN.low	100	QS.med	100	QW.low
VE.Low	VN.Mediu	VS.Low	VW.Low	GWE.medi	100	GWN.med	100	GWS.med	100	GWW.med	100	QE.low	100	QN.low	100	QS.low	100	QW.low
VE.Low	VN.Mediu	VS.Medi	VW.Low	GWE.medi	100	GWN.med	100	GWS.med	100	GWW.med	100	QE.low	100	QN.low	100	QS.low	100	QW.low
VE.Low	VN.Mediu	VS.H	VW.Low	GWE.medi	100	GWN.med	100	GWS.med	100	GWW.med	100	QE.low	100	QN.low	100	QS.med	100	QW.low
VE.Low	VN.Mediu	VS.E	VW.Low	GWE.medi	100	GWN.med	100	GWS.med	100	GWW.med	100	QE.low	100	QN.low	100	QS.med	100	QW.low
VE.Low	VN.H	VS.Low	VW.Low	GWE.medi	100	GWN.med	100	GWS.med	100	GWW.med	100	QE.low	100	QN.mec	100	QS.low	100	QW.low
VE.Low	VN.H	VS.Medi	VW.Low	GWE.medi	100	GWN.med	100	GWS.med	100	GWW.med	100	QE.low	100	QN.mec	100	QS.low	100	QW.low
VE.Low	VN.H	VS.H	VW.Low	GWE.medi	100	GWN.med	100	GWS.med	100	GWW.med	100	QE.low	100	QN.mec	100	QS.med	100	QW.low
VE.Low	VN.H	VS.E	VW.Low	GWE.medi	100	GWN.med	100	GWS.med	100	GWW.med	100	QE.low	100	QN.mec	100	QS.med	100	QW.low
VE.Low	VN.E	VS.Low	VW.Low	GWE.medi	100	GWN.med	100	GWS.med	100	GWW.med	100	QE.low	100	QN.mec	100	QS.low	100	QW.low
VE.Low	VN.E	VS.Medi	VW.Low	GWE.medi	100	GWN.med	100	GWS.med	100	GWW.med	100	QE.low	100	QN.mec	100	QS.low	100	QW.low
VE.Low	VN.E	VS.H	VW.Low	GWE.medi	100	GWN.med	100	GWS.med	100	GWW.med	100	QE.low	100	QN.mec	100	QS.med	100	QW.low
VE.Low	VN.E	VS.E	VW.Low	GWE.medi	100	GWN.med	100	GWS.med	100	GWW.med	100	QE.low	100	QN.mec	100	QS.med	100	QW.low
VE.Low	VN.Low	VS.Low	VW.Medi	GWE.medi	100	GWN.med	100	GWS.med	100	GWW.med	100	QE.low	100	QN.low	100	QS.low	100	QW.low
VE.Low	VN.Low	VS.Medi	VW.Medi	GWE.medi	100	GWN.med	100	GWS.med	100	GWW.med	100	QE.low	100	QN.low	100	QS.low	100	QW.low

Figure 4.4: Sample of IF-THEN rules in the first rule block

Rule Blocks

RB_Cycle | RB1 | RB5_West | RB4_South | RB3_North | RB2_East | *** All ***

	Name	If	And	Operators	Then	With	Comment
B6	RB2_East			Min / Max			
B6.G1		DSCE	GWE		GWFE	DoS [%]	
B6.G1.R1		DSCE.*low*	GWE.*low*	=>	GWFE.*low*	100	
B6.G1.R2		DSCE.*low*	GWE.*medium*	=>	GWFE.*medium*	100	
B6.G1.R3		DSCE.*low*	GWE.*high*	=>	GWFE.*high*	100	
B6.G1.R4		DSCE.*medium*	GWE.*low*	=>	GWFE.*low*	100	
B6.G1.R5		DSCE.*medium*	GWE.*medium*	=>	GWFE.*low*	100	
B6.G1.R6		DSCE.*medium*	GWE.*high*	=>	GWFE.*medium*	100	
B6.G1.R7		DSCE.*high*	GWE.*low*	=>	GWFE.*low*	100	
B6.G1.R8		DSCE.*high*	GWE.*medium*	=>	GWFE.*low*	100	
B6.G1.R9		DSCE.*high*	GWE.*high*	=>	GWFE.*low*	100	
*							

Figure 4.5: Sample of IF-THEN rules in the second rule block

Rule Blocks

RB_Cycle | RB1 | RB5_West | RB4_South | RB3_North | RB2_East | *** All ***

	Name	If	And	Operators	Then	With	Comment
B5	RB3_North			Min / Max			
B5.G1		DSCN	GWN		GWFN	DoS [%]	
B5.G1.R1		DSCN.*low*	GWN.*low*	=>	GWFN.*low*	100	
B5.G1.R2		DSCN.*low*	GWN.*medium*	=>	GWFN.*medium*	100	
B5.G1.R3		DSCN.*low*	GWN.*high*	=>	GWFN.*high*	100	
B5.G1.R4		DSCN.*medium*	GWN.*low*	=>	GWFN.*low*	100	
B5.G1.R5		DSCN.*medium*	GWN.*medium*	=>	GWFN.*low*	100	
B5.G1.R6		DSCN.*medium*	GWN.*high*	=>	GWFN.*medium*	100	
B5.G1.R7		DSCN.*high*	GWN.*low*	=>	GWFN.*low*	100	
B5.G1.R8		DSCN.*high*	GWN.*medium*	=>	GWFN.*low*	100	
B5.G1.R9		DSCN.*high*	GWN.*high*	=>	GWFN.*low*	100	

Figure 4.6: Sample of IF-THEN rules in the third rule block

Rule Blocks

RB_Cycle | RB1 | RB5_West | RB4_South | RB3_North | RB2_East | *** All ***

	Name	If	And	Operators	Then	With	Comment
B4	RB4_South			Min / Max			
B4.G1		DSCS	GWS		GWFS	DoS [%]	
B4.G1.R1		DSCS.low	GWS.low	=>	GWFS.low	100	
B4.G1.R2		DSCS.low	GWS.medium	=>	GWFS.medium	100	
B4.G1.R3		DSCS.low	GWS.high	=>	GWFS.high	100	
B4.G1.R4		DSCS.medium	GWS.low	=>	GWFS.low	100	
B4.G1.R5		DSCS.medium	GWS.medium	=>	GWFS.low	100	
B4.G1.R6		DSCS.medium	GWS.high	=>	GWFS.medium	100	
B4.G1.R7		DSCS.high	GWS.low	=>	GWFS.low	100	
B4.G1.R8		DSCS.high	GWS.medium	=>	GWFS.low	100	
B4.G1.R9		DSCS.high	GWS.high	=>	GWFS.low	100	
*							

Figure 4.7: Sample of IF-THEN rules in the fourth rule block

Rule Blocks

RB_Cycle | RB1 | RB5_West | RB4_South | RB3_North | RB2_East | *** All ***

	Name	If	And	Operators	Then	With	Comment
B3	RB5_West			Min / Max			
B3.G1		DSCW	GWW		GWFW	DoS [%]	
B3.G1.R1		DSCW.low	GWW.low	=>	GWFW.low	100	
B3.G1.R2		DSCW.low	GWW.medium	=>	GWFW.medium	100	
B3.G1.R3		DSCW.low	GWW.high	=>	GWFW.high	100	
B3.G1.R4		DSCW.medium	GWW.low	=>	GWFW.low	100	
B3.G1.R5		DSCW.medium	GWW.medium	=>	GWFW.low	100	
B3.G1.R6		DSCW.medium	GWW.high	=>	GWFW.medium	100	
B3.G1.R7		DSCW.high	GWW.low	=>	GWFW.low	100	
B3.G1.R8		DSCW.high	GWW.medium	=>	GWFW.low	100	
B3.G1.R9		DSCW.high	GWW.high	=>	GWFW.low	100	

Figure 4.8: Sample of IF-THEN rules in the fifth rule block

To construct the IF-THEN rules in each rule blocks, the results of the 289 simulation/optimization SYNCHRO model scenarios were recorded. Sample of the inputs and outputs extracted from these scenarios are illustrated in Table 4.1 and Table 4.2.

The numerical values of the approaches traffic volumes (shown in table 4.1) were transformed into corresponding fuzzy terms, following the definition of the traffic volume membership function (in Chapter 3). In Table 4.2, the output numerical values of the first rule block (extracted from the simulation/optimization), are fuzzified into the corresponding fuzzy terms. The merging of the fuzzy terms in tables 4.1 and 4.2 (for each raw) would form one IF-THEN rule in the first rule block. As such, given that we have 289 simulation/optimization scenarios, a total of 289 IF-THEN rules are coded for the first rule block. The output data of the FLM for all studied scenarios are provided in Table B.1 in Appendix B.

Fuzzy Variable Term				**Approach Traffic Flow (veh/hr)**			
E	**W**	**N**	**S**	**E**	**W**	**N**	**S**
L	L	L	L	324	324	324	324
L	L	L	M	324	324	324	695
L	L	L	MH	324	324	324	787
L	L	L	H	324	324	324	880
L	L	M	L	324	324	695	324
L	L	M	M	324	324	695	695
L	L	M	MH	324	324	695	787
L	L	M	H	324	324	695	880
L	L	MH	L	324	324	787	324
L	L	MH	M	324	324	787	695
L	L	MH	MH	324	324	787	787
L	L	MH	H	324	324	787	880
L	L	H	L	324	324	880	324
L	L	H	M	324	324	880	695
L	L	H	MH	324	324	880	787
L	L	H	H	324	324	880	880
L	M	L	L	324	695	324	324
L	M	L	M	324	695	324	695
L	M	L	MH	324	695	324	787
L	M	L	H	324	695	324	880

* Fuzzy terms clarification: "L": Low, "M": Medium, "MH": Medium to High, "H": High, "VH": Very High.

Table 4.1: Sample of Approaches Traffic Flows Input variables (Numeric and Corresponding Fuzzy Terms) – Inputs of First Rule Block

95 Percentile Queue (m)				Green Weight (GW) = Approach Green Time/Total Green Time				Cycle length (sec)	95 Percentile Queue Fuzzy Variable				Green Weight (GW) Fuzzy Variable				Cycle Time (C) Fuzzy Variable
E	W	N	S	E	W	N	S		E	W	N	S	E	W	N	S	
24.4	24.4	24.4	24.4	0.25	0.25	0.25	0.25	80	L	L	L	L	M	M	M	M	L
24.4	24.4	24.4	51.6	0.25	0.25	0.25	0.25	80	L	L	L	L	M	M	M	M	L
24.4	24.4	24.4	66.1	0.25	0.25	0.25	0.25	80	L	L	L	M	M	M	M	M	L
24.4	24.4	24.4	78.2	0.25	0.25	0.25	0.25	80	L	L	L	M	M	M	M	M	L
24.4	24.4	51.6	24.4	0.25	0.25	0.25	0.25	80	L	L	L	L	M	M	M	M	L
24.4	24.4	51.6	51.6	0.25	0.25	0.25	0.25	80	L	L	L	L	M	M	M	M	L
24.4	24.4	51.6	66.1	0.25	0.25	0.25	0.25	80	L	L	L	M	M	M	M	M	L
24.4	24.4	51.6	78.2	0.25	0.25	0.25	0.25	80	L	L	L	M	M	M	M	M	L
24.4	24.4	66.1	24.4	0.25	0.25	0.25	0.25	80	L	L	M	L	M	M	M	M	L
24.4	24.4	66.1	51.6	0.25	0.25	0.25	0.25	80	L	L	M	L	M	M	M	M	L
24.4	24.4	66.1	66.1	0.25	0.25	0.25	0.25	80	L	L	M	M	M	M	M	M	L
24.4	24.4	66.1	78.2	0.25	0.25	0.25	0.25	80	L	L	M	M	M	M	M	M	L
24.4	24.4	78.2	24.4	0.25	0.25	0.25	0.25	80	L	L	M	L	M	M	M	M	L
24.4	24.4	78.2	51.6	0.25	0.25	0.25	0.25	80	L	L	M	L	M	M	M	M	L
24.4	24.4	78.2	66.1	0.25	0.25	0.25	0.25	80	L	L	M	M	M	M	M	M	L
24.4	24.4	78.2	78.2	0.25	0.25	0.25	0.25	80	L	L	M	M	M	M	M	M	L
24.4	51.6	24.4	24.4	0.25	0.25	0.25	0.25	80	L	L	L	L	M	M	M	M	L
24.4	51.6	24.4	51.6	0.25	0.25	0.25	0.25	80	L	L	L	L	M	M	M	M	L
24.4	51.6	24.4	66.1	0.25	0.25	0.25	0.25	80	L	L	L	M	M	M	M	M	L
24.3	51.6	24.4	78.2	0.25	0.25	0.25	0.25	80	L	L	L	M	M	M	M	M	L

Table 4.2: Sample of the First Rule Block Output Variables (Numeric and Corresponding Fuzzy Terms)

4.3 Data Analysis

This section will particularly cover the analysis of the FuzzyTECH –based FLM outputs versus the SYNCHRO –based outputs, for each of the 289 simulation/optimization scenarios. Descriptive as well as comparative analyses are presented to quantify the percentages of difference of both models' outputs.

4.3.1 Descriptive analysis

To summarize the overall output data of the 289 simulation scenarios for each approach and for all approaches as well, a Descriptive Statistical Analysis (DSA) was conducted for each of the proposed FLM outputs (as shown in Table 4.3). For each output variable, different statistical measures were estimated including; minimum, maximum, mean, median, and the standard deviation (STDV).

Descriptive Statistics	Cycle (sec)	95 Percentile Queue (m)				% Green Weight (GW)				% Final Green Weight (GWF)				% Difference (GWF) and (GW)			
		E	W	N	S	E	W	N	S	E	W	N	S	E	W	N	S
Minimum	86.7	43.6	43.6	43.6	43.6	24.1	24.1	24.1	18.8	12.5	12.5	12.5	12.5	-158.2	-107.9	-107.9	-107.9
Maximum	153.3	159.7	159.7	159.7	159.8	29.3	29.3	29.3	29.3	69.3	50.0	52.6	50.6	50.0	48.0	48.0	48.0
Mean	88.2	85.9	85.0	87.4	85.5	25.2	24.1	24.7	24.0	51.3	43.5	44.6	42.7	-103.1	-80.8	-81.4	-78.0
Median	86.7	101.7	101.7	101.7	101.7	24.1	24.1	24.1	24.1	50.0	45.8	45.2	45.0	-107.9	-90.2	-87.3	-87.3
STDV	7.3	26.1	26.2	25.0	24.2	1.6	0.3	1.4	0.7	9.8	8.5	7.6	8.8	33.8	35.5	33.0	35.9
Minimum of all approaches		43.6				18.8				12.5				-158.2			
Maximum of all approaches		159.8				29.3				69.3				50.0			
Mean of all approaches		85.9				24.5				45.5				-85.8			

Table 4.3: Descriptive Statistical Analysis (DSA) of the FLM Output Numeric Values.

The average cycle time (of the 289 scenarios using the FLM) is 88.2 seconds. The cycle time value ranges between 86.7 and 153.3 seconds. Among the four approaches (East, West, North, and South), the 95 percentile queue ranges between 43.6 and 159.8 meters, with an average of 85.9 meters. The green weight (GW) varies from minimum of 18.8% and maximum of 29.3%, with an average of 24.5%. The average value of the final green weight (% GWF) is 45.5. The minimum and maximum values are 12.5% and 69.3%, respectively. It is to be noted that the GWF variable exhibits higher difference between the maximum and minimum values [69.3, 12.5], as compared to the corresponding difference of the GW variable [29.3, 18.8]. Furthermore, the standard deviation values of the GWF variable are higher than the corresponding values of the GW variable. The differences among the two variables (range and standard deviation) are merely due to the impact of the downstream congestion.

The % difference between the two main output variables (GW and the GWF) was estimated for each of the four approaches. The estimate of the % of difference between the two output variables can be used to study the effect of the downstream link's congestion on the green time allocation upstream the signalized intersection.

For each scenario (with different levels of traffic flow, and downstream congestion), Eqn. (4.1) was applied to estimate the percentage of difference between two variables (GW and GWF). Table 4.4 shows a sample of the East approach outputs and the calculated difference between the GW and GWF. The last column (difference) is colored with various shade levels. The darker the shade the higher the difference (regardless of the sign). Further analysis of these results is carried out to relate the various levels of traffic flow and DSC to the magnitude and the sign of difference between GW and GWF.

$$\% \, Difference \; between \; GW \; and \; GWF = 100x \frac{GW-GWF}{GW} \quad (4.1)$$

Inputs				Outputs					Calculated
Hourly Volume East Approach (veh/hr)	DSC Index East Approach	Volume Fuzzy term East	DSC East	Cycle (sec)	Cycle Fuzzy Term	95 percentile Queue East (m)	GW East	GWF East	% Difference GW and GWF =100* [(GW-GWF)/GW]
324	4.88	L	L	86.7	L	24.1	50.0	43.6	-107.9
324	5.34	L	L	86.7	L	24.1	50.0	43.6	-107.9
324	5.5	L	L	86.7	L	24.1	50.0	43.6	-107.9
695	10.32	M	L	86.7	L	24.1	50.0	87.2	-107.9
695	10.32	M	L	86.7	L	24.1	50.0	87.2	-107.9
695	10.32	M	L	86.7	L	24.1	50.0	90.9	-107.9
695	10.32	M	L	86.7	L	24.1	50.0	91.5	-107.9
695	12.4	M	L	86.7	L	24.1	50.0	90.9	-107.9
787	13.22	MH	M	86.7	L	24.1	45.0	101.7	-87.3
787	13.22	MH	M	86.7	L	24.1	45.0	101.7	-87.3
787	13.22	MH	M	86.7	L	24.1	45.0	101.7	-87.3
787	13.22	MH	M	86.7	L	24.1	45.0	101.7	-87.3
787	13.22	MH	M	86.7	L	24.1	45.0	101.7	-87.3
787	13.22	MH	M	86.7	L	24.1	45.0	101.7	-87.3
787	13.22	MH	M	86.7	L	24.1	45.0	101.7	-87.3
787	13.22	MH	M	86.7	L	24.1	45.0	101.7	-87.3
880	15.64	H	M	86.7	L	24.1	35.3	101.7	-46.6
880	15.64	H	M	86.7	L	24.1	35.3	101.7	-46.6
880	15.64	H	M	86.7	L	24.1	34.0	101.7	-41.2
880	15.72	H	M	86.7	L	24.1	34.9	101.7	-45.0
880	15.64	H	M	86.7	L	24.1	35.3	101.7	-46.6
880	15.64	H	M	86.7	L	24.1	35.3	101.7	-46.6
1112	21.66	VH	M	86.7	L	29.3	40.1	101.7	-36.6
1112	21.66	VH	M	86.7	L	29.3	43.6	101.7	-48.5
1112	21.66	VH	M	86.7	L	29.3	40.1	101.7	-36.6
1112	21.66	VH	M	97.2	LM	29.3	40.8	101.7	-39.1
1112	20.94	VH	M	109.0	LM	28.1	41.2	115.3	-46.8
1112	23.84	VH	M	114.9	M	27.7	32.7	119.6	-17.8
1112	25.28	VH	M	120.6	M	28.1	26.1	115.3	7.3
1112	28.1	VH	H	133.3	MH	25.0	12.5	159.7	50.0
1112	30.24	VH	H	133.3	MH	24.1	12.5	159.7	48.0
1112	32.3	VH	H	138.0	MH	24.1	12.5	159.7	48.0
1112	35.82	VH	H	153.3	H	24.1	12.5	159.7	48.0

Table 4.4: Sample of Output Variables (of the FLM) for the East Bound Approach

The GWF is set to act inversely proportional to the higher levels of the DSC. That is, the higher DSC level, the lesser the value of the GWF. The % difference between GW and GWF among the four approaches varies between -158% and 50%. The minimum observed value (-158%) was for the case of no high downstream congestion. The negative values of the % difference between two variables (GW and GWF) are observed when; 1) traffic flow level is (low) or (medium) and downstream congestion level is (low), and 2) traffic flow level is (medium-high) or (high) and the downstream congestion level is (medium).

On the other hand, the % difference between GW and GWF increases in the case of (very high) level of traffic flow and a (high) level of downstream congestion, (Figure 4.9).

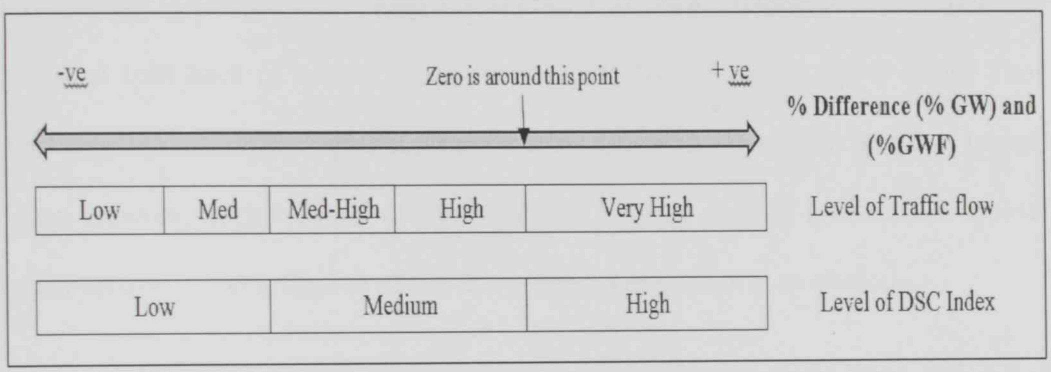


Figure 4.9: % Difference between two variables GW and GWF for various levels of traffic flow and DSC index (East approach).

The effect of the DSC variable on the value of the GWF (and hence the difference with GW) is evident in many cases. Few observations to mention here:

a) When the % difference between GW and GWF is negative, it means that GWF is higher than GW. This would occur when DSC index varies from low to medium, with the traffic flow ranging from low to high (Figure 4.9).

b) When the % difference between GW and GWF is positive, it means that GWF is lesser than GW. This would occur when DSC index is high, with a very high traffic flow.

In most of the commonly used existing traffic signal controllers, the DSC variable is not considered in the estimation of the signal timing of the various competing phases. For instance, if one approach has high or very high traffic flow compared to other competing approaches, the green weight (or green time) of this particular approach phase will increase to account for the higher number of upstream approach vehicles and queues; so as to serve more vehicles and relatively reduce the queue length along this approach, and as such improve the intersection level of service (LOS). This type of control is ideal only for isolated intersections, or when the downstream approaches are long enough so that their congestion levels and the potential spill back of queues along them would have minimal effect on the flow discharge rates from the upstream approaches. However, in reality, and in a typical urban network, such isolated control situation is quite rare. In a connected typical urban networks, the influence of the downstream congestion is so obvious.

If the signal control decisions are based on the upstream flow and queue measures only, erroneous decisions may actually be encountered if the downstream approaches are congested with spill back. If the downstream approach is so congested, it will influence the discharge rate of vehicles from the upstream approach, literally resulting in delays or unnecessary waste of green. The rationale here is to allocate green times negatively proportional to the downstream congestion levels; the higher the congestion levels on the downstream approach, the lesser the green (time or weight) to allocate to the upstream feeding approach phase. By considering the downstream congestion status as input to the FLM, possibilities of network grid locks are minimized and also the network overall delay.

In brief, the inclusion of downstream congestion status in the devised FLM although it may not be effective for isolated intersection control, it is likely to improve the effectiveness of the controller and enhances the mobility measures in a typical urban traffic network.

A similar analysis was conducted for the three remaining approaches (West, North, and South) to study the effect of the levels of the traffic flow and the downstream congestion on the final green weights, and the % difference between two variables (GW and the GWF). Tables 4.5, 4.6, and 4.7 show samples of the output FLM results and the calculated % difference between GW and the GWF. The % difference between two variables (GW and the GWF) under various levels of traffic flow and DSC indices are presented in Figures 4.10, 4.11, and 4.12 for the West, North, and South approaches, respectively.

Inputs				Outputs					Calculated
Hourly Volume West Approach (veh/hr)	DSC Index West Approach	Volume Fuzzy term West	DSC West	Cycle (sec)	Cycle Fuzzy Term	95 percentile Queue West (m)	GW West	GWF West	% Difference GW and GWF =100* [(GW-GWF)/GW]
324	4.88	L	L	86.7	L	24.1	50.0	43.6	-107.9
324	4.88	L	L	86.7	L	24.1	50.0	43.6	-107.9
324	4.88	L	L	86.7	L	24.1	50.0	43.6	-107.9
324	4.88	L	L	86.7	L	24.1	50.0	43.6	-107.9
695	10.32	M	L	86.7	L	24.1	50.0	90.9	-107.9
695	10.32	M	L	86.7	L	24.1	50.0	87.2	-107.9
695	10.32	M	L	86.7	L	24.1	50.0	90.9	-107.9
787	13.22	MH	M	86.7	L	24.1	45.0	101.7	-87.3
787	13.22	MH	M	86.7	L	24.1	45.0	101.7	-87.3
787	13.22	MH	M	86.7	L	24.1	45.0	101.7	-87.3
787	13.22	MH	M	86.7	L	24.1	45.0	101.7	-87.3
787	15.14	MH	M	86.7	L	24.1	35.6	101.7	-48.0
880	15.64	H	M	86.7	L	24.1	35.3	101.7	-46.6
880	15.64	H	M	86.7	L	24.1	35.3	101.7	-46.6
880	15.64	H	M	86.7	L	24.1	34.0	101.7	-41.2
880	16.44	H	M	99.3	LM	24.1	31.4	115.3	-30.5
880	17.14	H	M	102.4	LM	24.1	29.0	119.6	-20.6
880	17.14	H	M	107.9	LM	24.1	28.0	115.3	-16.4
880	18.58	H	M	109.0	LM	24.1	21.1	115.3	12.4
1112	25.28	VH	M	106.7	LM	29.3	26.1	101.7	11.2
1112	28.82	VH	H	133.3	MH	24.1	12.5	159.7	48.0
1112	30.96	VH	H	133.3	MH	24.1	12.5	159.7	48.0
1112	33.04	VH	H	138.0	MH	24.1	12.5	159.7	48.0
1112	35.82	VH	H	153.3	H	24.1	12.5	159.7	48.0

Table 4.5: Sample of Output Variables (of the FLM) for the West Bound Approach

Inputs				Outputs					Calculated
Hourly Volume North Approach (veh/hr)	DSC Index North Approach	Volume Fuzzy term North	DSC North	Cycle (sec)	Cycle Fuzzy Term	95 percentile Queue North (m)	GW North	GWF North	% Difference GW and GWF =100*[(GW-GWF)/GW]
324	4.88	L	L	86.7	L	24.1	50.0	43.6	-107.9
324	4.88	L	L	86.7	L	24.1	50.0	43.6	-107.9
324	4.88	L	L	86.7	L	24.1	50.0	43.6	-107.9
324	4.88	L	L	86.7	L	24.1	50.0	43.6	-107.9
695	10.32	M	L	86.7	L	24.1	50.0	91.5	-107.9
695	10.32	M	L	86.7	L	24.1	50.0	91.5	-107.9
695	10.32	M	L	86.7	L	24.1	50.0	87.2	-107.9
695	10.32	M	L	86.7	L	24.1	50.0	90.9	-107.9
787	13.22	MH	M	86.7	L	24.1	45.0	101.7	-87.3
787	13.22	MH	M	86.7	L	24.1	45.0	101.7	-87.3
787	13.22	MH	M	86.7	L	24.1	45.0	101.7	-87.3
787	13.22	MH	M	86.7	L	24.1	45.0	101.7	-87.3
880	15.64	H	M	86.7	L	24.1	35.3	101.7	-46.6
880	15.64	H	M	86.7	L	24.1	35.3	101.7	-46.6
880	15.64	H	M	86.7	L	25.7	44.8	101.7	-74.5
880	15.64	H	M	86.7	L	25.3	45.2	101.7	-78.6
880	17.14	H	M	86.7	L	24.1	28.0	101.7	-16.4
1112	22.38	VH	M	109.0	LM	28.1	40.1	115.3	-42.7
1112	25.28	VH	M	114.9	M	27.7	27.8	119.6	-0.3
1112	25.28	VH	M	120.6	M	28.1	26.1	115.3	7.3
1112	25.28	VH	M	106.7	LM	29.3	26.1	101.7	11.2
1112	28.82	VH	H	133.3	MH	24.1	12.5	159.7	48.0
1112	30.96	VH	H	133.3	MH	24.1	12.5	159.7	48.0
1112	33.04	VH	H	138.0	MH	24.1	12.5	159.7	48.0
1112	35.82	VH	H	153.3	H	24.1	12.5	159.7	48.0

Table 4.6: Sample of Output Variables (of the FLM) for the North Bound Approach

Inputs				Outputs					Calculated
Hourly Volume South Approach (veh/hr)	DSC Index South Approach	Volume Fuzzy term South	DSC South	Cycle (sec)	Cycle Fuzzy Term	95 percentile Queue South (m)	GW South	GWF South	% Difference GW and GWF=100*[(GW-GWF)/GW]
324	4.88	L	L	86.7	L	24.1	50.0	43.6	-107.9
695	10.32	M	L	86.7	L	24.1	50.0	91.5	-107.9
324	4.88	L	L	86.7	L	24.1	50.0	43.6	-107.9
695	10.32	M	L	86.7	L	24.1	50.0	91.5	-107.9
695	13.12	M	M	86.7	L	24.1	47.2	101.7	-96.2
695	13.12	M	M	86.7	L	24.1	45.8	101.7	-90.2
695	13.12	M	M	86.7	L	24.1	45.8	101.7	-90.2
787	13.22	MH	M	86.7	L	24.1	45.0	101.7	-87.3
787	13.22	MH	M	86.7	L	24.1	45.0	101.7	-87.3
787	13.22	MH	M	86.7	L	24.1	45.0	101.7	-87.3
880	15.64	H	M	86.7	L	25.3	45.2	101.7	-78.6
880	15.64	H	M	86.7	L	25.7	44.8	101.7	-74.5
787	15.14	MH	M	92.8	LM	22.4	35.6	101.7	-58.7
787	15.14	MH	M	102.4	LM	22.4	35.6	101.7	-58.7
787	15.86	MH	M	97.2	LM	21.5	32.2	101.7	-49.5
880	15.14	H	M	86.7	L	24.1	35.6	101.7	-48.0
880	15.64	H	M	86.7	L	24.1	35.3	101.7	-46.6
880	15.64	H	M	86.7	L	24.1	35.3	101.7	-46.6
880	15.64	H	M	86.7	L	24.1	35.3	101.7	-46.6
880	15.64	H	M	86.7	L	24.1	35.3	101.7	-46.6
880	15.64	H	M	86.7	L	24.1	34.0	101.7	-41.2
880	16.44	H	M	86.7	L	24.1	31.4	101.7	-30.5
880	17.14	H	M	86.7	L	24.1	29.0	101.7	-20.6
880	17.14	H	M	92.8	LM	24.1	29.0	101.7	-20.6
880	17.14	H	M	107.9	LM	24.1	28.0	115.3	-16.4
880	17.14	H	M	86.7	L	24.1	28.0	101.7	-16.4
880	17.86	H	M	107.9	LM	24.1	24.5	115.3	-1.9
880	20.82	H	M	120.6	M	24.1	12.5	115.3	48.0
880	27.2	H	M	138.0	MH	24.1	12.5	115.3	48.0
1112	35.82	VH	H	153.3	H	24.1	12.5	159.8	48.0

Table 4.7: Sample of Output Variables (of the FLM) for the South Bound Approach

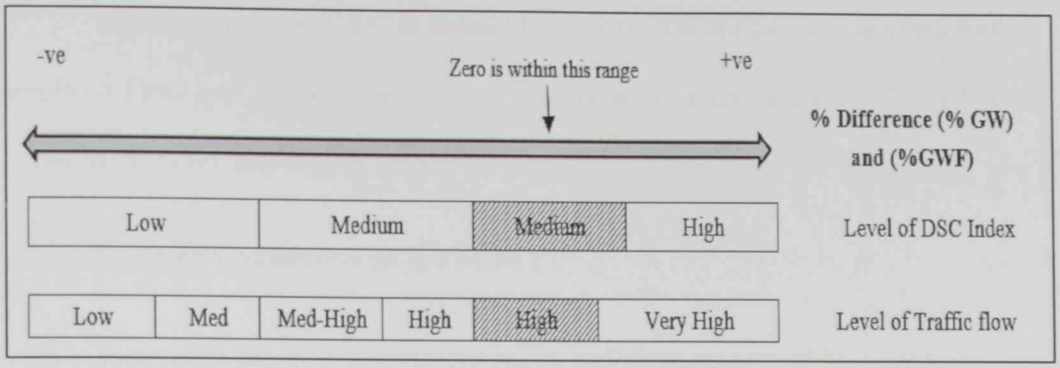


Figure 4.10: % Difference between two variables GW and GWF for various levels of traffic flow and DSC index (West approach).

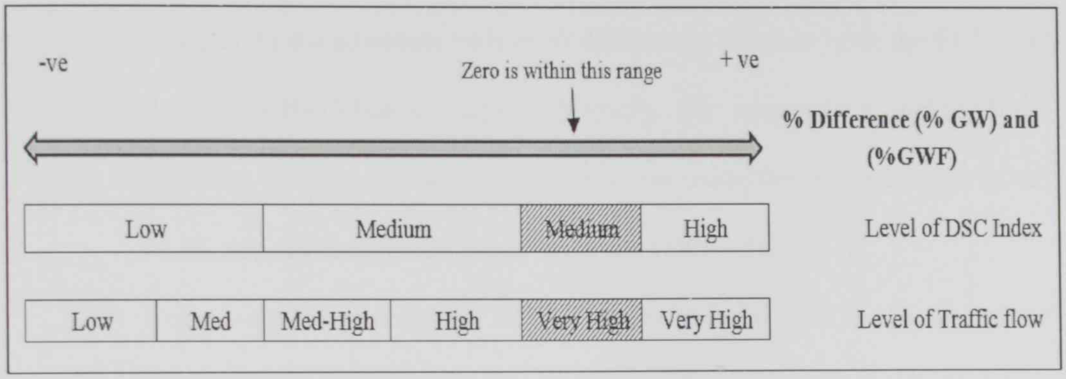


Figure 4.11: % Difference between two variables GW and GWF for various levels of traffic flow and DSC index (North approach).

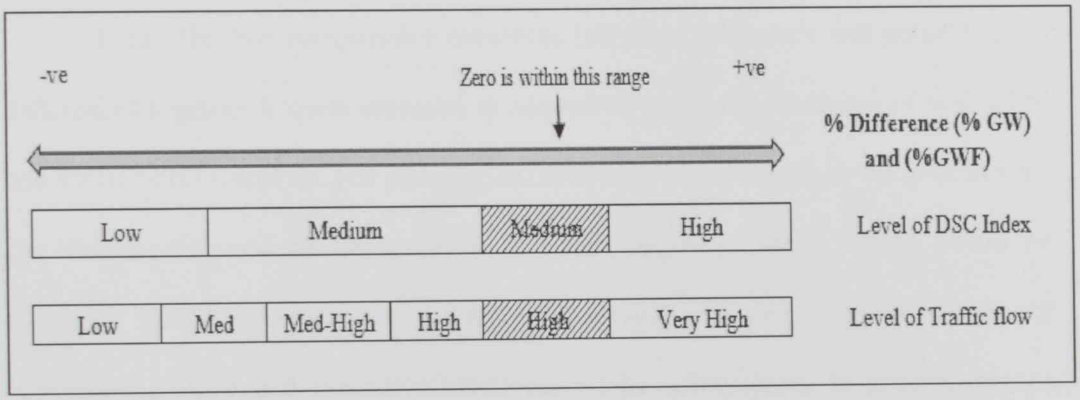


Figure 4.12: % Difference between two variables GW and GWF for various levels of traffic flow and DSC index (South approach).

In conclusion, the GWF is found higher than GW for cases of *medium* or *high* levels of DSC and *high* or *very high* traffic flow. In such cases, the % difference between the GWF and the GW is significantly positive (Figures 4.9 to 4.12).

4.4 Testing and Calibration of the FLM

In order to test the FLM effectiveness, and the closeness of its output variables to the "optimal" solutions of the SYNCHRO model, comparative analyses were carried out in two different ways:

a) Comparing the **absolute values of difference** between both the FLM and the SYNCHRO-based outputs. Namely, the comparison included the variables of the cycle time (C), green times using the GW estimates of the FLM, and the final green times using the GWF of the FLM.
b) Comparing the **percentage of difference** between both the FLM and the SYNCHRO-based outputs. Namely, the comparison included the variables of the cycle time (C), green times using the GW estimates of the FLM, and the final green times using the GWF of the FLM.

Using the two comparative measures (absolute difference and percentage of difference) together is quite essential to adequately asses the closeness of both FLM and SYNCHRO solutions. For instance, in cases of low green times or cycle estimates, the increase/decrease of green times or cycle length by small values would be translated into high percentage values, and as such the percentage of difference between the FLM and the SYNCHRO cannot be solely used. In general, higher percentage of difference values can be accepted when the absolute difference values are relatively small.

The comparison of the outputs (using the two measures) was utilized here as part of the calibration process of the FLM itself, and to assess the accuracy of setting its membership functions and its rule blocks.

Calibration is a fundamental requirement to accept the FLM model. Calibration refers to the adjustment of model parameters to improve the model's ability to reproduce local traffic conditions (U.S-DoT, FHWA, 21st century operations using 21st century technologies).

Steps of the FLM calibration include the identification of parameters to calibrate (such as membership functions of rule blocks), the output variables to assess their closeness to desired outputs, setting priority to the importance of these output variables for the calibration process (high importance level should be accepted by the acceptance criteria, low importance level may/or may not be accepted by the acceptance criteria), identification of the acceptance method, run the FLM model, assessing the output variables for acceptance, and finally making decisions on whether to accept and stop the calibration process or to make further adjustments and recalibrate (its membership functions or rule blocks) again if required.

Table 4.8 and Figure 4.13 summarize the calibration stages of the FLM followed in this research. As can be seen in Table 4.8, three output variables were selected for the purpose of assessing the closeness of the FLM solution vis-à-vis the SYNCHRO one.

- Green times (sec) using the GW estimate of the FLM is set to a *very high* importance levels. The FLM is designed to replicate optimal signal controllers, and as such it must be able reproduce the "optimal" (SYNCHRO) green times to a high level of accuracy.

- The Cycle time is set to a *high* importance level. The FLM is designed to replicate optimal signal controllers, and as such it must be able reproduce the "optimal" (SYNCHRO) cycle times to a high level of accuracy.
- The Final Green times using the GWF estimates of the FLM is set to a *low* importance level. Since the GWF does explicitly consider the downstream congestion (DSC), which is not considered in SYNCHRO, it is expected that the estimated green times using the GWF may significantly differ from the green times estimated by SYNCHRO. As such, it is not mandatory that the final green times using the GWF estimates of the FLM are close to the "optimal" green times estimates of SYNCHRO.

<table>
<tr><th>Calibration stages</th><th colspan="2">Explanations</th></tr>
<tr><td>Identification of variables to assess</td><td colspan="2">- Green times (sec) using the GW estimate of the FLM;
- Final Green times (sec) using the GWF estimate of the FLM;
- Cycle time (sec)</td></tr>
<tr><td rowspan="4">Output Variables and Importance Levels</td><td>Variables</td><td>Importance level</td></tr>
<tr><td>Green times (sec) using the GW estimate of the FLM</td><td>Very High</td></tr>
<tr><td>Cycle time (sec)</td><td>High</td></tr>
<tr><td>Final Green times (sec) using the GWF estimate of the FLM</td><td>Low</td></tr>
<tr><td>Acceptance Criteria</td><td colspan="2">The average percentage difference between the FLM and SYNCHRO not to exceed the confidence level, which is considered as 10%. This condition may be relaxed only if the absolute value of difference is relatively small.</td></tr>
</table>

Table 4.8: The FLM Calibration Stages

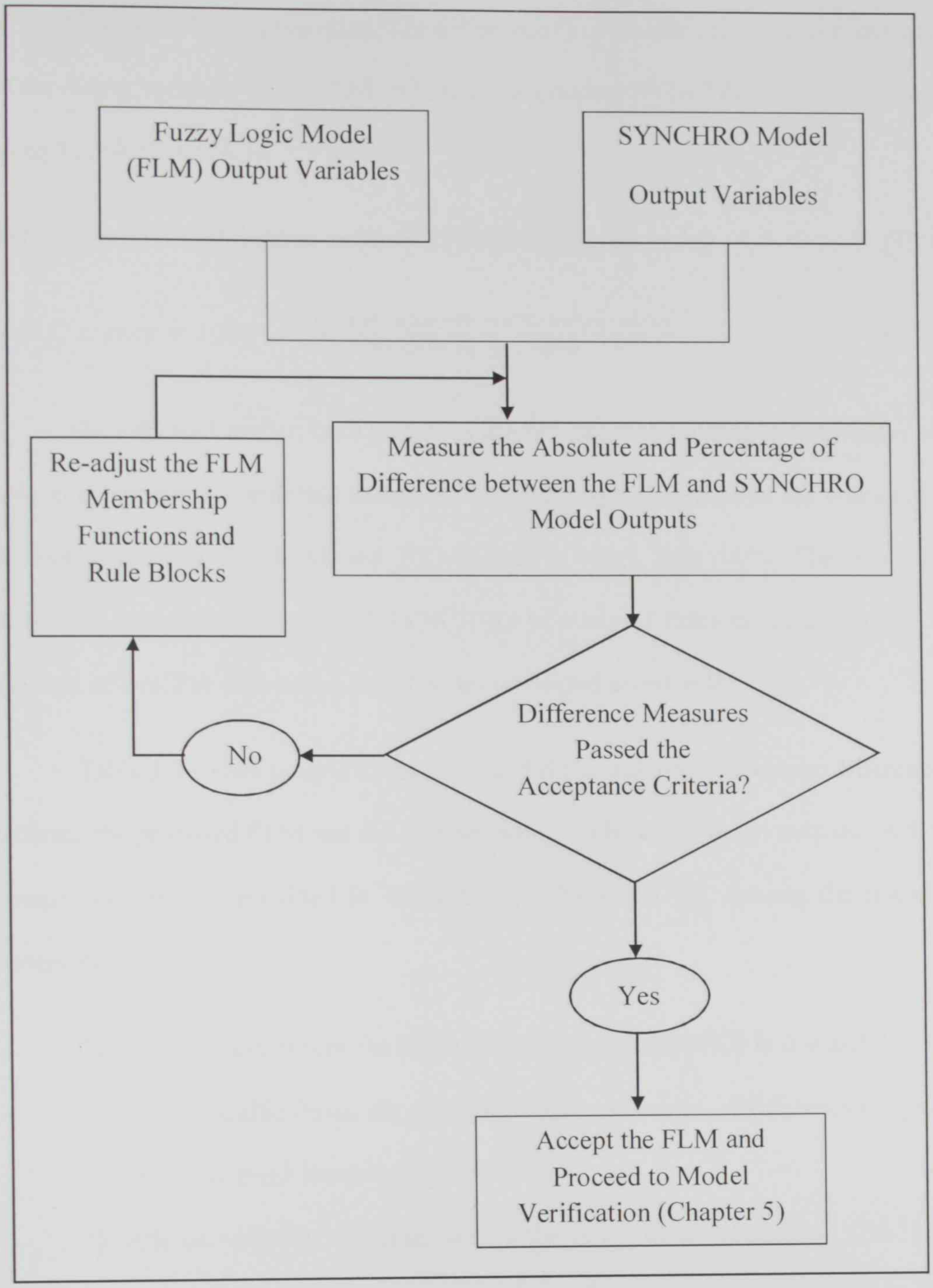


Figure 4.13: Flowchart of the FLM calibration process

The same input numerical values of the input variables used in the 289 simulation/optimization runs were used in the FLM. The output variables (namely, the cycle time, the green times of the four competing approaches, and the final green times of the FLM model) were recorded. The difference (in absolute value and percentage) of the output variables of the FLM and the corresponding SYNCHRO were estimated using Eq. (4.2) and (4.3).

$$Difference = FLM\ output\ value - SYNCHRO\ output\ value \tag{4.2}$$

$$\%Difference = 100x\ \frac{FLM\ output\ value - SYNCHRO\ output\ value}{SYNCHRO\ output\ value} \tag{4.3}$$

As indicated earlier, both measures are important in judging the closeness of solutions. For some simulation scenarios, the percentage difference of the green time estimates between the FLM and SYNCHRO is more than 10%. The absolute difference between the FLM and SYNCHRO in many of these cases is actually 2 seconds or less. For such cases, the FLM is considered acceptable.

Table 4.9 shows sample of the estimated difference and percentage difference between the proposed FLM and the corresponding SYNCHRO-based outputs. A full comparison table is provided in Table B.2 (in Appendix B). Among the notable observations:

1) For the cases where the downstream congestion (DSC) is *low* and *low to medium* traffic flows, the differences and percentage of difference of cycle time, and green times were positive.
2) Alternatively, for the cases where the downstream congestion (DSC) is *high* and *high to very high* traffic flows the differences and percentage of differences of cycle time, and green times were negative.

Descriptive statistical analysis (DSA) was carried out on the difference and the percentage difference between the FLM and SYNCHRO-based outputs. Tables 4.11 and 4.12 present the findings of the descriptive analysis.

The cycle time difference ranges between [-12, 19] seconds (corresponding to percentage difference range of [-8%, 21%]), with an average difference of 4.8 sec (6%). The green times difference ranges between [-5.5, 6.4] seconds (corresponding to percentage difference range of [-15.3%, 39.8%]), with an average difference of 1.2 seconds (7.7%).

The final green times (which accounts for the Downstream congestion DSC) difference ranges between [-10.6, 10.6] seconds (corresponding to percentage difference range of [-66%, 54%]), with an average difference of 1.2 seconds (7.6%).

Figures 4.14 illustrates the distribution of the percentage of difference in the cycle time estimates of the FLM and the SYNCHRO models. It is clear that for the majority of the 289 simulation cases, the percentage of difference is within the 10% allowable limit. Only very few cases (where the traffic flows are high), the percentage of difference in the cycle time exceed the 10%. Similarly, Figures 4.15 and 4.16 show the percentage of difference of the green times and the final green times estimates, respectively. As indicated earlier, the FLM-based final green times have higher deviations from the corresponding SYNCHRO-based green times, because the FLM explicitly accounts for the DSC. Figure 4.15 shows the distributions of the percentage difference of the green times between the FLM and the SYNCHRO models for the four competing approaches. As can be seen, the percentage of difference in the 289 simulation runs is within the range of 10% or less. The average percentage difference is 7.7% with around 8% standard deviation. Finally, Figure 4.16 shows the distributions of the percentage difference of the FLM final green times and the corresponding SYNCHRO green times for the four competing approaches. The percentage of difference of this variable show more variability and dispersion as it (the variable) is sensitive to the DSC status. Still, the majority of the 289 simulation cases meet the 10% error limit. Many cases exceed this 10% limit. This is apparent through the higher standard deviation values in Table 4.11 (about 16% for the individual approaches). This variable was set to a low priority level of meeting the calibration requirement and as such it is considered acceptable.

Inputs								Outputs																		
								Difference: (FLM-SYNCHRO)									% Difference: 100*(FLM-SYNCHRO)/ SYNCHRO									
Volumes Terms				DSC Terms				Cycle (sec)	Green Times (sec)				Final Green Times (FLM)– Green time (SYNCHRO) (sec)				Cycle (sec)	Green Times (sec)				Final Green Times (FLM)– Green time (SYNCHRO)/ Green time (SYNCHRO) (sec)			
E	W	N	S	E	W	N	S		E	W	N	S	E	W	N	S		E	W	N	S	E	W	N	S
L	L	L	L	L	L	L	L	6.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	8.3	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
M	MH	M	M	L	M	L	L	6.7	1.7	1.7	1.7	1.7	2.1	0.3	2.1	2.1	8.3	10.4	10.4	10.4	10.4	13.2	2.0	13.2	13.2
H	H	M	L	M	M	L	L	6.7	3.9	0.9	0.9	0.9	6.6	-3.5	1.8	1.8	8.3	24.6	5.7	5.7	5.7	41.5	-21.8	10.9	10.9
H	H	M	M	M	M	L	L	6.7	3.9	0.9	0.9	0.9	6.6	-3.5	1.8	1.8	8.3	24.6	5.7	5.7	5.7	41.5	-21.8	10.9	10.9
H	H	MH	L	M	M	M	L	-3.3	-3.0	-1.8	0.2	1.2	1.9	-6.5	-2.8	4.0	-3.7	-13.6	-9.4	1.3	7.6	8.7	-34.0	-16.3	24.9
H	H	H	H	M	M	M	M	17.9	3.5	4.4	5.5	4.4	9.4	0.4	7.8	0.4	19.9	17.7	24.4	30.8	24.4	47.1	2.0	43.1	2.0
L	L	H	VH	L	L	M	M	-3.3	-0.3	0.7	-1.3	-2.6	2.8	3.8	-6.9	-3.0	-3.7	-1.5	4.7	-7.0	-11.2	16.4	23.6	-38.5	-12.9
MH	MH	VH	MH	M	M	M	M	-3.3	-0.3	-0.3	-2.6	-0.3	-1.0	-1.0	-0.2	-1.0	-3.7	-1.5	-1.5	-11.2	-1.5	-6.2	-6.2	-0.8	-6.2
MH	MH	VH	H	M	M	M	M	-3.3	-0.3	-0.3	-2.6	-0.3	-1.0	-1.0	-0.2	-1.0	-3.7	-1.5	-1.5	-11.2	-1.5	-6.2	-6.2	-0.8	-6.2
MH	L	VH	H	M	L	M	M	-3.3	-0.3	0.7	-2.6	-1.3	-1.8	5.4	-1.3	-5.6	-3.7	-1.5	4.7	-11.2	-7.0	-10.6	33.4	-5.5	-31.2
VH	L	VH	M	M	L	M	M	-3.3	-1.6	-0.1	-1.6	-0.1	-4.3	3.2	-4.3	2.1	-3.7	-7.5	-0.5	-7.5	-0.5	-20.4	19.8	-20.4	13.0
VH	H	VH	M	M	M	M	M	19.0	4.1	6.4	6.1	2.4	9.5	0.1	10.6	-1.1	21.1	18.8	39.8	30.7	14.8	43.0	0.5	53.0	-7.2
VH	H	VH	MH	M	M	M	M	4.9	-0.9	2.5	1.1	2.1	6.0	-8.0	2.9	4.0	4.4	-3.1	12.1	4.3	11.0	21.3	-38.1	11.2	21.0
VH	VH	VH	L	M	M	M	L	-3.3	-1.1	-1.1	-1.1	-0.1	0.1	0.1	0.1	-3.5	-3.0	-4.2	-4.2	-4.2	-0.4	0.2	0.2	0.2	-21.9
VH	VH	VH	M	H	H	H	M	3.3	-0.1	-0.3	-0.3	4.0	-2.7	-1.7	-1.7	9.3	2.6	-0.3	-0.9	-0.9	19.9	-8.3	-5.4	-5.4	46.7
VH	VH	VH	MH	H	H	H	M	-6.7	-3.9	-2.9	-2.9	3.0	-4.7	-3.7	-3.7	5.3	-4.8	-11.4	-8.7	-8.7	12.4	-13.7	-11.1	-11.1	22.2
VH	VH	VH	H	H	H	H	M	-12.0	-5.5	-4.5	-4.5	2.5	-5.5	-4.5	-4.5	2.5	-8.0	-15.3	-12.9	-12.9	8.9	-15.3	-12.9	-12.9	8.9
VH	VH	VH	VH	H	H	H	H	-6.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-4.2	-4.6	-4.6	-4.6	-4.6	-4.6	-4.6	-4.6	-4.6

Table 4.9: Sample of the Estimated Difference between the FLM and SYNCHRO Green Times and Cycle Outputs.

Descriptive Statistics	Cycle	Green Times Difference (sec): (FLM Green Time-SYNCHRO Green Time)				Final Green Time Difference (sec): (FLM Final Green Time-SYNCHRO Green Time)			
		E	W	N	S	E	W	N	S
Minimum	-12.0	-5.5	-4.5	-4.5	-2.6	-5.5	-8.0	-10.6	-7.2
Maximum	19.0	4.1	6.4	6.1	4.8	10.2	7.2	10.6	9.3
Mean	4.8	1.4	1.2	1.1	1.1	3.1	0.6	0.7	0.3
Median	6.7	1.7	1.7	1.7	1.7	3.1	1.7	1.3	1.0
STDV	4.3	1.7	1.1	1.3	1.1	2.9	2.8	2.7	2.9
Minimum	-12.0	-5.5				-10.6			
Maximum	19.0	6.4				10.6			
Mean	4.8	1.2				1.2			

Table 4.10: Descriptive Statistical Analysis (DSA) for the Difference Results (Difference between FLM and SYNCHRO Outputs).

Descriptive Statistics	Cycle	Percentage Difference of Green Times (%): 100*(FLM Green Time-SYNCHRO Green Time)/SYNCHRO Green Time				Percentage Difference of Final Green Times (%): 100*(FLM Final Green Time-SYNCHRO Green Time)/SYNCHRO Green Time			
		E	W	N	S	E	W	N	S
Minimum	-8.0	-15.3	-12.9	-12.9	-11.9	-27.9	-38.1	-66.0	-38.5
Maximum	21.1	24.6	39.8	30.8	28.1	53.6	44.8	53.0	46.7
Mean	6.0	8.9	7.4	7.4	7.0	18.9	4.2	4.9	2.5
Median	8.3	10.4	10.4	10.4	10.4	19.1	10.4	7.5	6.2
STDV	5.0	9.4	6.0	6.9	6.3	16.7	16.2	15.7	17.1
Minimum	-8.0	-15.3				-66.0			
Maximum	21.1	39.8				53.6			
Mean	6.0	7.7				7.6			

Table 4.11: Descriptive Statistical Analysis for the Percentage Difference Results (Percentage Difference between FLM and SYNCHRO Outputs).

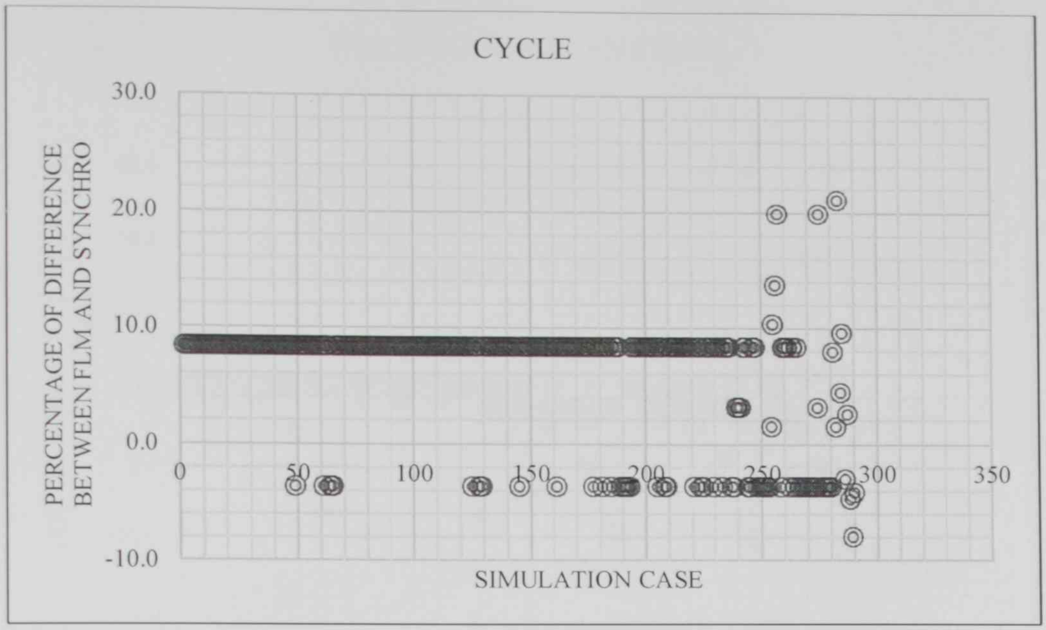


Figure 4.14: Percentage difference between the FLM and the corresponding SYNCRO-based Cycle output variables

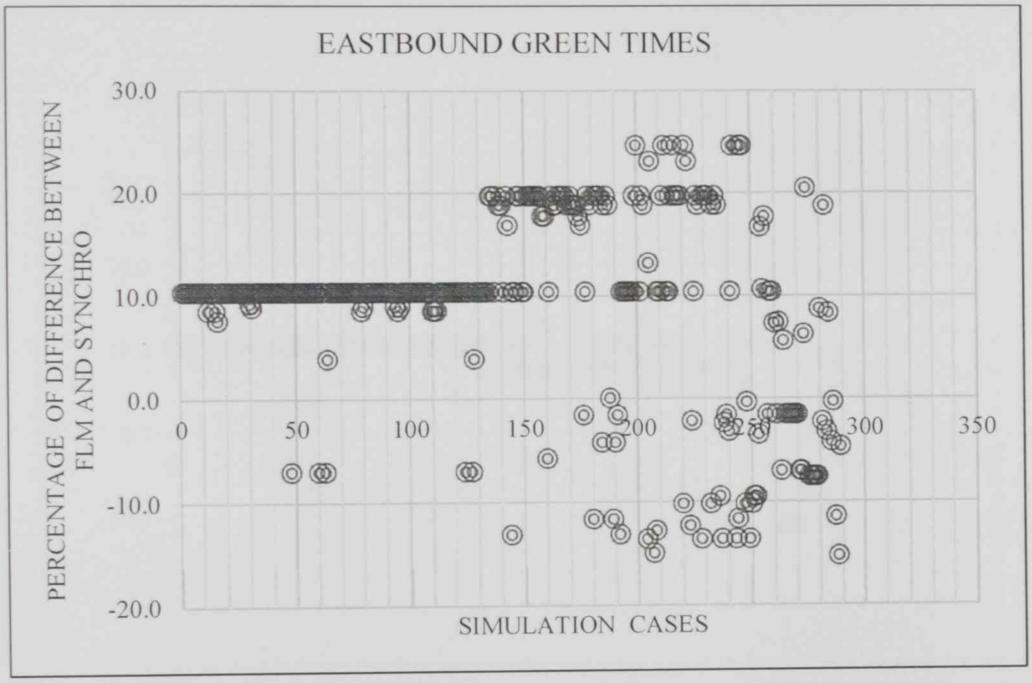


Figure 4.15 (A): Eastbound Approach

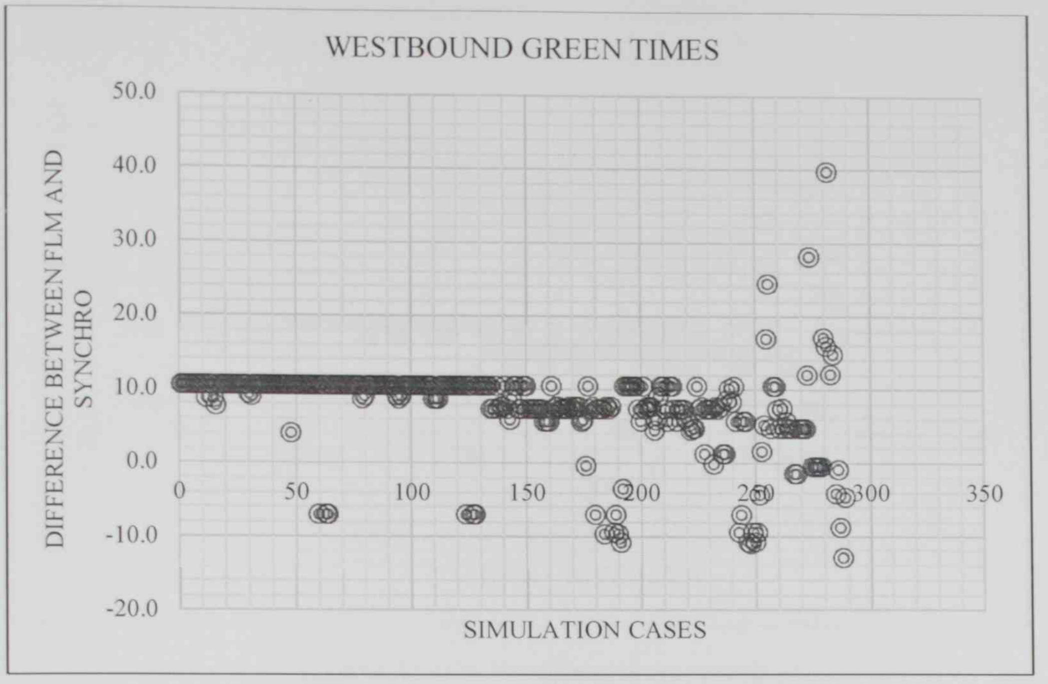


Figure 4.15 (B): Westbound Approach

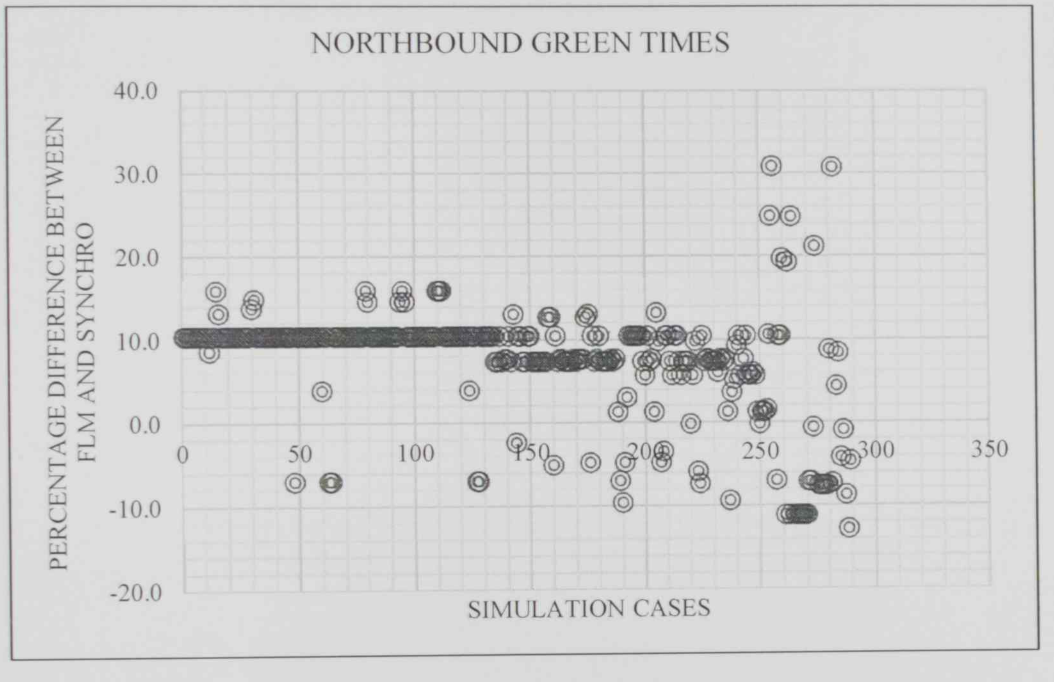


Figure 4.15 (C): Northbound Approach

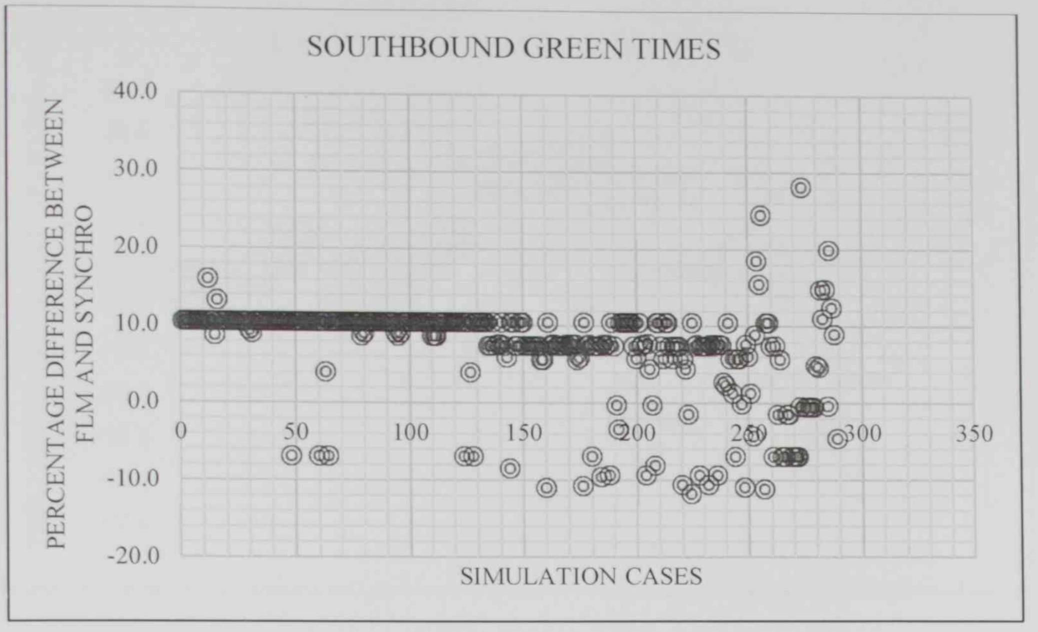


Figure 4.15 (D): Southbound Approach

Figure 4.15: Percentage difference between the FLM and the corresponding SYNCRO-based Green Times output variables

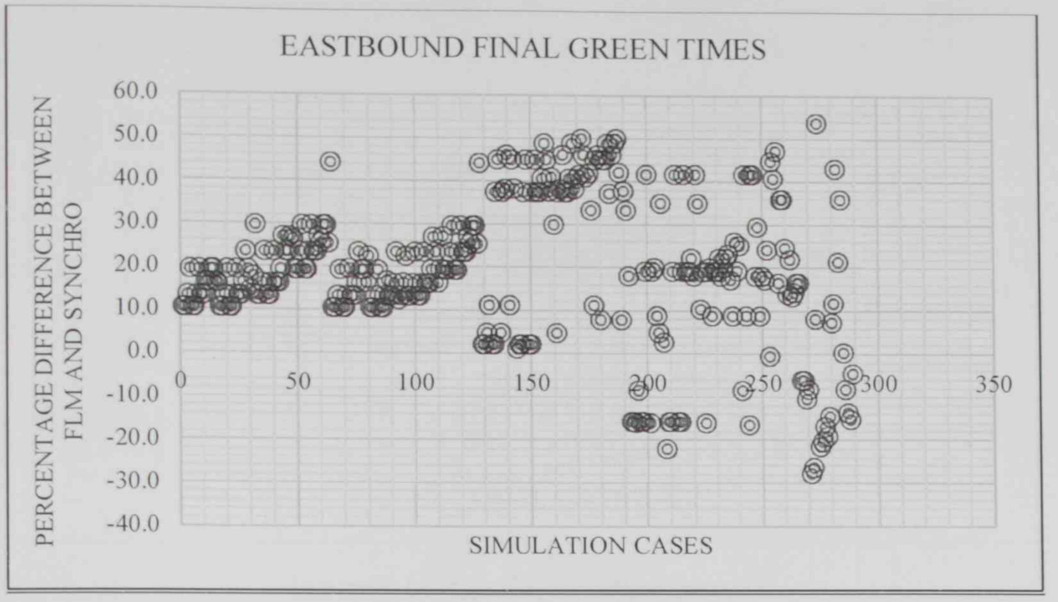


Figure 4.16 (A): Eastbound Approach

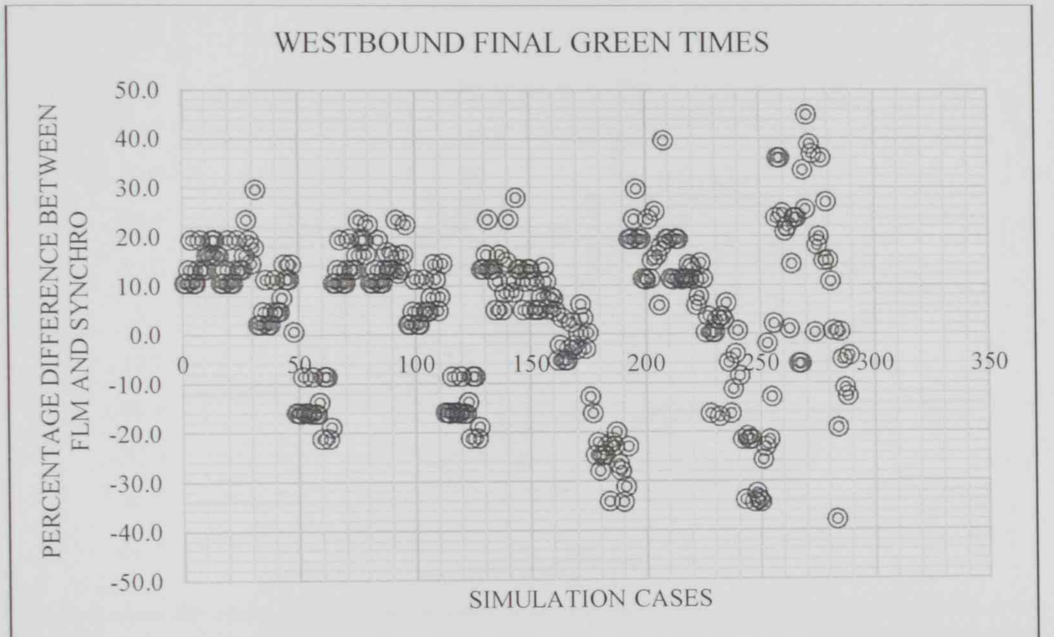


Figure 4.16 (B): Westbound Approach

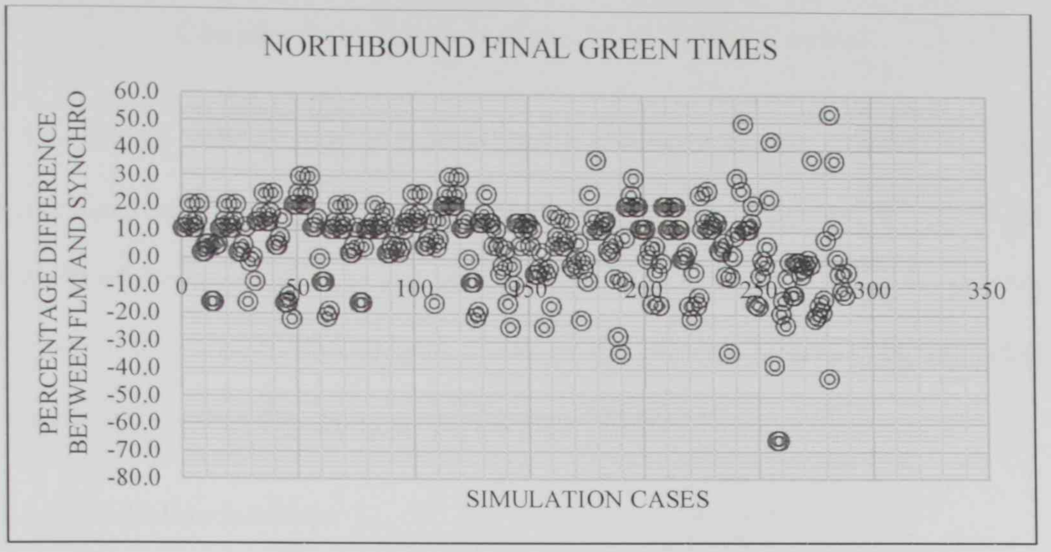


Figure 4.16 (C): Northbound Approach

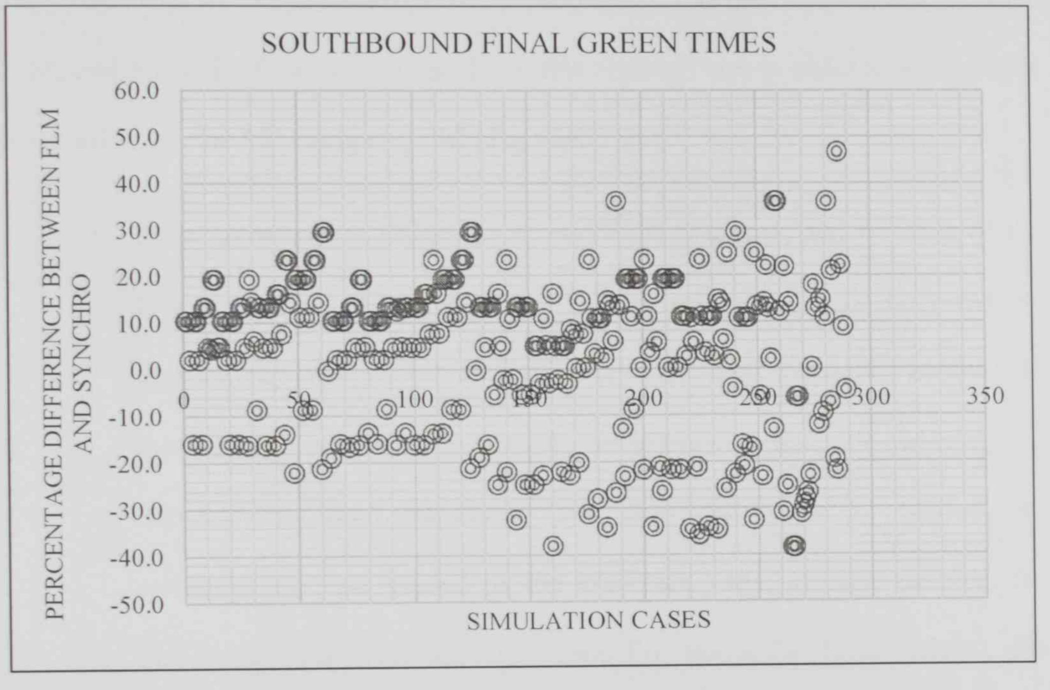


Figure 4.16 (D): Southbound Approach

Figure 4.16: Percentage difference between the FLM and the corresponding SYNCRO-based Final Green Times output variables

Chapter 5: Validation of the FLM Signal Control

Model validation is a fundamental requirement to the approval and the generalization of the any new model. Various tests were conducted to ensure the validity of the proposed FLM and to assess the extent to which it meets the purpose for which it was built. This chapter discusses and presents in details the validation process and results of the proposed traffic signal FLM.

5.1 FLM Validation Steps

A new set of randomly selected set of data was selected for model validation. Such data differ from these used in model calibration. The obtained outputs from the FLM, and SYNCHRO were compared. In this research and in order to validate the proposed FLM, the following steps were applied:

1. **Data Generation**: Using the FuzzyTECH software, and for each of the four approaches, a new data set of input variables (traffic flow and the downstream congestion index) were generated. A built in tool in FuzzyTECH was used to generate an exhaustive data file covering the domains of input variables. The data generation is carried out systematically and guided by the minimum value of each variable, the maximum value, and the step value. For the traffic flow (veh/hr), the minimum, maximum, and step value were 324, 1112, and 250, respectively. For the downstream congestion index, the minimum, maximum, and step value were 4.86, 35.82, and 15, respectively. The resulting data file has 50625 numerical records covering the possible domains of the two input variables.

2. **Input Data Debugging**: A built-in module in FuzzyTECH was used to debug the generated exhaustive data file. Debugging entails deploying the FLM on the input data file and estimating all decision variables (namely the cycle time, green weight, final green weight, green times, and final green times). Table 5.1 shows a sample of the generated file as well as the estimated cycle and green weights of the FLM.
3. **Data Extraction**: Following the application of the FLM to the generated data file and the estimation of the output variables through the debugging, all data (inputs and outputs) were extracted and recorded as "csv (comma delimited)" file.
4. **Validation Sample Data Selection and SYNCHRO Modeling**: Out of extracted data, a random sample was selected. SYNCHRO was then used to model the selected input variables. For each modeled case, SYNCHRO outputs (cycle time and green times for each approach) were recorded.
5. **FLM and SYNCHRO Comparison:** The outputs of both models were compared in two different ways:
    a. Comparing the **difference** between both the FLM and the SYNCHRO-based outputs. Namely, the comparison included the variables of the cycle time (C), green times using the GW estimates of the FLM, and the final green times using the GWF of the FLM.
    b. Comparing the **percentage of difference** between both the FLM and the SYNCHRO-based outputs. Namely, the comparison included the variables of the cycle time (C), green times using the GW estimates of the FLM, and the final green times using the GWF of the FLM.

The geometric, traffic, and controller parameters which were used in the SYNCHRO runs for testing the model, were similar to the ones used for model development and calibration as stated earlier in Chapter 3.

- **Geometric Parameters:**
  - Number of lanes: 3 shared lanes
  - Split phase arrangement
  - Link length, L: 500 m
  - Link speed: 60 km/hr
  - Lane width: 3.7 m
  - Saturation flow rate: 1900 veh/hr/lane
  - Passenger car length: 7.6 m
  - Heavy vehicle length: 13.7 m
- **Traffic Parameters:**
  - Right turn percentage: 30 % of approach volume
  - Through movement percentage: 60 % of approach volume
  - Left turn percentage: 10 % of approach volume
  - Peak hour factor (PHF) = 0.92
  - Growth factor: 0.95
  - Percentage of heavy vehicles: 2%
- **Control Parameters:**
  - Signal control type: Pre-timed signalized intersection, protected left turn movement, split phase operation.
  - Yellow time: 3 sec
  - All red: 1 sec

Downstream Congestion Index				Traffic Flow (veh/hr)				Cycle (sec)	Final Green Weight (%)				Green Weight (%)			
E	W	N	S	E	W	N	S		E	W	N	S	E	W	N	S
4.86	4.86	4.86	4.86	324	324	324	324	86.67	50	50	50	50	24	24	24	24
4.86	4.86	4.86	4.86	324	574	324	324	86.67	50	50	50	50	24	24	24	24
4.86	4.86	4.86	4.86	324	824	324	324	86.67	50	50	50	50	24	24	24	24
4.86	4.86	4.86	4.86	324	1074	324	324	83.40	50	50	50	50	25	25	25	25
4.86	4.86	4.86	4.86	324	1112	324	324	83.40	50	50	50	50	25	25	25	25
4.86	4.86	4.86	4.86	1112	574	324	324	83.40	50	50	50	50	25	25	25	25
20.86	35.82	4.86	35.82	574	324	824	1074	86.67	12.5	12.5	50	12.5	24	24	24	29
20.86	35.82	4.86	35.82	574	574	824	1074	86.67	12.5	12.5	50	12.5	24	24	24	29
20.86	35.82	4.86	35.82	574	824	824	1074	83.40	50	50	50	50	25	25	25	25
20.86	35.82	4.86	35.82	574	1074	824	1074	83.40	50	50	50	50	25	25	25	25
20.86	35.82	4.86	35.82	574	824	1074	1112	83.40	50	50	50	50	25	25	25	25
20.86	35.82	4.86	35.82	574	1074	1074	1112	83.40	50	50	50	50	25	25	25	25
20.86	35.82	4.86	35.82	574	1112	1074	1112	83.40	50	50	50	50	25	25	25	25
35.82	20.86	4.86	35.82	574	574	574	1112	83.40	50	50	50	50	25	25	25	25
35.82	20.86	4.86	35.82	574	824	574	1112	83.40	50	50	50	50	25	25	25	25
35.82	35.82	35.82	35.82	1112	824	1112	1074	83.40	50	50	50	50	25	25	25	25
35.82	35.82	35.82	35.82	1112	1074	1112	1074	153.3	12.5	12.5	12.5	12.5	24	24	24	24
35.82	35.82	35.82	35.82	1112	1112	1112	1074	153.3	12.5	12.5	12.5	12.5	24	24	24	24
35.82	35.82	35.82	35.82	1112	324	1112	1112	83.40	50	50	50	50	25	25	25	25
35.82	35.82	35.82	35.82	1112	574	1112	1112	83.40	50	50	50	50	25	25	25	25
35.82	35.82	35.82	35.82	1112	824	1112	1112	83.40	50	50	50	50	25	25	25	25
35.82	35.82	35.82	35.82	1112	1074	1112	1112	153.3	12.5	12.5	12.5	12.5	24	24	24	24
35.82	35.82	35.82	35.82	1112	1112	1112	1112	153.3	12.5	12.5	12.5	12.5	24	24	24	24

Table 5.1: Sample of the FuzzyTECH Validation Generated File and Estimated FLM Outputs

5.2 Results and Comparative Analysis

Among the FuzzyTECH exhaustive generated data file, only few number of cases were randomly selected as shown in Table 5.2. The different levels of the traffic flow (from *low* to *very high* levels), and the downstream congestion levels (from *low* to *high* levels) were almost covered in the selected cases.

Based on the FLM estimates of the green weights (GW) and final green weight (GWF), Eqns. 3.15 and 3.16, the green times and final green times were calculated as shown in Table 5.3. Table 5.4 shows the SYNCHRO corresponding outputs for the validation cases. The difference and the percentage difference between SYNCHRO and FLM results are presented in Tables 5.5 and 5.6, respectively.

Moreover, in order to summarize the overall output data of the 15 simulation scenarios for each approach and for all approaches as well, Descriptive Statistical Analysis (DSA) was performed on the difference and the percentage difference between the FLM and SYNCHRO-based outputs (as shown in Tables 5.7 and 5.8). For each output variable, different statistical measures were estimated including; minimum, maximum, mean, median, and the standard deviation (STDV).

5.2.1 Green Times and Final Green Times analysis

Among the four approaches, the green times difference ranges between [-14.2, 3.3] seconds (corresponding to percentage difference range of [-45.6%, 10.8%]), with an average difference of -1.3 seconds (-3.3%).

In order to study the effect of the downstream link's congestion on the green time allocation upstream the signalized intersection, the % difference between the two main output variables (FLM final green time and SYNCHRO green time) was estimated for each of the four approaches.

Among the four approaches, the final green times difference ranges between [-14.2, 24.4] seconds (corresponding to percentage difference range of [-55.8%, 152.4%]), with an average difference of -1.3 seconds (-3.4%).

Positive values of the difference and percentage difference were experienced when the final green times provided by the FLM were greater than the ones determined by SYNCHRO. This was experienced generally with the scenarios of "*low*" DSC index. Negative values of the difference and percentage difference were experienced when the final green times provided by the FLM were lesser than the ones determined by SYNCHRO. This was experienced generally with the scenarios of "*medium*" or "*high*" DSC index.

5.2.2 Cycle time analysis

The cycle time difference ranges between [-46.6, 13.3] seconds (corresponding to percentage difference range of [-35.8%, 9.5%]), with an average difference of -5.1 sec (-3.5%). The negative values of the difference and percentage difference between the FLM and the SYNCHRO means that the optimized cycle time obtained from SYNCHRO was higher than the one estimated from the FLM.

Reference to Tables 5.5 and 5.6, it is apparent that the minimum difference and percent difference of the cycle time correspond to *medium to high*, *high*, or *very high* traffic flows with *medium* average DSC index. The maximum values of the cycle time difference and percentage of difference relate to the case of *low* DSC index and *very high* traffic flow.

In general, it can be concluded that FLM is quite effective and sufficient to replicate "optimization" signal control procedures (SYNCHRO). The validation of results indicated that the FLM is mostly effective for cases of *medium or high* DSC and *medium to high* traffic flows.

Case	Downstream congestion index				Traffic flow (veh/hr)				Cycle (sec)	Final green weight (%)				Green weight (%)			
	E	W	N	S	E	W	N	S		E	W	N	S	E	W	N	S
1	4.86	4.86	4.86	4.86	574	574	574	574	86.7	50.0	50.0	50.0	50.0	24.1	24.1	24.1	24.1
2	20.86	20.86	20.86	20.86	574	574	574	574	86.7	12.5	12.5	12.5	12.5	24.1	24.1	24.1	24.1
3	20.86	20.86	20.86	20.86	824	824	824	824	86.7	19.7	12.5	12.5	12.5	25.1	24.1	24.1	24.1
4	35.82	35.82	35.82	35.82	824	824	824	824	86.7	12.5	12.5	12.5	12.5	25.1	24.1	24.1	24.1
5	4.86	4.86	4.86	4.86	1074	1074	1074	1074	153.3	50.0	50.0	50.0	50.0	24.1	24.1	24.1	24.1
6	35.82	35.82	4.86	4.86	1074	1074	824	1074	83.4	50.0	50.0	50.0	50.0	25.0	25.0	25.0	25.0
7	35.82	35.82	4.86	4.86	1074	1112	824	1074	83.4	50.0	50.0	50.0	50.0	25.0	25.0	25.0	25.0
8	4.86	35.82	4.86	35.82	324	824	824	824	86.7	50.0	12.5	50.0	12.5	24.0	24.0	24.0	24.0
9	4.86	20.86	20.86	35.82	574	324	324	324	86.7	50.0	12.5	12.5	12.5	24.0	24.0	24.0	24.0
10	4.86	4.86	35.82	35.82	574	1112	824	824	83.4	50.0	50.0	50.0	50.0	25.0	25.0	25.0	25.0
11	20.86	35.82	4.86	20.86	824	824	324	324	86.7	12.5	12.5	50.0	12.5	24.0	24.0	24.0	24.0
12	20.86	20.86	20.86	20.86	824	574	824	1074	83.4	50.0	50.0	50.0	50.0	25.0	25.0	25.0	25.0
13	20.86	4.86	35.82	20.86	1074	1112	324	324	83.4	50.0	50.0	50.0	50.0	25.0	25.0	25.0	25.0
14	35.82	20.86	20.86	4.86	1112	574	324	574	83.4	50.0	50.0	50.0	50.0	25.0	25.0	25.0	25.0
15	35.82	4.86	35.82	4.86	1112	324	824	1112	83.4	50.0	50.0	50.0	50.0	25.0	25.0	25.0	25.0

Table 5.2: Selected Validation Cases from the FuzzyTECH Data Generation File

Case	Downstream congestion index				Traffic flow (veh/hr)				Cycle (sec)	Final green time (sec)				Green time (sec)			
	E	W	N	S	E	W	N	S		E	W	N	S	E	W	N	S
1	4.86	4.86	4.86	4.86	574	574	574	574	86.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7
2	20.86	20.86	20.86	20.86	574	574	574	574	86.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7
3	20.86	20.86	20.86	20.86	824	824	824	824	86.7	24.4	15.4	15.4	15.4	18.2	17.5	17.5	17.5
4	35.82	35.82	35.82	35.82	824	824	824	824	86.7	17.7	17.7	17.7	17.7	18.2	17.5	17.5	17.5
5	4.86	4.86	4.86	4.86	1074	1074	1074	1074	153.3	34.3	34.3	34.3	34.3	34.3	34.3	34.3	34.3
6	35.82	35.82	4.86	4.86	1074	1074	824	1074	83.4	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9
7	35.82	35.82	4.86	4.86	1074	1112	824	1074	83.4	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9
8	4.86	35.82	4.86	35.82	324	824	824	824	86.7	28.3	7.1	28.3	7.1	17.7	17.7	17.7	17.7
9	4.86	20.86	20.86	35.82	574	324	324	324	86.7	40.4	10.1	10.1	10.1	17.7	17.7	17.7	17.7
10	4.86	4.86	35.82	35.82	574	1112	824	824	83.4	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9
11	20.86	35.82	4.86	20.86	824	824	324	324	86.7	10.1	10.1	40.4	10.1	17.7	17.7	17.7	17.7
12	20.86	20.86	20.86	20.86	824	574	824	1074	83.4	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9
13	20.86	4.86	35.82	20.86	1074	1112	324	324	83.4	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9
14	35.82	20.86	20.86	4.86	1112	574	324	574	83.4	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9
15	35.82	4.86	35.82	4.86	1112	324	824	1112	83.4	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9

Table 5.3: FuzzyTECH Estimated Cycle, Green Times and Final Green Times for the Validation Cases

Case	Downstream congestion index				Traffic flow (veh/hr)				Green time (sec)				Cycle length (sec)
	E	W	N	S	E	W	N	S	E	W	N	S	
1	4.86	4.86	4.86	4.86	574	574	574	574	16	16	16	16	80
2	20.86	20.86	20.86	20.86	574	574	574	574	16	16	16	16	80
3	20.86	20.86	20.86	20.86	824	824	824	824	20	18	18	18	90
4	35.82	35.82	35.82	35.82	824	824	824	824	20	18	18	18	90
5	4.86	4.86	4.86	4.86	1074	1074	1074	1074	31	31	31	31	140
6	35.82	35.82	4.86	4.86	1074	1074	824	1074	31	30	23	30	130
7	35.82	35.82	4.86	4.86	1074	1112	824	1074	30	31	23	30	130
8	4.86	35.82	4.86	35.82	324	824	824	824	16	16	16	16	80
9	4.86	20.86	20.86	35.82	574	324	324	324	16	16	16	16	80
10	4.86	4.86	35.82	35.82	574	1112	824	824	17	23	17	17	90
11	20.86	35.82	4.86	20.86	824	824	324	324	16	16	16	16	80
12	20.86	20.86	20.86	20.86	824	574	824	1074	19	16	17	22	90
13	20.86	4.86	35.82	20.86	1074	1112	324	324	21	21	16	16	90
14	35.82	20.86	20.86	4.86	1112	574	324	574	16	16	16	16	80
15	35.82	4.86	35.82	4.86	1112	324	824	1112	21	16	16	21	90

Table 5.4: SYNCHRO Estimated Cycle and Green Times for Validation Cases

Case	Inputs								Outputs Difference								
	Downstream congestion index Fuzzy Term				Traffic flow Fuzzy Term				Cycle Difference (sec): (FLM Cycle time- SYNCHRO Cycle time)	Green Times Difference (sec): (FLM Green Time- SYNCHRO Green Time)				Final Green Time Difference (sec): (FLM Final Green Time- SYNCHRO Green Time)			
	E	W	N	S	E	W	N	S		E	W	N	S	E	W	N	S
1	L	L	L	L	M	M	M	M	6.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
2	M	M	M	M	M	M	M	M	6.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
3	M	M	M	M	MH	MH	MH	MH	-3.3	-1.8	-0.5	-0.5	-0.5	4.4	-2.6	-2.6	-2.6
4	H	H	H	H	MH	MH	MH	MH	-3.3	-1.8	-0.5	-0.5	-0.5	-2.3	-0.3	-0.3	-0.3
5	L	L	L	L	VH	VH	VH	VH	13.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
6	H	H	L	L	VH	VH	MH	VH	-46.6	-14.2	-13.2	-6.2	-13.2	-14.2	-13.2	-6.2	-13.2
7	H	H	L	L	VH	VH	MH	VH	-46.6	-13.2	-14.2	-6.2	-13.2	-13.2	-14.2	-6.2	-13.2
8	L	H	L	H	L	MH	MH	MH	6.7	1.7	1.7	1.7	1.7	12.3	-8.9	12.3	-8.9
9	L	M	M	H	M	L	L	L	6.7	1.7	1.7	1.7	1.7	24.4	-5.9	-5.9	-5.9
10	L	L	H	H	M	VH	MH	MH	-6.6	-0.1	-6.2	-0.1	-0.1	-0.1	-6.2	-0.1	-0.1
11	M	H	L	M	MH	MH	L	L	6.7	1.7	1.7	1.7	1.7	-5.9	-5.9	24.4	-5.9
12	M	M	M	M	MH	M	MH	VH	-6.6	-2.2	0.9	-0.1	-5.2	-2.2	0.9	-0.1	-5.2
13	M	L	H	M	VH	VH	L	L	-6.6	-4.2	-4.2	0.9	0.9	-4.2	-4.2	0.9	0.9
14	H	M	M	L	VH	M	L	M	3.4	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
15	H	L	H	L	VH	L	MH	VH	-6.6	-4.2	0.9	0.9	-4.2	-4.2	0.9	0.9	-4.2

Table 5.5: Difference between the FLM and SYNCHRO Outputs for the Validation Cases

Case	Inputs									Outputs Percentage Difference							
	Downstream congestion index Fuzzy Term				Traffic flow Fuzzy Term				%Difference Cycle (sec): 100*(FLM Cycle time-SYNCHRO Cycle time)/ SYNCHRO Cycle time	%Difference Green Times (sec): 100*(FLM Green Time-SYNCHRO Green Time)/ SYNCHRO Green Time				%Difference Final Green Time (sec): 100* (FLM Final Green Time-SYNCHRO Green Time)/ SYNCHRO Green Time			
	E	W	N	S	E	W	N	S		E	W	N	S	E	W	N	S
1	L	L	L	L	M	M	M	M	8.3	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
2	M	M	M	M	M	M	M	M	8.3	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
3	M	M	M	M	MH	MH	MH	MH	-3.7	-8.9	-2.9	-2.9	-2.9	21.8	-14.3	-14.3	-14.3
4	H	H	H	H	MH	MH	MH	MH	-3.7	-8.9	-2.9	-2.9	-2.9	-11.7	-1.9	-1.9	-1.9
5	L	L	L	L	VH	VH	VH	VH	9.5	10.8	10.8	10.8	10.8	10.8	10.8	10.8	10.8
6	H	H	L	L	VH	VH	MH	VH	-35.8	-45.6	-43.8	-26.7	-43.8	-45.6	-43.8	-26.7	-43.8
7	H	H	L	L	VH	VH	MH	VH	-35.8	-43.8	-45.6	-26.7	-43.8	-43.8	-45.6	-26.7	-43.8
8	L	H	L	H	L	MH	MH	MH	8.3	10.4	10.4	10.4	10.4	76.7	-55.8	76.7	-55.8
9	L	M	M	H	M	L	L	L	8.3	10.4	10.4	10.4	10.4	152.4	-36.9	-36.9	-36.9
10	L	L	H	H	M	VH	MH	MH	-7.3	-0.9	-26.7	-0.9	-0.9	-0.9	-26.7	-0.9	-0.9
11	M	H	L	M	MH	MH	L	L	8.3	10.4	10.4	10.4	10.4	-36.9	-36.9	152.4	-36.9
12	M	M	M	M	MH	M	MH	VH	-7.3	-11.3	5.3	-0.9	-23.4	-11.3	5.3	-0.9	-23.4
13	M	L	H	M	VH	VH	L	L	-7.3	-19.8	-19.8	5.3	5.3	-19.8	-19.8	5.3	5.3
14	H	M	M	L	VH	M	L	M	4.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3
15	H	L	H	L	VH	L	MH	VH	-7.3	-19.8	5.3	5.3	-19.8	-19.8	5.3	5.3	-19.8

Table 5.6: Percentage Difference between the FLM and SYNCHRO Outputs for the Validation Cases

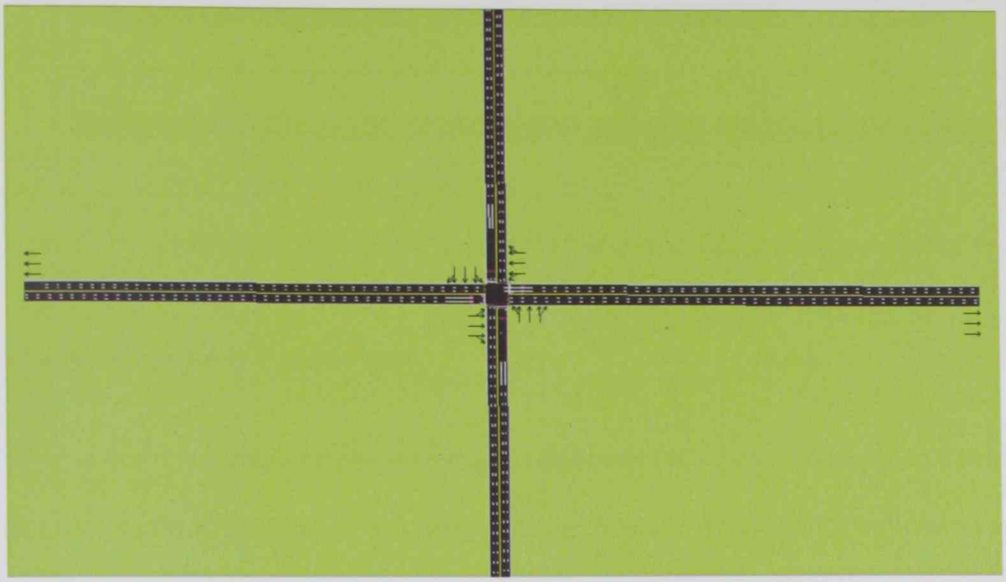
Descriptive Statistics	Cycle	Green Times Difference (sec): (FLM Green Time-SYNCHRO Green Time)				Final Green Time Difference (sec): (FLM Final Green Time-SYNCHRO Green Time)			
		E	W	N	S	E	W	N	S
Minimum	-46.6	-14.2	-14.2	-6.2	-13.2	-14.2	-14.2	-6.2	-13.2
Maximum	13.3	3.3	3.3	3.3	3.3	24.4	3.3	24.4	3.3
Mean	-5.1	-1.9	-1.6	0.0	-1.6	0.2	-3.5	1.6	-3.4
Minimum	-46.6	-14.2				-14.2			
Maximum	13.3	3.3				24.4			
Mean	-5.1	-1.3				-1.3			

Table 5.7: Descriptive Statistical Analysis (DSA) for the Difference Results (Difference between FLM and SYNCHRO Outputs) - Validation Cases.

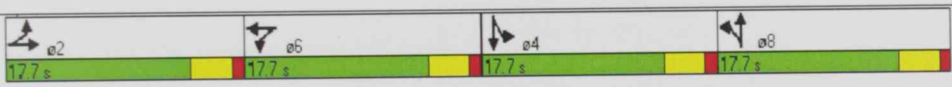
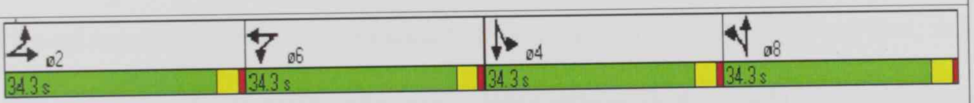
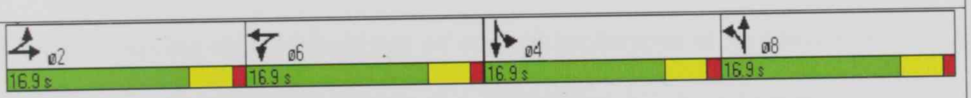
Descriptive Statistics	Cycle	Percentage Difference of Green Times (%): 100*(FLM Green Time-SYNCHRO Green Time)/SYNCHRO Green Time				Percentage Difference of Final Green Times (%): 100*(FLM Final Green Time-SYNCHRO Green Time)/SYNCHRO Green Time			
		E	W	N	S	E	W	N	S
Minimum	-35.8	-45.6	-45.6	-26.7	-43.8	-45.6	-55.8	-36.9	-55.8
Maximum	9.5	10.8	10.8	10.8	10.8	152.4	10.8	152.4	10.8
Mean	-3.5	-6.1	-4.2	1.2	-4.3	6.5	-15.6	11.2	-15.7
Minimum	-35.8	-45.6				-55.8			
Maximum	9.5	10.8				152.4			
Mean	-3.5	-3.3				-3.4			

Table 5.8: Descriptive Statistical Analysis for the Percentage Difference Results (Percentage Difference between FLM and SYNCHRO Outputs) - Validation Cases.

Layout the intersection



Lane Movements and Groups:

Scenario Number	Phases (Final Green Times)
1	
3	
5	
6	

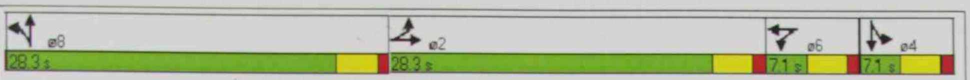
8	
9	

Table 5.9: Intersection Geometry, lane Movements and Groups, Phase Timing and Sequence for Some Selected Scenarios, based on the FLM Final Green Times.

5.2.3 Average delay comparison

For the selected validation 16 cases, additional tests were conducted to examine the effect of the proposed FLM on intersections' average delays. Each validation case was actually (modeled) simulated three times; one using the FLM estimated green times, second using the FLM final green times, and finally using the HCM optimal green times. The intersection average delay time was estimated for each of the three models for each validation case. Table 5.10 shows the values of the green times which were implemented in the simulation software SYNCHRO as well as the corresponding average delay time (seconds/vehicle). For each case, the SYNCHRO model green time settings were adjusted to be equal to the derived values of the FLM or the HCM models. The last three columns of Table 5.10 show the obtained intersection average delay by applying the three groups of green times.

Ideally, testing a new control logic should be done by deploying the control in a network and then assessing its performance vis-à-vis existing controllers. None of the reviewed research papers of relevance to this research have actually done that, and they have mostly used simulation of some isolated intersection for delay comparisons. It goes without saying that deployment of control prototypes at a network level is a rather challenging task by itself as it would entails many authorities approvals, detectors installation, and development as well as deployment cost that was not readily available in this research. This explains why a simulation environment was used to assess the effectiveness of the developed FLM.

For the delay estimates, the three models of each validation case were developed for isolated intersection control. That is, we estimated only the average delay for the intersection to which the control is deployed. Herein, the network effect is not captured as the logic was only applied to one intersection.

With the use of an isolated intersection, the delay times associated with the FLM might not be favorable as compared with the HCM. Keeping in mind that the FLM main advantage is that it does account for network congestion effect downstream the intersection, it is expected (and that was shown earlier) that there could be significant differences between the FLM extracted green times and the corresponding HCM ones.

It is as such quite logical that the HCM model would result in least delay values, as it is by definition the optimal model for isolated intersection control. The FLM estimated green times would result in closer delay values to these HCM ones. The FLM final green times would result in completely deviant values of green times (from those of the HCM) and as such higher delay values for the "isolated" intersection, but certainly lesser values in case on network deployment and real time control operation.

Testing the fuzzy logic model in an isolated intersection is not realistic especially in urban areas with closely spaced signalized intersections, where the conditions of the downstream links clearly affect the intersections discharge rates and hence the appropriate allocations of green times. The only accurate and representative test for the FLM would be in field and in a real-time control environment. This will then require the installation of multiple link detectors to estimate the dynamic variants traffic state variables (namely, the link flows and the queues). The control decisions (green times or final green times) can be then estimated and deployed. The resulting delay times in a real-time field environment are the only true values. In a simulation environment on the other hand, the tests are limited by the many assumptions of uniform traffic flows, turning percentages, heavy vehicle percentages, etc. In fact, in a real-time environment, the implicit assumptions upon which the optimal HCM control decisions were obtained (such as uniform fixed flows and fixed turning percentages) cannot be actually validated.

Case	Traffic Flows (veh/hr)				FLM Control Decision Variables									HCM Model					Intersection Average Delay Times (sec/veh)		
					Cycle (sec)	FLM Green Times (sec)				FLM Final Green Times (sec)				Cycle (sec)	HCM Green Times (sec)				Based on FLM Green times	Based on FLM Final Green times	Based on Optimized HCM model
	E	W	N	S		E	W	N	S	E	W	N	S		E	W	N	S			
1	574	574	574	574	86.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	80	16	16	16	16	31.8	31.8	34
2	574	574	574	574	86.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	17.7	80	16	16	16	16	31.8	31.8	34
3	824	824	824	824	86.7	18.2	17.5	17.5	17.5	24.4	15.4	15.4	15.4	90	20	18	18	18	58	104.3	51.1
4	824	824	824	824	86.7	18.2	17.5	17.5	17.5	17.7	17.7	17.7	17.7	90	20	18	18	18	58	57.3	51.1
5	1074	1074	1074	1074	153.3	34.3	34.3	34.3	34.3	34.3	34.3	34.3	34.3	140	31	31	31	31	100.2	100.2	100
6	1074	1074	824	1074	83.4	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9	130	31	30	23	30	148.8	148.8	83.6
7	1074	1112	824	1074	83.4	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9	130	30	31	23	30	154.7	154.7	85.9
8	324	824	824	824	86.7	17.7	17.7	17.7	17.7	28.3	7.1	28.3	7.1	80	16	16	16	16	53.8	1334.5	49.1
9	574	324	324	324	86.7	17.7	17.7	17.7	17.7	40.4	10.1	10.1	10.1	80	16	16	16	16	28.8	50.2	31.3
10	574	1112	824	824	83.4	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9	90	17	23	17	17	99.6	99.6	58
11	824	824	324	324	86.7	17.7	17.7	17.7	17.7	10.1	10.1	40.4	10.1	80	16	16	16	16	48.8	496.5	45.5
12	824	574	824	1074	83.4	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9	90	19	16	17	22	91.7	91.7	54.6
13	1074	1112	324	324	83.4	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9	90	21	21	16	16	146.5	146.5	67.7

14	111 2	574	324	574	83.4	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9	80	16	16	16	16	99.9	99.9	87.7
15	111 2	324	824	111 2	83.4	16.9	16.9	16.9	16.9	16.9	16.9	16.9	16.9	90	21	16	16	21	144.3	144.3	79

Table 5.10: The green times for different testing scenarios and associated average intersection delays.

Chapter 6: Conclusion

6.1 Overview and Summary of Findings

This research aimed at developing a FLM that can effectively perform and provide solutions close to optimal benchmark solutions. Among the primary functional requirements of the FLM is its ability to function effectively in all traffic conditions ranging from free flow traffic conditions to grid-locks. The FLM should not be limited to isolated intersection control. It should incorporate logic to account for the network traffic effect; at least the effect of the neighboring intersection congestion and spill backs. It should be flexible enough to act in both ways as warranted. The FLM development should not be based on intuitions solely as this may lead to system that is far deviant from optimal solutions. In fact, optimal solutions should be used to derive the inference engine of the FLM. In light of these main functional requirements, the findings of this research are reviewed in this Chapter.

Regarding the functional requirement that FLM should effectively perform and provide solutions close to optimal benchmark solutions, the FLM was designed and formulated to follow the HCM signal optimization method. In fact, the FLM is particularly formed to mimic the HCM signal optimization method (in SYNCHRO). Among the decision variables of the FLM are the cycle length (that corresponds to the optimal cycle length of the HCM method) and the phase green times (corresponding to the ones derived by SYNCHRO). As for the functional requirement on developing the FLM to account for the network traffic effect; at least the effect of the neighboring intersection congestion and spill backs, the developed FLM explicitly accounts for the effect of the downstream congestion on the traffic signal control design (mainly the green times allocations).

A simulation model was used rather than collecting field data of traffic measures with different hourly volumes to enable the calibration and validity of the model for various traffic conditions. The FLM was calibrated through simulation data of a sample intersection of four legs, accounting for all turning movements and using a split signal phasing. Moreover, and in order to ensure covering all traffic flow conditions from free flow to grid locks, the Level of Service (LOS) concepts with the base of v/c ratio was used in forming the FLM (specifically, in defining the traffic flows membership function). For example, the *low* approach volume is related to uncongested situations (LOS A through C), while *very high* term represents LOS of F.

To account for the traffic congestion downstream the intersection, the FLM utilized the downstream congestion measure (DSC). This measure was included as an index that is directly related to the 95 percentile queue length, as well as the link length. The definition of the maximum and minimum DSC of the link were determined based on the 95 percentile queue obtained from the optimized solutions and the link length.

Simulation was used in the calibration of the inference engine of the proposed FLM. 289 simulation runs were carefully selected to cover all possible traffic conditions and LOSs. The HCM signal optimization method was used in optimizing the signals, estimating the optimal cycle time, green times of each phase, and the corresponding expected 95 percentile queue. The downstream congestion index was estimated for any signal phase based on the 95% queues output from the simulation runs. Mathematical manipulations were then used to estimate the called "green weights" of each phase. Such weights were then used in calibrating the inference engine and the rule base of the proposed FLM.

Using the specialized software (FuzzyTECH), a FLM with five main rule blocks calibrated. The membership functions were designed by relating the inputs with the outputs recorded from the simulation stage and for each approach. The final green weights were "intuitively" calibrated to account for the downstream congestion.

The FuzzyTECH software was used in modeling the proposed FLM, and running the exact 289 scenarios that were used in the FLM calibration. Comparative and descriptive analyses (of the FLM versus the SYNCHRO) were conducted for the obtained results. The absolute values of difference, and the percentage of difference between both the FLM and the SYNCHRO-based outputs were estimated. The variables of the cycle time (C), green times using the GW estimates of the FLM, and the final green times using the GWF of the FLM, were used in the comparison and calibration. The acceptance criteria related to the closeness of the FLM to the SYNCHRO model was that; the average percentage difference between the FLM and SYNCHRO not to exceed the confidence level, which is considered as 10%.

Table 6.1 presents the number of runs with different intervals of accuracy (percentage of difference between the FLM and SYNCHRO). Table 6.2 shows the percentage of runs (out of the 289 runs) with different intervals of accuracy (percentage of difference between the FLM and SYNCHRO). The estimates of the cycle times by the FLM are quite close to these estimated by the SYNCHRO. 98.6% of the tested 289 scenarios are within the range of [-10% - 10%] percentile difference of the cycle estimates of the FLM and SYNCHRO. The green times estimates of both FLM and SYNCHRO are also quite comparable. 70.2% of the tested 289 scenarios are within the range of [-10% - 10%] percentile difference of the East approach's green time estimates of the FLM and SYNCHRO. 95.2% of the tested 289 scenarios are within the range of [-10% - 10%] percentile difference of the West approach's green time estimates of the FLM and SYNCHRO. 87.9% of the tested 289 scenarios are within the range of [-10% - 10%] percentile difference of the North approach's green time estimates of the FLM and SYNCHRO. 93.8% of the tested 289 scenarios are within the range of [-10% - 10%] percentile difference of the South approach's green time estimates of the FLM and SYNCHRO.

Interval of Percentage Difference	Number of Runs								
	Cycle (sec)	Green Times (sec)				Final Green Times (FLM)– Green time (SYNCHRO)/ Green time (SYNCHRO) (sec)			
		E	W	N	S	E	W	N	S
[-10%,10%]	285	203	275	254	271	50	98	120	96
[-10%,-20%] or [10%, 20%]	3	76	11	30	16	119	131	126	123
[-20%, -30%] or [20%,30%]	1	10	2	3	2	56	43	31	51
<-30% or > 30%	0	0	1	2	0	64	17	12	19
Total	289	289	289	289	289	289	289	289	289

Table 6.1: Number of Runs with Different Intervals of Percentage of Difference between the FLM and SYNCHRO

Interval of Percentage Difference	Number of Runs								
	Cycle (sec)	Green Times (sec)				Final Green Times (FLM)– Green time (SYNCHRO)/ Green time (SYNCHRO) (sec)			
		E	W	N	S	E	W	N	S
[-10%,10%]	98.6	70.2	95.2	87.9	93.8	17.3	33.9	41.5	33.2
[-10%,-20%] or [10%, 20%]	1.0	26.3	3.8	10.4	5.5	41.2	45.3	43.6	42.6

[-20%, -30%] or [20%,30%]	0.3	3.5	0.7	1.0	0.7	19.4	14.9	10.7	17.6
<-30% or > 30%	0.0	0.0	0.3	0.7	0.0	22.1	5.9	4.2	6.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 6.2: Percentage of Runs (out of the 289 runs) with Different Intervals of Percentage of Difference between the FLM and SYNCHRO

Out of calibration comparison results, two main observations were noticed including; 1) for *low* downstream congestion (DSC) and *low to medium* traffic flows, the differences and percentage of difference of cycle time, and green times were positive, 2) for *high* downstream congestion (DSC) and *high to very high* traffic flows the differences and percentage of differences of cycle time, and green times were negative.

The proposed FLM was tested for validity. A new set of data (that is different than the ones used in the calibration) was used. For each of the four approaches, the % difference between the two main output variables (FLM final green time and SYNCHRO green time) was estimated.

The general outcome was that the proposed FLM is quite effective and sufficient to replicate "optimization" signal control procedures (SYNCHRO). The validation of results indicated that the FLM is mostly effective for cases of *medium or high* DSC and *medium to high* traffic flows.

6.2 Limitations of the Research

- This research assumed specific variables, which might vary with other signalized intersections. Changing the values of these parameters or variable may lead to change in the results and the final conclusions. These limitations are as follows;
  - This research assumed specific geometric parameters such as the number of lanes, phase arrangements, link length, link speed, lane width, saturation flow rate, passenger car length, and heavy vehicle length. Changing these parameters may affect the calibration of the FLM and may mandate fine tuning of the inference engine.
  - Specific traffic parameters were assumed such as the right turn percentage, through movement percentage, left turn percentage, peak hour factor, and the percentage of heavy vehicles. Changing these parameters may affect the calibration of the FLM and may mandate fine tuning of the inference engine.
  - The FLM is designed to mimic a pre-timed signalized intersection with protected left turn movement, split phase operation. Yellow and all red times were assumed to be 3 sec and 1 sec, respectively. Changing these parameters may affect the calibration of the FLM and may mandate fine tuning of the inference engine.

- The FLM model was developed and calibrated using simulation data of isolated intersection. The traffic measures which were used to calibrate the FLM; namely the SYNCHRO derived traffic flows, queue length, cycle length and green times are generated using an isolated intersection. The neighboring effect (the downstream congestion) was estimated. The isolated intersection data may not adequately reflect several aspects or network effects such as signal progression effect, or car platooning.

6.3 Recommendations and Suggestions for Further Investigations

- Sensitivity analysis to capture the effect of the various parameters accuracy can be quite helpful. For instance, various turning movement percentage and/or traffic stream compositions can help understanding the effectiveness of the calibrated FLM (with specific parameters) in case of its deployment in situations entailing various values of these parameters.
- The evaluation of the proposed FLM was done by comparing it to the optimal solution decisions (bench mark comparison against the cycle and the green times). Further evaluation using other performance measures such as the resulting average travel time, delay time, and fuel consumption can be quite helpful.
- Different types of traffic signal control (such as actuated or semi-actuated traffic signal control) can be tested, and compared with the developed FLM as well as the benchmark optimal pre-timed signal control.
- The FLM model was developed and calibrated using simulation data of isolated intersection. The isolated intersection data may not adequately reflect several aspects or network effects such as signal progression effect, or car platooning. Future research work may consider further calibration data to be generated from a network or arterials.

- The devised FLM estimates the cycle length and estimates the green time allocation of the various phases. The phase sequencing in the presented model is assumed fixed; no phase skipping unless the green time allocation to the phase is estimated as zero. An additional control stage can be easily augmented to comparatively evaluate the green weights (or final green weights) of the current red phases and as such selects the next green phase (one with highest green weight or final green weight). This will handle the logic of phase sequencing.
- The proposed FLM uses mainly few input parameters that can be easily extracted from approach detectors. Field detectors can be arranged to provide information on approach flows and current queues, which are basically the inputs to the proposed FLM. Sensitivity analysis can be carried out to investigate the impact of the detectors locations (and errors) on the effectiveness of the FLM.
- A field data collection can be used to generate and design a new FLM, and then compare the results with the proposed model. In addition, by collecting the field data, a new membership functions might be designed based on different traffic flow unit, which is the hourly passenger car unit instead of hourly vehicles.
- The proposed FLM did not account for the effect of pedestrians. The model can be easily amended to capture the effect of pedestrian movement and to explicitly introduce pedestrian phases.
- The proposed FLM did not account for the effect of transit systems priority (TSP). TSP can be easily handled by introducing the "priority" in the form of

higher green weights. The fifth rule block can be modified to introduce the TSP effect on the final green weight.

Bibliography

Arora, M., & Banga, V. (2012). Intelligent Traffic Light Control System using Morphological Edge Detection and Fuzzy Logic. International Conference on Intelligent Computational Systems (ICICS'2012) Jan. 7-8, pg 151- 154.

Askerzade, & Mahmud, M. (2011). Design and implementation of group traffic control system using Fuzzy Logic. International Journal of Research and Reviews in Applied Sciences, IJRRAS. Vol. 6, No.2, pg 196- 202.

Cai, C., Wong, C., & Heydecker, B. (2009). Adaptive traffic signal control using approximate dynamic programming. Transportation Research Part C. Vol. 17, pg 456–474.

Felici, G., Rinaldi,G., Sforza, A., & Truemper, K. (2006). A logic programming based approach for on-line traffic control. Transportation Research Part C. Vol. 14, pg 175–189.

Hou, R., Wang, Q., Wang, J., Wang, J., Lu, Y., & Kim, U.J. (2012). A Fuzzy Control Method of Traffic Light with Countdown Ability. International Journal of Control and Automation. Vol. 5, No. 4, pg 93-102.

Kosonen, I. (2003). Multi-agent fuzzy signal control based on real-time simulation. Transportation Research Part C. Vol. 11, pg 389–403.

Mehan, S. (2011). Introduction of Traffic Light Controller with Fuzzy Control System. International Journal of Electronics & Communication Technology (IJECT). Vol. 2, pg 119-122.

Mucsi, K., Khan, A., & Ahmadi, M. (2011). An Adaptive Neuro-Fuzzy Inference System for estimating the number of vehicles for queue management at signalized intersections. Transportation Research Part C. Vol. 19, pg 1033–1047.

Murat, Y., & Gedizlioglu, E. (2005). A fuzzy logic multi-phased signal control model for isolated junctions. Transportation Research Part C. Vol. 13, pg 19–36.

Pranevičius, H., & Kraujalis, T. (2012). Knowledge based traffic signal control model for signalized intersection. Transport. Vol. 27, No. 3, pg 263–267.

Prakash, T., & Tiwari, R. (2011). Counter-based Traffic Management Scheme for Vehicular Networks. Journal of Emerging Trends in Computing and Information Sciences. Vol 2, No.6, pg 251-256.

Ross, T. J. *Fuzzy Logic with engineering applications.* 111 River Street, Hoboken, NJ 07030, USA: John Wiley & Sons Inc., 2004.

Royani, T., Haddadnia, J., & Alipoor, M. (2013). Control of Traffic Light in Isolated Intersections Using Fuzzy Neural Network and Genetic Algorithm. International Journal of Computer and Electrical Engineering. Vol. 5, No. 1, pg 142-146.

Ross, R.P., Prassas, E, S., & Mcshane, W. R. *Traffic Engineering*. Upper Saddle River New Jersey: Pearson Prentice Hall, 2004.

Saini, B., Sodhi, A., & Saini, B. (2012). Coordinated Intelligent Traffic Control System (CITCS). International Journal of Applied Information Systems (IJAIS). Vol. 4, No.7, pg 11-14.

Schmo¨cker, J., Ahuja, S., & Bell, M.G.H. (2008). Multi-objective signal control of urban junctions – Framework and a London case study. Transportation Research Part C. Vol. 16, pg 454–470.

Skabardonis, A., & Geroliminis, N. (2008). Real-Time Monitoring and Control on Signalized Arterials. Journal of Intelligent Transportation Systems: Technology, Planning, and Operations. Vol. 12, No. 2, pg 64–74.

Trabia, M., Kaseko, M., & Ande, M. (1999). A two-stage fuzzy logic controller for traffic signals. Transportation Research Part C. Vol. 7, pg 353-367.

Teodorovic, D. (1999). Fuzzy logic systems for transportation engineering: the state of the art. Transportation Research Part A. Vol. 33, pg 337-364.

Transportation Research Board, Highway Capacity Manual, Special Report 209 (Washington, D.C., 1994).

United States Department of Transportation (U.S-DoT), Federal Highway Administration (FHWA). Synthesis of Active Traffic Management Experiences in Europe and Related Articles. (Washington, March 2010).

United States Department of Transportation (U.S-DoT), Federal Highway Administration (FHWA), 21st century operations using 21st century technologies. url: http://ops.fhwa.dot.gov/trafficanalysistools/tat_vol4/sec5.htm, last accessed on 17.09.2015

Wolshon, B., and Taylor W. (1999) Analysis of intersection delay under real-time adaptive signal control. Transportation Research Part C. Vol. 7, pg 53-72.

Zaied, A., & Al Othman, W. (2011). Development of a fuzzy logic traffic system for isolated signalized intersections in the State of Kuwait. Expert Systems with Applications. Vol. 38, pg 9434–9441.

Zarandi, M., & Rezapour, S. (2008). A Fuzzy Signal Controller for Isolated Intersections. Journal of Uncertain Systems. Vol. 3, No. 3, pg 174-182.

Appendix A

Simulation runs derived from the SYNCHRO simulation software

Approach Flow Fuzzy Term				Modeled Approach Flow (veh/hr)				The 95 Percentile Queue Length (m)				Green Times (sec)				Cycle length (sec)
E	W	N	S	E	W	N	S	E	W	N	S	E	W	N	S	
L	L	L	L	324	324	324	324	24.4	24.4	24.4	24.4	16	16	16	16	80
L	L	L	M	324	324	324	695	24.4	24.4	24.4	51.6	16	16	16	16	80
L	L	L	MH	324	324	324	787	24.4	24.4	24.4	66.1	16	16	16	16	80
L	L	L	H	324	324	324	880	24.4	24.4	24.4	78.2	16	16	16	16	80
L	L	M	L	324	324	695	324	24.4	24.4	51.6	24.4	16	16	16	16	80
L	L	M	M	324	324	695	695	24.4	24.4	51.6	51.6	16	16	16	16	80
L	L	M	MH	324	324	695	787	24.4	24.4	51.6	66.1	16	16	16	16	80
L	L	M	H	324	324	695	880	24.4	24.4	51.6	78.2	16	16	16	16	80
L	L	MH	L	324	324	787	324	24.4	24.4	66.1	24.4	16	16	16	16	80
L	L	MH	M	324	324	787	695	24.4	24.4	66.1	51.6	16	16	16	16	80
L	L	MH	MH	324	324	787	787	24.4	24.4	66.1	66.1	16	16	16	16	80
L	L	MH	H	324	324	787	880	24.4	24.4	66.1	78.2	16	16	16	16	80
L	L	H	L	324	324	880	324	24.4	24.4	78.2	24.4	16	16	16	16	80
L	L	H	M	324	324	880	695	24.4	24.4	78.2	51.6	16	16	16	16	80
L	L	H	MH	324	324	880	787	24.4	24.4	78.2	66.1	16	16	16	16	80
L	L	H	H	324	324	880	880	24.4	24.4	78.2	78.2	16	16	16	16	80
L	M	L	L	324	695	324	324	24.4	51.6	24.4	24.4	16	16	16	16	80
L	M	L	M	324	695	324	695	24.4	51.6	24.4	51.6	16	16	16	16	80
L	M	L	MH	324	695	324	787	24.4	51.6	24.4	66.1	16	16	16	16	80
L	M	L	H	324	695	324	880	24.3	51.6	24.4	78.2	16	16	16	16	80
L	M	M	L	324	695	695	324	24.4	51.6	51.6	24.4	16	16	16	16	80
L	M	M	M	324	695	695	695	24.4	51.6	51.6	51.6	16	16	16	16	80

L	M	M	MH	324	695	695	787	24.4	51.6	51.6	66.1	16	16	16	16	80
L	M	M	H	324	695	695	880	24.4	51.6	51.6	78.2	16	16	16	16	80
L	M	MH	L	324	695	787	324	24.4	51.6	66.1	24.4	16	16	16	16	80
L	M	MH	M	324	695	787	695	24.4	51.6	66.1	51.6	16	16	16	16	80
L	M	MH	MH	324	695	787	787	24.4	51.6	66.1	66.1	16	16	16	16	80
L	M	MH	H	324	695	787	880	24.3	51.6	66.1	78.2	16	16	16	16	80
L	M	H	L	324	695	880	324	24.4	51.6	78.2	24.4	16	16	16	16	80
L	M	H	M	324	695	880	695	24.4	51.6	78.2	51.6	16	16	16	16	80
L	M	H	MH	324	695	880	787	24.4	51.6	78.2	66.1	16	16	16	16	80
L	M	H	H	324	695	880	880	24.4	51.6	78.2	78.2	16	16	16	16	80
L	MH	L	L	324	787	324	324	24.4	66.1	24.4	24.4	16	16	16	16	80
L	MH	L	M	324	787	324	695	24.4	66.1	24.4	51.6	16	16	16	16	80
L	MH	L	MH	324	787	324	787	24.4	66.1	24.4	66.1	16	16	16	16	80
L	MH	L	H	324	787	324	880	24.4	66.1	24.4	78.2	16	16	16	16	80
L	MH	M	L	324	787	695	324	24.4	66.1	51.6	24.4	16	16	16	16	80
L	MH	M	M	324	787	695	695	24.4	66.1	51.6	51.6	16	16	16	16	80
L	MH	M	MH	324	787	695	787	24.4	66.1	51.6	66.1	16	16	16	16	80
L	MH	M	H	324	787	695	880	24.4	66.1	51.6	78.2	16	16	16	16	80
L	MH	MH	L	324	787	787	324	24.4	66.1	66.1	24.4	16	16	16	16	80
L	MH	MH	M	324	787	787	695	24.4	66.1	66.1	51.6	16	16	16	16	80
L	MH	MH	MH	324	787	787	787	24.4	66.1	66.1	66.1	16	16	16	16	80
L	MH	MH	H	324	787	787	880	24.4	66.1	66.1	78.2	16	16	16	16	80
L	MH	H	L	324	787	880	324	24.4	66.1	78.2	24.4	16	16	16	16	80
L	MH	H	M	324	787	880	695	24.4	66.1	78.2	51.6	16	16	16	16	80
L	MH	H	MH	324	787	880	787	24.4	66.1	78.2	66.1	16	16	16	16	80
L	MH	H	H	324	787	880	880	26.7	75.7	82.8	82.8	19	17	19	19	90

L	H	L	L	324	880	324	324	24.4	78.2	24.4	24.4	16	16	16	16	80
L	H	L	M	324	880	324	695	24.4	78.2	24.4	51.6	16	16	16	16	80
L	H	L	MH	324	880	324	787	24.4	78.2	24.4	66.1	16	16	16	16	80
L	H	L	H	324	880	324	880	24.4	78.2	24.4	78.2	16	16	16	16	80
L	H	M	L	324	880	695	324	24.4	78.2	51.6	24.4	16	16	16	16	80
L	H	M	M	324	880	695	695	24.4	78.2	51.6	51.6	16	16	16	16	80
L	H	M	MH	324	880	695	787	24.4	78.2	51.6	66.1	16	16	16	16	80
L	H	M	H	324	880	695	880	24.4	78.2	51.6	78.2	16	16	16	16	80
L	H	MH	L	324	880	787	324	24.4	78.2	66.1	24.4	16	16	16	16	80
L	H	MH	M	324	880	787	695	24.4	78.2	66.1	51.6	16	16	16	16	80
L	H	MH	MH	324	880	787	787	24.4	78.2	66.1	66.1	16	16	16	16	80
L	H	MH	H	324	880	787	880	26.7	82.2	75.7	82.2	19	19	17	19	90
L	H	H	L	324	880	880	324	24.4	78.2	78.2	24.4	16	16	16	16	80
L	H	H	M	324	880	880	695	24.4	78.2	78.2	51.6	16	16	16	16	80
L	H	H	MH	324	880	880	787	26.7	82.2	82.2	75.7	19	19	19	17	90
L	H	H	H	324	880	880	880	27.5	82.2	82.2	82.2	17	19	19	19	90
M	L	L	L	695	324	324	324	51.6	24.4	24.4	24.4	16	16	16	16	80
M	L	L	M	695	324	324	695	51.6	24.4	24.4	51.6	16	16	16	16	80
M	L	L	MH	695	324	324	787	51.6	24.4	24.4	66.1	16	16	16	16	80
M	L	L	H	695	324	324	880	51.6	24.4	24.4	78.2	16	16	16	16	80
M	L	M	L	695	324	695	324	51.6	24.4	51.6	24.4	16	16	16	16	80
M	L	M	M	695	324	695	695	51.6	24.4	51.6	51.6	16	16	16	16	80
M	L	M	MH	695	324	695	787	51.6	24.4	51.6	66.1	16	16	16	16	80
M	L	M	H	695	324	695	880	51.6	24.4	51.6	78.6	16	16	16	16	80
M	L	MH	L	695	324	787	324	51.6	24.4	66.1	24.4	16	16	16	16	80
M	L	MH	M	695	324	787	695	51.6	24.4	66.1	51.6	16	16	16	16	80

M	L	MH	MH	695	324	787	787	51.6	24.4	66.1	66.1	16	16	16	16	80
M	L	MH	H	695	324	787	880	51.6	24.4	66.1	78.2	16	16	16	16	80
M	L	H	L	695	324	880	324	51.6	24.4	78.2	24.4	16	16	16	16	80
M	L	H	M	695	324	880	695	51.6	24.4	78.2	51.6	16	16	16	16	80
M	L	H	MH	695	324	880	787	51.6	24.4	78.2	66.1	16	16	16	16	80
M	L	H	H	695	324	880	880	51.6	24.4	78.2	78.2	16	16	16	16	80
M	M	L	L	695	695	324	324	51.6	51.6	24.4	24.4	16	16	16	16	80
M	M	L	M	695	695	324	695	51.6	51.6	24.4	51.6	16	16	16	16	80
M	M	L	MH	695	695	324	787	51.6	51.6	24.4	66.1	16	16	16	16	80
M	M	L	H	695	695	324	880	51.6	51.6	24.4	78.2	16	16	16	16	80
M	M	M	L	695	695	695	324	51.6	51.6	51.6	24.4	16	16	16	16	80
M	M	M	M	695	695	695	695	51.6	51.6	51.6	51.6	16	16	16	16	80
M	M	M	MH	695	695	695	787	51.6	51.6	51.6	66.1	16	16	16	16	80
M	M	M	H	695	695	695	880	51.6	51.6	51.6	74.2	16	16	16	16	80
M	M	MH	L	695	695	787	324	51.6	51.6	66.1	24.4	16	16	16	16	80
M	M	MH	M	695	695	787	695	51.6	51.6	66.1	51.6	16	16	16	16	80
M	M	MH	MH	695	695	787	787	51.6	51.6	66.1	66.1	16	16	16	16	80
M	M	MH	H	695	695	787	880	51.6	51.6	66.1	78.2	16	16	16	16	80
M	M	H	L	695	695	880	324	51.6	51.6	66.1	24.4	16	16	16	16	80
M	M	H	M	695	695	880	695	51.6	51.6	78.2	51.6	16	16	16	16	80
M	M	H	MH	695	695	880	787	51.6	51.6	78.2	66.1	16	16	16	16	80
M	M	H	H	695	695	880	880	51.6	51.6	78.2	78.2	16	16	16	16	80
M	MH	L	L	695	787	324	324	51.6	66.1	24.4	24.4	16	16	16	16	80
M	MH	L	M	695	787	324	695	51.6	66.1	24.4	51.6	16	16	16	16	80
M	MH	L	MH	695	787	324	787	51.6	66.1	24.4	66.1	16	16	16	16	80
M	MH	L	H	695	787	324	880	51.6	66.1	24.4	78.2	16	16	16	16	80

M	MH	M	L	695	787	695	324	51.6	66.1	51.6	24.4	16	16	16	16	80
M	MH	M	M	695	787	695	695	51.6	66.1	51.6	51.6	16	16	16	16	80
M	MH	M	MH	695	787	695	787	51.6	66.1	51.6	66.1	16	16	16	16	80
M	MH	M	H	695	787	695	880	51.6	66.1	51.6	78.2	16	16	16	16	80
M	MH	MH	L	695	787	787	324	51.6	66.1	66.1	24.4	16	16	16	16	80
M	MH	MH	M	695	787	787	695	51.6	66.1	66.1	51.6	16	16	16	16	80
M	MH	MH	MH	695	787	787	787	51.6	66.1	66.1	66.1	16	16	16	16	80
M	MH	MH	H	695	787	787	880	51.6	66.1	66.1	78.2	16	16	16	16	80
M	MH	H	L	695	787	880	324	51.6	66.1	78.2	24.4	16	16	16	16	80
M	MH	H	M	695	787	880	695	51.6	66.1	78.2	51.6	16	16	16	16	80
M	MH	H	MH	695	787	880	787	51.6	66.1	78.2	66.1	16	16	16	16	80
M	MH	H	H	695	787	880	880	51.6	66.1	78.2	78.2	16	16	16	16	80
M	H	L	L	695	880	324	324	51.6	78.2	24.4	24.4	16	16	16	16	80
M	H	L	M	695	880	324	695	51.6	78.2	24.4	51.6	16	16	16	16	80
M	H	L	MH	695	880	324	787	51.6	78.2	24.4	66.1	16	16	16	16	80
M	H	L	H	695	880	324	880	51.6	78.2	24.4	78.2	16	16	16	16	80
M	H	M	L	695	880	695	324	51.6	78.2	51.6	24.4	16	16	16	16	80
M	H	M	M	695	880	695	695	51.6	78.2	51.6	51.6	16	16	16	16	80
M	H	M	MH	695	880	695	787	51.6	78.2	51.6	66.1	16	16	16	16	80
M	H	M	H	695	880	695	880	51.6	78.2	51.6	78.2	16	16	16	16	80
M	H	MH	L	695	880	787	324	51.6	78.2	66.1	24.4	16	16	16	16	80
M	H	MH	M	695	880	787	695	51.6	78.2	66.1	51.6	16	16	16	16	80
M	H	MH	MH	695	880	787	787	51.6	78.2	66.1	66.1	16	16	16	16	80
M	H	MH	H	695	880	787	880	56.1	82.2	75.7	82.2	19	19	17	19	90
M	H	H	L	695	880	880	324	51.6	78.2	78.2	24.4	16	16	16	16	80
M	H	H	M	695	880	880	695	51.6	78.2	78.2	51.6	16	16	16	16	80

M	H	H	MH	695	880	880	787	56.1	82.2	82.2	75.7	19	19	19	17	90
M	H	H	H	695	880	880	880	62	82.2	82.2	82.2	17	19	19	19	90
MH	L	L	L	787	324	324	324	66.1	24.4	24.4	24.4	16	16	16	16	80
MH	L	L	M	787	324	324	695	66.1	24.4	24.4	51.6	16	16	16	16	80
MH	L	L	MH	787	324	324	787	66.1	24.4	24.4	66.1	16	16	16	16	80
MH	L	L	H	787	324	324	880	66.1	24.4	24.4	78.2	16	16	16	16	80
MH	L	M	L	787	324	695	324	66.1	24.4	51.6	24.4	16	16	16	16	80
MH	L	M	M	787	324	695	695	66.1	24.4	51.6	51.6	16	16	16	16	80
MH	L	M	MH	787	324	695	787	66.1	24.4	51.6	66.1	16	16	16	16	80
MH	L	M	H	787	324	695	880	66.1	24.4	51.6	78.2	16	16	16	16	80
MH	L	MH	L	787	324	787	324	66.1	24.4	66.1	24.4	16	16	16	16	80
MH	L	MH	M	787	324	787	695	66.1	24.4	66.1	51.6	16	16	16	16	80
MH	L	MH	MH	787	324	787	787	66.1	24.4	66.1	66.1	16	16	16	16	80
MH	L	MH	H	787	324	787	880	66.1	24.4	66.1	78.2	16	16	16	16	80
MH	L	H	L	787	324	880	324	66.1	24.4	78.2	24.4	16	16	16	16	80
MH	L	H	M	787	324	880	695	66.1	24.4	78.2	51.6	16	16	16	16	80
MH	L	H	MH	787	324	880	787	66.1	24.4	78.2	66.1	16	16	16	16	80
MH	L	H	H	787	324	880	880	63.3	27.9	82.2	82.2	20	16	19	19	90
MH	M	L	L	787	695	324	324	66.1	51.6	24.4	24.4	16	16	16	16	80
MH	M	L	M	787	695	324	695	66.1	51.6	24.4	51.6	16	16	16	16	80
MH	M	L	MH	787	695	324	787	66.1	51.6	24.4	66.1	16	16	16	16	80
MH	M	L	H	787	695	324	880	66.1	51.6	24.4	78.2	16	16	16	16	80
MH	M	M	L	787	695	695	324	66.1	51.6	51.6	24.4	16	16	16	16	80
MH	M	M	M	787	695	695	695	66.1	51.6	51.6	51.6	16	16	16	16	80
MH	M	M	MH	787	695	695	787	66.1	51.6	51.6	66.1	16	16	16	16	80
MH	M	M	H	787	695	695	880	66.1	51.6	51.6	78.2	16	16	16	16	80

MH	M	MH	L	787	695	787	324	66.1	51.6	66.1	24.4	16	16	16	16	80
MH	M	MH	M	787	695	787	695	66.1	51.6	66.1	51.6	16	16	16	16	80
MH	M	MH	MH	787	695	787	787	66.1	51.6	66.1	66.1	16	16	16	16	80
MH	M	MH	H	787	695	787	880	66.1	51.6	66.1	78.2	16	16	16	16	80
MH	M	H	L	787	695	880	324	66.1	51.6	78.2	24.4	16	16	16	16	80
MH	M	H	M	787	695	880	695	66.1	51.6	78.2	51.6	16	16	16	16	80
MH	M	H	MH	787	695	880	787	66.1	51.6	78.2	66.1	16	16	16	16	80
MH	M	H	H	787	695	880	880	63.3	65.6	82.2	82.2	20	16	19	19	90
MH	MH	L	L	787	787	324	324	66.1	66.1	24.4	24.4	16	16	16	16	80
MH	MH	L	M	787	787	324	695	66.1	66.1	24.4	51.6	16	16	16	16	80
MH	MH	L	MH	787	787	324	787	66.1	66.1	24.4	66.1	16	16	16	16	80
MH	MH	L	H	787	787	324	880	66.1	66.1	24.4	78.2	16	16	16	16	80
MH	MH	M	L	787	787	695	324	66.1	66.1	51.6	24.4	16	16	16	16	80
MH	MH	M	M	787	787	695	695	66.1	66.1	51.6	51.6	16	16	16	16	80
MH	MH	M	MH	787	787	695	787	66.1	66.1	51.6	66.1	16	16	16	16	80
MH	MH	M	H	787	787	695	880	66.1	66.1	51.6	78.2	16	16	16	16	80
MH	MH	MH	L	787	787	787	324	66.1	66.1	66.1	24.4	16	16	16	16	80
MH	MH	MH	M	787	787	787	695	66.1	66.1	66.1	51.6	16	16	16	16	80
MH	MH	MH	MH	787	787	787	787	66.1	66.1	66.1	66.1	16	16	16	16	80
MH	MH	MH	H	787	787	787	880	66.1	66.1	66.1	78.2	16	16	16	16	80
MH	MH	H	L	787	787	880	324	66.1	66.1	78.2	24.4	16	16	16	16	80
MH	MH	H	M	787	787	880	695	66.1	66.1	78.2	51.6	16	16	16	16	80
MH	MH	H	MH	787	787	880	787	66.1	66.1	78.2	66.1	16	16	16	16	80
MH	MH	H	H	787	787	880	880	68.6	75.7	82.2	82.2	19	17	19	19	90
MH	H	L	L	787	880	324	324	66.1	78.2	24.4	24.4	16	16	16	16	80
MH	H	L	M	787	880	324	695	66.1	78.2	24.4	51.6	16	16	16	16	80

MH	H	L	MH	787	880	324	787	66.1	78.2	24.4	66.1	16	16	16	16	80
MH	H	L	H	787	880	324	880	63.3	82.2	27.9	82.2	20	19	16	19	90
MH	H	M	L	787	880	695	324	66.1	78.2	51.6	24.4	16	16	16	16	80
MH	H	M	M	787	880	695	695	66.1	78.2	51.6	51.6	16	16	16	16	80
MH	H	M	MH	787	880	695	787	66.1	78.2	51.6	66.1	16	16	16	16	80
MH	H	M	H	787	880	695	880	63.6	82.2	65.6	82.2	20	19	16	19	90
MH	H	MH	L	787	880	787	324	66.1	78.2	66.1	24.4	16	16	16	16	80
MH	H	MH	M	787	880	787	695	66.1	78.2	66.1	51.6	16	16	16	16	80
MH	H	MH	MH	787	880	787	787	66.1	78.2	66.1	66.1	16	16	16	16	80
MH	H	MH	H	787	880	787	880	68.6	82.2	75.7	82.2	19	19	17	19	90
MH	H	H	L	787	880	880	324	63.3	82.2	82.2	27.9	20	19	19	16	90
MH	H	H	M	787	880	880	695	63.3	82.2	82.2	65.6	20	19	19	16	90
MH	H	H	MH	787	880	880	787	68.6	82.2	82.2	75.7	19	19	19	17	90
MH	H	H	H	787	880	880	880	63.3	85.7	85.7	85.7	20	18	18	18	90
H	L	L	L	880	324	324	324	78.2	24.4	24.4	24.4	16	16	16	16	80
H	L	L	M	880	324	324	695	78.2	24.4	24.4	51.6	16	16	16	16	80
H	L	L	MH	880	324	324	787	78.2	24.4	24.4	66.1	16	16	16	16	80
H	L	L	H	880	324	324	880	78.2	24.4	24.4	78.2	16	16	16	16	80
H	L	M	L	880	324	695	324	78.2	24.4	51.6	24.4	16	16	16	16	80
H	L	M	M	880	324	695	695	78.2	24.4	51.6	51.6	16	16	16	16	80
H	L	M	MH	880	324	695	787	78.2	24.4	51.6	66.1	16	16	16	16	80
H	L	M	H	880	324	695	880	78.2	24.4	51.6	78.2	16	16	16	16	80
H	L	MH	L	880	324	787	324	78.2	24.4	66.1	24.4	16	16	16	16	80
H	L	MH	M	880	324	787	695	78.2	24.4	66.1	51.6	16	16	16	16	80
H	L	MH	MH	880	324	787	787	78.2	24.4	66.1	66.1	16	16	16	16	80
H	L	MH	H	880	324	787	880	69.5	27.9	75.7	82.2	22	16	17	19	90

H	L	H	L	880	324	880	324	78.2	24.4	78.2	24.4	16	16	16	16	80
H	L	H	M	880	324	880	695	78.2	24.4	78.2	51.6	16	16	16	16	80
H	L	H	MH	880	324	880	787	69.5	27.9	82.2	75.7	22	16	19	17	90
H	L	H	H	880	324	880	880	78.6	27.9	82.2	82.2	20	16	19	19	90
H	M	L	L	880	695	324	324	78.2	51.6	24.4	24.4	16	16	16	16	80
H	M	L	M	880	695	324	695	78.2	51.6	24.4	51.6	16	16	16	16	80
H	M	L	MH	880	695	324	787	78.2	51.6	24.4	66.1	16	16	16	16	80
H	M	L	H	880	695	324	880	78.2	51.6	24.4	78.2	16	16	16	16	80
H	M	M	L	880	695	695	324	78.2	51.6	51.6	24.4	16	16	16	16	80
H	M	M	M	880	695	695	695	78.2	51.6	51.6	51.6	16	16	16	16	80
H	M	M	MH	880	695	695	787	78.2	51.6	51.6	66.1	16	16	16	16	80
H	M	M	H	880	695	695	880	78.2	51.6	51.6	78.2	16	16	16	16	80
H	M	MH	L	880	695	787	324	78.2	51.6	66.1	24.4	16	16	16	16	80
H	M	MH	M	880	695	787	695	78.2	51.6	66.1	51.6	16	16	16	16	80
H	M	MH	MH	880	695	787	787	78.2	51.6	66.1	66.1	16	16	16	16	80
H	M	MH	H	880	695	787	880	69.5	65.6	75.7	82.2	22	16	17	19	90
H	M	H	L	880	695	880	324	78.2	51.6	78.2	24.4	16	16	16	16	80
H	M	H	M	880	695	880	695	78.2	51.6	78.2	51.6	16	16	16	16	80
H	M	H	MH	880	695	880	787	69.5	65.6	82.2	75.7	22	16	19	17	90
H	M	H	H	880	695	880	880	78.6	65.6	82.2	82.2	20	16	19	19	90
H	MH	L	L	880	787	324	324	78.2	66.1	24.4	24.4	16	16	16	16	80
H	MH	L	M	880	787	324	695	78.2	66.1	24.4	51.6	16	16	16	16	80
H	MH	L	MH	880	787	324	787	78.2	66.1	24.4	66.1	16	16	16	16	80
H	MH	L	H	880	787	324	880	69.5	75.7	27.9	82.2	22	17	16	19	90
H	MH	M	L	880	787	695	324	78.2	66.1	51.6	24.4	16	16	16	16	80
H	MH	M	M	880	787	695	695	78.2	66.1	51.6	51.6	16	16	16	16	80

H	MH	M	MH	880	787	695	787	78.2	66.1	51.6	66.1	16	16	16	16	80
H	MH	M	H	880	787	695	880	69.5	75.7	65.6	82.2	22	17	16	19	90
H	MH	MH	L	880	787	787	324	78.2	66.1	66.1	24.4	16	16	16	16	80
H	MH	MH	M	880	787	787	695	78.2	66.1	66.1	51.6	16	16	16	16	80
H	MH	MH	MH	880	787	787	787	78.2	66.1	66.1	66.1	16	16	16	16	80
H	MH	MH	H	880	787	787	880	75	75.7	75.7	82.2	21	17	17	19	90
H	MH	H	L	880	787	880	324	69.5	75.7	82.2	27.9	22	17	19	16	90
H	MH	H	M	880	787	880	695	69.5	75.7	82.2	65.6	22	17	19	16	90
H	MH	H	MH	880	787	880	787	75	75.7	82.2	75.7	21	17	19	17	90
H	MH	H	H	880	787	880	880	75	75.7	85.7	85.7	21	17	18	18	90
H	H	L	L	880	880	324	324	78.2	78.2	24.4	24.4	16	16	16	16	80
H	H	L	M	880	880	324	695	78.2	78.2	24.4	51.6	16	16	16	16	80
H	H	L	MH	880	880	324	787	69.5	82.2	27.9	75.7	22	19	16	17	90
H	H	L	H	880	880	324	880	78.6	82.2	27.9	82.2	20	19	16	19	90
H	H	M	L	880	880	695	324	78.2	78.2	51.6	24.4	16	16	16	16	80
H	H	M	M	880	880	695	695	78.2	78.2	51.6	51.6	16	16	16	16	80
H	H	M	MH	880	880	695	787	69.5	82.2	65.6	75.7	22	19	16	17	90
H	H	M	H	880	880	695	880	78.6	82.2	65.6	82.2	20	19	16	19	90
H	H	MH	L	880	880	787	324	69.5	82.2	75.7	27.9	22	19	17	16	90
H	H	MH	M	880	880	787	695	69.5	82.2	75.7	65.6	22	19	17	16	90
H	H	MH	MH	880	880	787	787	75	82.2	75.7	75.7	21	19	17	17	90
H	H	MH	H	880	880	787	880	75	85.7	75.7	85.7	21	18	17	18	90
H	H	H	L	880	880	880	324	78.6	82.2	82.2	27.9	20	19	19	16	90
H	H	H	M	880	880	880	695	78.6	82.2	82.2	65.6	20	19	19	16	90
H	H	H	MH	880	880	880	787	75	85.7	85.7	75.7	21	18	18	17	90
H	H	H	H	880	880	880	880	78.6	85.7	85.7	85.7	20	18	18	18	90

L	L	H	VH	324	324	880	1112	27.5	27.9	85.7	101.2	17	16	18	23	90
L	L	VH	L	324	324	1112	324	24.4	24.4	107.8	24.4	16	16	16	16	80
L	L	VH	M	324	324	1112	695	24.4	24.4	107.8	51.6	16	16	16	16	80
L	L	VH	MH	324	324	1112	787	24.4	24.4	107.8	66.1	16	16	16	16	80
L	L	VH	H	324	324	1112	880	27.5	27.9	101.2	81.4	17	16	23	18	90
L	M	VH	M	324	695	1112	695	24.4	51.6	107.8	51.6	16	16	16	16	80
L	M	VH	MH	324	695	1112	787	27.1	65.6	101.2	75.7	18	16	23	17	90
M	M	VH	M	695	695	1112	695	51.6	51.6	107.8	51.6	16	16	16	16	80
M	L	VH	H	695	324	1112	880	62	27.9	101.2	85.7	17	16	23	18	90
M	M	VH	H	695	695	1112	880	62	27.9	101.2	85.7	17	16	23	18	90
MH	MH	VH	MH	787	787	1112	787	75.7	75.7	101.2	75.7	17	17	23	17	90
MH	MH	VH	H	787	787	1112	880	75.7	75.7	101.2	75.7	17	17	23	17	90
MH	L	VH	H	787	324	1112	880	75.7	27.9	101.2	85.7	17	16	23	18	90
MH	M	VH	H	787	695	1112	880	75.7	65.6	101.2	85.7	17	16	23	18	90
H	L	VH	H	880	324	1112	880	85.7	27.9	104.7	85.7	18	16	22	18	90
H	M	VH	H	880	695	1112	880	85.7	65.6	104.7	85.7	18	16	22	18	90
H	MH	VH	H	880	787	1112	880	85.7	65.6	104.7	85.7	18	16	22	18	90
H	H	VH	H	880	880	1112	880	82.2	89.3	108.3	89.3	19	17	21	17	90
VH	L	VH	L	1112	324	1112	324	108.3	27.9	108.3	27.9	21	16	21	16	90
VH	L	VH	M	1112	324	1112	695	108.3	27.9	108.3	65.6	21	16	21	16	90
VH	L	VH	MH	1112	324	1112	787	108.3	27.9	108.3	79.3	21	16	21	16	90
VH	M	VH	M	1112	695	1112	695	108.3	65.6	108.3	65.6	21	16	21	16	90
VH	M	VH	MH	1112	695	1112	787	108.3	65.6	108.3	79.3	21	16	21	16	90
VH	MH	VH	MH	1112	787	1112	787	108.3	79.3	108.3	79.3	21	16	21	16	90
VH	H	VH	L	1112	880	1112	324	104.7	92.9	111.9	27.9	22	16	20	16	90
VH	H	VH	M	1112	880	1112	695	104.7	92.9	111.9	65.6	22	16	20	16	90

VH	H	VH	MH	1112	880	1112	787	119.2	104.1	126.4	94.7	28	21	26	19	110
VH	H	VH	H	1112	880	1112	880	126.4	104.1	126.4	104.1	26	21	26	21	110
VH	VH	VH	L	1112	1112	1112	324	126.4	126.4	126.4	34.5	26	26	26	16	110
VH	VH	VH	M	1112	1112	1112	695	140.5	144.1	144.1	97.6	32	31	31	20	130
VH	VH	VH	MH	1112	1112	1112	787	151.2	154.8	154.8	115.5	34	33	33	24	140
VH	VH	VH	H	1112	1112	1112	880	161.5	165.2	165.2	136	36	35	35	28	150
VH	VH	VH	VH	1112	1112	1112	1112	179.1	179.1	179.1	179.1	36	36	36	36	160

Table A.1: The whole 289 simulation runs derived from the SYNCHRO simulation software.

Appendix B

FLM output data, and comparison results with SYNCHRO

Modeled Approach Flow (veh/hr)				Downstream Congestion Index				Cycle length (sec)	% Final Green Weight (GWF)				Green Weight (GW)				The 95 Percentile Queue Length (m)			
E	W	N	S	E	W	N	S		E	W	N	S	E	W	N	S	E	W	N	S
324	324	324	324	4.88	4.88	4.88	4.88	86.67	50.00	50.00	50.00	50.00	0.24	0.24	0.24	0.24	43.65	43.65	43.65	43.65
324	324	324	695	4.88	4.88	4.88	10.32	86.67	50.00	50.00	50.00	50.00	0.24	0.24	0.24	0.24	43.65	43.65	43.65	91.54
324	324	324	787	4.88	4.88	4.88	13.22	86.67	50.00	50.00	50.00	45.04	0.24	0.24	0.24	0.24	43.65	43.65	43.65	101.70
324	324	324	880	4.88	4.88	4.88	15.64	86.67	50.00	50.00	50.00	35.27	0.24	0.24	0.24	0.24	43.65	43.65	43.65	101.70
324	324	695	324	4.88	4.88	10.32	4.88	86.67	50.00	50.00	50.00	50.00	0.24	0.24	0.24	0.24	43.65	43.65	91.54	43.65
324	324	695	695	4.88	4.88	10.32	10.32	86.67	50.00	50.00	50.00	50.00	0.24	0.24	0.24	0.24	43.65	43.65	91.54	91.54
324	324	695	787	4.88	4.88	10.32	13.22	86.67	50.00	50.00	50.00	45.04	0.24	0.24	0.24	0.24	43.65	43.65	87.19	101.70
324	324	695	880	4.88	4.88	10.32	15.64	86.67	50.00	50.00	50.00	35.27	0.24	0.24	0.24	0.24	43.65	43.65	90.91	101.70
324	324	787	324	4.88	4.88	13.22	4.88	86.67	50.00	50.00	45.04	50.00	0.24	0.24	0.24	0.24	43.65	43.65	101.70	43.65
324	324	787	695	4.88	4.88	13.22	10.32	86.67	50.00	50.00	45.04	50.00	0.24	0.24	0.24	0.24	43.65	43.65	101.70	87.19
324	324	787	787	4.88	4.88	13.22	13.22	86.67	50.00	50.00	45.04	45.04	0.24	0.24	0.24	0.24	43.65	43.65	101.70	101.70
324	324	787	880	4.88	4.88	13.22	15.64	86.67	50.00	50.00	45.04	44.81	0.24	0.24	0.24	0.26	43.65	43.65	101.70	101.70
324	324	880	324	4.88	4.88	15.64	4.88	86.67	50.00	50.00	35.27	50.00	0.24	0.24	0.24	0.24	43.65	43.65	101.70	43.65
324	324	880	695	4.88	4.88	15.64	10.32	86.67	50.00	50.00	35.27	50.00	0.24	0.24	0.24	0.24	43.65	43.65	101.70	90.91
324	324	880	787	4.88	4.88	15.64	13.22	86.67	50.00	50.00	44.81	45.04	0.24	0.24	0.26	0.24	43.65	43.65	101.70	101.70
324	324	880	880	4.88	4.88	15.64	15.64	86.67	50.00	50.00	45.16	45.16	0.24	0.24	0.25	0.25	43.65	43.65	101.70	101.70
324	695	324	324	4.88	10.32	4.88	4.88	86.67	50.00	50.00	50.00	50.00	0.24	0.24	0.24	0.24	43.65	91.54	43.65	43.65
324	695	324	695	4.88	10.32	4.88	10.32	86.67	50.00	50.00	50.00	50.00	0.24	0.24	0.24	0.24	43.65	91.54	43.65	91.54
324	695	324	787	4.88	10.32	4.88	13.22	86.67	50.00	50.00	50.00	45.04	0.24	0.24	0.24	0.24	43.65	87.19	43.65	101.70
324	695	324	880	4.86	10.32	4.88	15.64	86.67	50.00	50.00	50.00	35.27	0.24	0.24	0.24	0.24	43.65	90.91	43.65	101.70
324	695	695	324	4.88	10.32	10.32	4.88	86.67	50.00	50.00	50.00	50.00	0.24	0.24	0.24	0.24	43.65	91.54	91.54	43.65
324	695	695	695	4.88	10.32	10.32	10.32	86.67	50.00	50.00	50.00	50.00	0.24	0.24	0.24	0.24	43.65	91.54	91.54	91.54
324	695	695	787	4.88	10.32	10.32	13.22	86.67	50.00	50.00	50.00	45.04	0.24	0.24	0.24	0.24	43.65	87.19	87.19	101.70

324	695	695	880	4.88	10.32	10.32	15.64	86.67	50.00	50.00	50.00	35.27	0.24	0.24	0.24	0.24	43.65	90.91	90.91	101.70
324	695	787	324	4.88	10.32	13.22	4.88	86.67	50.00	50.00	45.04	50.00	0.24	0.24	0.24	0.24	43.65	87.19	101.70	43.65
324	695	787	695	4.88	10.32	13.22	10.32	86.67	50.00	50.00	45.04	50.00	0.24	0.24	0.24	0.24	43.65	87.19	101.70	87.19
324	695	787	787	4.88	10.32	13.22	13.22	86.67	50.00	50.00	45.04	45.04	0.24	0.24	0.24	0.24	43.65	87.19	101.70	101.70
324	695	787	880	4.86	10.32	13.22	15.64	86.67	50.00	50.00	45.04	33.96	0.24	0.24	0.24	0.24	43.65	87.19	101.70	101.70
324	695	880	324	4.88	10.32	15.64	4.88	86.67	50.00	50.00	35.27	50.00	0.24	0.24	0.24	0.24	43.65	90.91	101.70	43.65
324	695	880	695	4.88	10.32	15.64	10.32	86.67	50.00	50.00	43.05	50.00	0.24	0.24	0.25	0.24	43.65	90.91	101.70	90.91
324	695	880	787	4.88	10.32	15.64	13.22	86.67	50.00	50.00	42.53	45.04	0.24	0.24	0.25	0.24	43.65	87.19	101.70	101.70
324	695	880	880	4.88	10.32	15.64	15.64	86.67	50.00	50.00	35.27	35.27	0.24	0.24	0.24	0.24	43.65	90.91	101.70	101.70
324	787	324	324	4.88	13.22	4.88	4.88	86.67	50.00	45.04	50.00	50.00	0.24	0.24	0.24	0.24	43.65	101.70	43.65	43.65
324	787	324	695	4.88	13.22	4.88	10.32	86.67	50.00	45.04	50.00	50.00	0.24	0.24	0.24	0.24	43.65	101.70	43.65	87.19
324	787	324	787	4.88	13.22	4.88	13.22	86.67	50.00	45.04	50.00	45.04	0.24	0.24	0.24	0.24	43.65	101.70	43.65	101.70
324	787	324	880	4.88	13.22	4.88	15.64	86.67	50.00	45.04	50.00	33.96	0.24	0.24	0.24	0.24	43.65	101.70	43.65	101.70
324	787	695	324	4.88	13.22	10.32	4.88	86.67	50.00	45.04	50.00	50.00	0.24	0.24	0.24	0.24	43.65	101.70	87.19	43.65
324	787	695	695	4.88	13.22	10.32	10.32	86.67	50.00	45.04	50.00	50.00	0.24	0.24	0.24	0.24	43.65	101.70	87.19	87.19
324	787	695	787	4.88	13.22	10.32	13.22	86.67	50.00	45.04	50.00	45.04	0.24	0.24	0.24	0.24	43.65	101.70	87.19	101.70
324	787	695	880	4.88	13.22	10.32	15.64	86.67	50.00	45.04	50.00	33.96	0.24	0.24	0.24	0.24	43.65	101.70	87.19	101.70
324	787	787	324	4.88	13.22	13.22	4.88	86.67	50.00	45.04	45.04	50.00	0.24	0.24	0.24	0.24	43.65	101.70	101.70	43.65
324	787	787	695	4.88	13.22	13.22	10.32	86.67	50.00	45.04	45.04	50.00	0.24	0.24	0.24	0.24	43.65	101.70	101.70	87.19
324	787	787	787	4.88	13.22	13.22	13.22	86.67	50.00	45.04	45.04	45.04	0.24	0.24	0.24	0.24	43.65	101.70	101.70	101.70
324	787	787	880	4.88	13.22	13.22	15.64	86.67	50.00	45.04	45.04	33.96	0.24	0.24	0.24	0.24	43.65	101.70	101.70	101.70
324	787	880	324	4.88	13.22	15.64	4.88	86.67	50.00	45.04	33.96	50.00	0.24	0.24	0.24	0.24	43.65	101.70	101.70	43.65
324	787	880	695	4.88	13.22	15.64	10.32	86.67	50.00	45.04	33.96	50.00	0.24	0.24	0.24	0.24	43.65	101.70	101.70	87.19
324	787	880	787	4.88	13.22	15.64	13.22	86.67	50.00	45.04	33.96	45.04	0.24	0.24	0.24	0.24	43.65	101.70	101.70	101.70
324	787	880	880	5.34	15.14	16.56	16.56	86.67	50.00	35.58	30.81	30.81	0.24	0.24	0.24	0.24	43.65	101.70	101.70	101.70
324	880	324	324	4.88	15.64	4.88	4.88	86.67	50.00	35.27	50.00	50.00	0.24	0.24	0.24	0.24	43.65	101.70	43.65	43.65

324	880	324	695	4.88	15.64	4.88	10.32	86.67	50.00	35.27	50.00	50.00	0.24	0.24	0.24	0.24	43.65	101.70	43.65	90.91
324	880	324	787	4.88	15.64	4.88	13.22	86.67	50.00	33.96	50.00	45.04	0.24	0.24	0.24	0.24	43.65	101.70	43.65	101.70
324	880	324	880	4.88	15.64	4.88	15.64	86.67	50.00	35.27	50.00	35.27	0.24	0.24	0.24	0.24	43.65	101.70	43.65	101.70
324	880	695	324	4.88	15.64	10.32	4.88	86.67	50.00	35.27	50.00	50.00	0.24	0.24	0.24	0.24	43.65	101.70	43.65	101.70
324	880	695	695	4.88	15.64	10.32	10.32	86.67	50.00	35.27	50.00	50.00	0.24	0.24	0.24	0.24	43.65	101.70	90.91	43.65
324	880	695	787	4.88	15.64	10.32	13.22	86.67	50.00	33.96	50.00	45.04	0.24	0.24	0.24	0.24	43.65	101.70	90.91	90.91
324	880	695	880	4.88	15.64	10.32	15.64	86.67	50.00	35.27	50.00	35.27	0.24	0.24	0.24	0.24	43.65	101.70	87.19	101.70
324	880	787	324	4.88	15.64	13.22	4.88	86.67	50.00	33.96	45.04	50.00	0.24	0.24	0.24	0.24	43.65	101.70	90.91	101.70
324	880	787	695	4.88	15.64	13.22	10.32	86.67	50.00	33.96	45.04	50.00	0.24	0.24	0.24	0.24	43.65	101.70	101.70	43.65
324	880	787	787	4.88	15.64	13.22	13.22	86.67	50.00	33.96	45.04	45.04	0.24	0.24	0.24	0.24	43.65	101.70	101.70	87.19
324	880	787	880	5.34	16.44	15.14	16.44	86.67	50.00	31.39	35.58	31.39	0.24	0.24	0.24	0.24	43.65	101.70	101.70	101.70
324	880	880	324	4.88	15.64	15.64	4.88	86.67	50.00	35.27	35.27	50.00	0.24	0.24	0.24	0.24	43.65	101.70	101.70	101.70
324	880	880	695	4.88	15.64	15.64	10.32	86.67	50.00	35.27	35.27	50.00	0.24	0.24	0.24	0.24	43.65	101.70	101.70	43.65
324	880	880	787	5.34	16.44	16.44	15.14	86.67	50.00	31.39	31.39	35.58	0.24	0.24	0.24	0.24	43.65	101.70	101.70	90.91
324	880	880	880	5.5	16.44	16.44	16.44	86.67	50.00	31.39	31.39	31.39	0.24	0.24	0.24	0.24	43.65	101.70	101.70	101.70
695	324	324	324	10.32	4.88	4.88	4.88	86.67	50.00	50.00	50.00	50.00	0.24	0.24	0.24	0.24	91.54	43.65	43.65	43.65
695	324	324	695	10.32	4.88	4.88	10.32	86.67	50.00	50.00	50.00	50.00	0.24	0.24	0.24	0.24	91.54	43.65	43.65	91.54
695	324	324	787	10.32	4.88	4.88	13.22	86.67	50.00	50.00	50.00	45.04	0.24	0.24	0.24	0.24	87.19	43.65	58.16	87.19
695	324	324	880	10.32	4.88	4.88	15.64	86.67	50.00	50.00	50.00	35.27	0.24	0.24	0.24	0.24	90.91	43.65	54.44	90.91
695	324	695	324	10.32	4.88	10.32	4.88	86.67	50.00	50.00	50.00	50.00	0.24	0.24	0.24	0.24	91.54	43.65	91.54	43.65
695	324	695	695	10.32	4.88	10.32	10.32	86.67	50.00	50.00	50.00	50.00	0.24	0.24	0.24	0.24	91.54	43.65	91.54	91.54
695	324	695	787	10.32	4.88	10.32	13.22	86.67	50.00	50.00	50.00	45.04	0.24	0.24	0.24	0.24	87.19	43.65	87.19	101.70
695	324	695	880	10.32	4.88	10.32	15.72	86.67	50.00	50.00	50.00	34.88	0.24	0.24	0.24	0.24	90.91	43.65	90.91	101.70
695	324	787	324	10.32	4.88	13.22	4.88	86.67	50.00	50.00	45.04	50.00	0.24	0.24	0.24	0.24	87.19	43.65	101.70	43.65
695	324	787	695	10.32	4.88	13.22	10.32	86.67	50.00	50.00	45.04	50.00	0.24	0.24	0.24	0.24	87.19	43.65	101.70	87.19
695	324	787	787	10.32	4.88	13.22	13.22	86.67	50.00	50.00	45.04	45.04	0.24	0.24	0.24	0.24	87.19	43.65	101.70	101.70

695	324	787	880	10.32	4.88	13.22	15.64	86.67	50.00	50.00	45.04	33.96	0.24	0.24	0.24	0.24	87.19	43.65	101.70	101.70
695	324	880	324	10.32	4.88	15.64	4.88	86.67	50.00	50.00	35.27	50.00	0.24	0.24	0.24	0.24	90.91	43.65	101.70	43.65
695	324	880	695	10.32	4.88	15.64	10.32	86.67	50.00	50.00	35.27	50.00	0.24	0.24	0.24	0.24	90.91	43.65	101.70	90.91
695	324	880	787	10.32	4.88	15.64	13.22	86.67	50.00	50.00	44.81	45.04	0.24	0.24	0.26	0.24	87.19	43.65	101.70	101.70
695	324	880	880	10.32	4.88	15.64	15.64	86.67	50.00	50.00	45.16	35.27	0.24	0.24	0.25	0.24	90.91	43.65	101.70	101.70
695	695	324	324	10.32	10.32	4.88	4.88	86.67	50.00	50.00	50.00	50.00	0.24	0.24	0.24	0.24	91.54	91.54	43.65	43.65
695	695	324	695	10.32	10.32	4.88	10.32	86.67	50.00	50.00	50.00	50.00	0.24	0.24	0.24	0.24	91.54	91.54	43.65	91.54
695	695	324	787	10.32	10.32	4.88	13.22	86.67	50.00	50.00	50.00	45.04	0.24	0.24	0.24	0.24	87.19	87.19	43.65	101.70
695	695	324	880	10.32	10.32	4.88	15.64	86.67	50.00	50.00	50.00	35.27	0.24	0.24	0.24	0.24	90.91	90.91	43.65	101.70
695	695	695	324	10.32	10.32	10.32	4.88	86.67	50.00	50.00	50.00	50.00	0.24	0.24	0.24	0.24	91.54	91.54	91.54	43.65
695	695	695	695	10.32	10.32	10.32	10.32	86.67	50.00	50.00	50.00	50.00	0.24	0.24	0.24	0.24	91.54	91.54	91.54	91.54
695	695	695	787	10.32	10.32	10.32	13.22	86.67	50.00	50.00	50.00	45.04	0.24	0.24	0.24	0.24	87.19	87.19	87.19	101.70
695	695	695	880	10.32	10.32	10.32	14.84	86.67	50.00	50.00	50.00	39.14	0.24	0.24	0.24	0.24	90.91	90.91	90.91	101.70
695	695	787	324	10.32	10.32	13.22	4.88	86.67	50.00	50.00	45.04	50.00	0.24	0.24	0.24	0.24	87.19	87.19	101.70	43.65
695	695	787	695	10.32	10.32	13.22	10.32	86.67	50.00	50.00	45.04	50.00	0.24	0.24	0.24	0.24	87.19	87.19	101.70	87.19
695	695	787	787	10.32	10.32	13.22	13.22	86.67	50.00	50.00	45.04	45.04	0.24	0.24	0.24	0.24	87.19	87.19	101.70	101.70
695	695	787	880	10.32	10.32	13.22	15.64	86.67	50.00	50.00	45.04	33.96	0.24	0.24	0.24	0.24	87.19	87.19	101.70	101.70
695	695	880	324	10.32	10.32	13.22	4.88	86.67	50.00	50.00	46.45	50.00	0.24	0.24	0.24	0.24	90.91	90.91	101.70	43.65
695	695	880	695	10.32	10.32	15.64	10.32	86.67	50.00	50.00	45.16	50.00	0.24	0.24	0.25	0.24	90.91	90.91	101.70	90.91
695	695	880	787	10.32	10.32	15.64	13.22	86.67	50.00	50.00	44.81	45.04	0.24	0.24	0.26	0.24	87.19	87.19	101.70	101.70
695	695	880	880	10.32	10.32	15.64	15.64	86.67	50.00	50.00	45.16	35.27	0.24	0.24	0.25	0.24	90.91	90.91	101.70	101.70
695	787	324	324	10.32	13.22	4.88	4.88	86.67	50.00	45.04	50.00	50.00	0.24	0.24	0.24	0.24	87.19	101.70	43.65	43.65
695	787	324	695	10.32	13.22	4.88	10.32	86.67	50.00	45.04	50.00	50.00	0.24	0.24	0.24	0.24	87.19	101.70	43.65	87.19
695	787	324	787	10.32	13.22	4.88	13.22	86.67	50.00	45.04	50.00	45.04	0.24	0.24	0.24	0.24	87.19	101.70	43.65	101.70
695	787	324	880	10.32	13.22	4.88	15.64	86.67	50.00	45.04	50.00	33.96	0.24	0.24	0.24	0.24	87.19	101.70	43.65	101.70
695	787	695	324	10.32	13.22	10.32	4.88	86.67	50.00	45.04	50.00	50.00	0.24	0.24	0.24	0.24	87.19	101.70	87.19	43.65

695	787	695	695	10.32	13.22	10.32	10.32	86.67	50.00	45.04	50.00	50.00	0.24	0.24	0.24	0.24	87.19	101.70	87.19	87.19
695	787	695	787	10.32	13.22	10.32	13.22	86.67	50.00	45.04	50.00	45.04	0.24	0.24	0.24	0.24	87.19	101.70	87.19	101.70
695	787	695	880	10.32	13.22	10.32	15.64	86.67	50.00	45.04	50.00	33.96	0.24	0.24	0.24	0.24	87.19	101.70	87.19	101.70
695	787	787	324	10.32	13.22	13.22	4.88	86.67	50.00	45.04	45.04	50.00	0.24	0.24	0.24	0.24	87.19	101.70	101.70	43.65
695	787	787	695	10.32	13.22	13.22	10.32	86.67	50.00	45.04	45.04	50.00	0.24	0.24	0.24	0.24	87.19	101.70	101.70	87.19
695	787	787	787	10.32	13.22	13.22	13.22	86.67	50.00	45.04	45.04	45.04	0.24	0.24	0.24	0.24	87.19	101.70	101.70	101.70
695	787	787	880	10.32	13.22	13.22	15.64	86.67	50.00	45.04	45.04	33.96	0.24	0.24	0.24	0.24	87.19	101.70	101.70	101.70
695	787	880	324	10.32	13.22	15.64	4.88	86.67	50.00	45.04	33.96	50.00	0.24	0.24	0.24	0.24	87.19	101.70	101.70	43.65
695	787	880	695	10.32	13.22	15.64	10.32	86.67	50.00	45.04	44.81	50.00	0.24	0.24	0.26	0.24	87.19	101.70	101.70	87.19
695	787	880	787	10.32	13.22	15.64	13.22	86.67	50.00	45.04	44.81	45.04	0.24	0.24	0.26	0.24	87.19	101.70	101.70	101.70
695	787	880	880	10.32	13.22	15.64	15.64	86.67	50.00	45.04	44.81	33.96	0.24	0.24	0.26	0.24	87.19	101.70	101.70	101.70
695	880	324	324	10.32	15.64	4.88	4.88	86.67	50.00	35.27	50.00	50.00	0.24	0.24	0.24	0.24	90.91	101.70	43.65	43.65
695	880	324	695	10.32	15.64	4.88	10.32	86.67	50.00	35.27	50.00	50.00	0.24	0.24	0.24	0.24	90.91	101.70	43.65	90.91
695	880	324	787	10.32	15.64	4.88	13.22	86.67	50.00	33.96	50.00	45.04	0.24	0.24	0.24	0.24	87.19	101.70	43.65	101.70
695	880	324	880	10.32	15.64	4.88	15.64	86.67	50.00	35.27	50.00	35.27	0.24	0.24	0.24	0.24	90.91	101.70	43.65	101.70
695	880	695	324	10.32	15.64	10.32	4.88	86.67	50.00	35.27	50.00	50.00	0.24	0.24	0.24	0.24	90.91	101.70	90.91	43.65
695	880	695	695	10.32	15.64	10.32	10.32	86.67	50.00	35.27	50.00	50.00	0.24	0.24	0.24	0.24	90.91	101.70	90.91	90.91
695	880	695	787	10.32	15.64	10.32	13.22	86.67	50.00	33.96	50.00	45.04	0.24	0.24	0.24	0.24	87.19	101.70	87.19	101.70
695	880	695	880	10.32	15.64	10.32	15.64	86.67	50.00	35.27	50.00	35.27	0.24	0.24	0.24	0.24	90.91	101.70	90.91	101.70
695	880	787	324	10.32	15.64	13.22	4.88	86.67	50.00	33.96	45.04	50.00	0.24	0.24	0.24	0.24	87.19	101.70	101.70	43.65
695	880	787	695	10.32	15.64	13.22	10.32	86.67	50.00	33.96	45.04	50.00	0.24	0.24	0.24	0.24	87.19	101.70	101.70	87.19
695	880	787	787	10.32	15.64	13.22	13.22	86.67	50.00	33.96	45.04	45.04	0.24	0.24	0.24	0.24	87.19	101.70	101.70	101.70
695	880	787	880	11.22	16.44	15.14	16.44	86.67	50.00	31.39	35.58	31.39	0.24	0.24	0.24	0.24	87.19	101.70	101.70	101.70
695	880	880	324	10.32	15.64	15.64	4.88	86.67	50.00	35.27	35.27	50.00	0.24	0.24	0.24	0.24	90.91	101.70	101.70	43.65
695	880	880	695	10.32	15.64	15.64	10.32	86.67	50.00	35.27	35.27	50.00	0.24	0.24	0.24	0.24	90.91	101.70	101.70	90.91
695	880	880	787	11.22	16.44	16.44	15.14	86.67	50.00	31.39	31.39	35.58	0.24	0.24	0.24	0.24	87.19	101.70	101.70	101.70

695	880	880	880	12.4	16.44	16.44	16.44	86.67	50.00	31.39	31.39	31.39	0.24	0.24	0.24	0.24	90.91	101.70	101.70	101.70
787	324	324	324	13.22	4.88	4.88	4.88	86.67	45.04	50.00	50.00	50.00	0.24	0.24	0.24	0.24	101.70	43.65	43.65	43.65
787	324	324	695	13.22	4.88	4.88	10.32	86.67	45.04	50.00	50.00	50.00	0.24	0.24	0.24	0.24	101.70	43.65	43.65	87.19
787	324	324	787	13.22	4.88	4.88	13.22	86.67	45.04	50.00	50.00	45.04	0.24	0.24	0.24	0.24	101.70	43.65	43.65	101.70
787	324	324	880	13.22	4.88	4.88	15.64	86.67	45.04	50.00	50.00	33.96	0.24	0.24	0.24	0.24	101.70	43.65	43.65	101.70
787	324	695	324	13.22	4.88	10.32	4.88	86.67	45.04	50.00	50.00	50.00	0.24	0.24	0.24	0.24	101.70	43.65	87.19	43.65
787	324	695	695	13.22	4.88	10.32	10.32	86.67	45.04	50.00	50.00	50.00	0.24	0.24	0.24	0.24	101.70	43.65	87.19	87.19
787	324	695	787	13.22	4.88	10.32	13.22	86.67	65.46	50.00	50.00	45.04	0.27	0.24	0.24	0.24	101.70	43.65	87.19	101.70
787	324	695	880	13.22	4.88	10.32	15.64	86.67	65.46	50.00	50.00	33.96	0.27	0.24	0.24	0.24	101.70	43.65	87.19	101.70
787	324	787	324	13.22	4.88	13.22	4.88	86.67	45.04	50.00	45.04	50.00	0.24	0.24	0.24	0.24	101.70	43.65	101.70	43.65
787	324	787	695	13.22	4.88	13.22	10.32	86.67	65.46	50.00	45.04	50.00	0.27	0.24	0.24	0.24	101.70	43.65	101.70	87.19
787	324	787	787	13.22	4.88	13.22	13.22	86.67	63.69	50.00	45.04	45.04	0.27	0.24	0.24	0.24	101.70	43.65	101.70	101.70
787	324	787	880	13.22	4.88	13.22	15.64	86.67	63.69	50.00	45.04	33.96	0.27	0.24	0.24	0.24	101.70	43.65	101.70	101.70
787	324	880	324	13.22	4.88	15.64	4.88	86.67	45.04	50.00	33.96	50.00	0.24	0.24	0.24	0.24	101.70	43.65	101.70	43.65
787	324	880	695	13.22	4.88	15.64	10.32	86.67	65.46	50.00	33.96	50.00	0.27	0.24	0.24	0.24	101.70	43.65	101.70	87.19
787	324	880	787	13.22	4.88	15.64	13.22	86.67	63.69	50.00	44.81	45.04	0.27	0.24	0.26	0.24	101.70	43.65	101.70	101.70
787	324	880	880	12.66	5.58	16.44	16.44	86.67	49.45	50.00	42.02	31.39	0.24	0.24	0.26	0.24	101.70	43.65	101.70	101.70
787	695	324	324	13.22	10.32	4.88	4.88	86.67	45.04	50.00	50.00	50.00	0.24	0.24	0.24	0.24	101.70	87.19	43.65	43.65
787	695	324	695	13.22	10.32	4.88	10.32	86.67	45.04	50.00	50.00	50.00	0.24	0.24	0.24	0.24	101.70	87.19	43.65	87.19
787	695	324	787	13.22	10.32	4.88	13.22	86.67	65.46	50.00	50.00	45.04	0.27	0.24	0.24	0.24	101.70	87.19	43.65	101.70
787	695	324	880	13.22	10.32	4.88	15.64	86.67	65.46	50.00	50.00	33.96	0.27	0.24	0.24	0.24	101.70	87.19	43.65	101.70
787	695	695	324	13.22	10.32	10.32	4.88	86.67	45.04	50.00	50.00	50.00	0.24	0.24	0.24	0.24	101.70	87.19	87.19	43.65
787	695	695	695	13.22	10.32	10.32	10.32	86.67	45.04	50.00	50.00	50.00	0.24	0.24	0.24	0.24	101.70	87.19	87.19	87.19
787	695	695	787	13.22	10.32	10.32	13.22	86.67	65.46	50.00	50.00	45.04	0.27	0.24	0.24	0.24	101.70	87.19	87.19	101.70
787	695	695	880	13.22	10.32	10.32	15.64	86.67	65.46	50.00	50.00	33.96	0.27	0.24	0.24	0.24	101.70	87.19	87.19	101.70
787	695	787	324	13.22	10.32	13.22	4.88	86.67	65.46	50.00	45.04	50.00	0.27	0.24	0.24	0.24	101.70	87.19	101.70	43.65

787	695	787	695	13.22	10.32	13.22	10.32	86.67	65.46	50.00	45.04	50.00	0.27	0.24	0.24	0.24	101.70	87.19	101.70	87.19
787	695	787	787	13.22	10.32	13.22	13.22	86.67	65.46	50.00	45.04	45.04	0.27	0.24	0.24	0.24	101.70	87.19	101.70	101.70
787	695	787	880	13.22	10.32	13.22	15.64	86.67	65.46	50.00	45.04	33.96	0.27	0.24	0.24	0.24	101.70	87.19	101.70	101.70
787	695	880	324	13.22	10.32	15.64	4.88	86.67	65.46	50.00	33.96	50.00	0.27	0.24	0.24	0.24	101.70	87.19	101.70	43.65
787	695	880	695	13.22	10.32	15.64	10.32	86.67	65.46	50.00	44.81	50.00	0.27	0.24	0.26	0.24	101.70	87.19	101.70	87.19
787	695	880	787	13.22	10.32	15.64	13.22	86.67	65.46	50.00	44.81	45.04	0.27	0.24	0.26	0.24	101.70	87.19	101.70	101.70
787	695	880	880	12.66	13.12	16.44	16.44	86.67	69.26	45.75	42.02	31.39	0.27	0.24	0.26	0.24	101.70	101.70	101.70	101.70
787	787	324	324	13.22	13.22	4.88	4.88	86.67	45.04	45.04	50.00	50.00	0.24	0.24	0.24	0.24	101.70	101.70	43.65	43.65
787	787	324	695	13.22	13.22	4.88	10.32	86.67	65.46	45.04	50.00	50.00	0.27	0.24	0.24	0.24	101.70	101.70	43.65	87.19
787	787	324	787	13.22	13.22	4.88	13.22	86.67	63.69	45.04	50.00	45.04	0.27	0.24	0.24	0.24	101.70	101.70	43.65	101.70
787	787	324	880	13.22	13.22	4.88	15.64	86.67	63.69	45.04	50.00	33.96	0.27	0.24	0.24	0.24	101.70	101.70	43.65	101.70
787	787	695	324	13.22	13.22	10.32	4.88	86.67	65.46	45.04	50.00	50.00	0.27	0.24	0.24	0.24	101.70	101.70	87.19	43.65
787	787	695	695	13.22	13.22	10.32	10.32	86.67	65.46	45.04	50.00	50.00	0.27	0.24	0.24	0.24	101.70	101.70	87.19	87.19
787	787	695	787	13.22	13.22	10.32	13.22	86.67	65.46	45.04	50.00	45.04	0.27	0.24	0.24	0.24	101.70	101.70	87.19	101.70
787	787	695	880	13.22	13.22	10.32	15.64	86.67	65.46	45.04	50.00	33.96	0.27	0.24	0.24	0.24	101.70	101.70	87.19	101.70
787	787	787	324	13.22	13.22	13.22	4.88	86.67	63.69	45.04	45.04	50.00	0.27	0.24	0.24	0.24	101.70	101.70	101.70	43.65
787	787	787	695	13.22	13.22	13.22	10.32	86.67	65.46	45.04	45.04	50.00	0.27	0.24	0.24	0.24	101.70	101.70	101.70	87.19
787	787	787	787	13.22	13.22	13.22	13.22	86.67	63.69	45.04	45.04	45.04	0.27	0.24	0.24	0.24	101.70	101.70	101.70	101.70
787	787	787	880	13.22	13.22	13.22	15.64	86.67	63.69	45.04	45.04	33.96	0.27	0.24	0.24	0.24	101.70	101.70	101.70	101.70
787	787	880	324	13.22	13.22	15.64	4.88	86.67	63.69	45.04	33.96	50.00	0.27	0.24	0.24	0.24	101.70	101.70	101.70	43.65
787	787	880	695	13.22	13.22	15.64	10.32	86.67	65.46	45.04	44.81	50.00	0.27	0.24	0.26	0.24	101.70	101.70	101.70	87.19
787	787	880	787	13.22	13.22	15.64	13.22	86.67	63.69	45.04	44.81	45.04	0.27	0.24	0.26	0.24	101.70	101.70	101.70	101.70
787	787	880	880	13.72	15.14	16.44	16.44	86.67	60.80	35.58	42.02	31.39	0.27	0.24	0.26	0.24	101.70	101.70	101.70	101.70
787	880	324	324	13.22	15.64	4.88	4.88	86.67	45.04	33.96	50.00	50.00	0.24	0.24	0.24	0.24	101.70	101.70	43.65	43.65
787	880	324	695	13.22	15.64	4.88	10.32	86.67	65.46	33.96	50.00	50.00	0.27	0.24	0.24	0.24	101.70	101.70	43.65	87.19
787	880	324	787	13.22	15.64	4.88	13.22	86.67	63.69	33.96	50.00	45.04	0.27	0.24	0.24	0.24	101.70	101.70	43.65	101.70

787	880	324	880	12.66	16.44	5.58	16.44	86.67	49.45	31.39	50.00	31.39	0.24	0.24	0.24	0.24	101.70	101.70	43.65	101.70
787	880	695	324	13.22	15.64	10.32	4.88	86.67	65.46	33.96	50.00	50.00	0.27	0.24	0.24	0.24	101.70	101.70	87.19	43.65
787	880	695	695	13.22	15.64	10.32	10.32	86.67	65.46	33.96	50.00	50.00	0.27	0.24	0.24	0.24	101.70	101.70	87.19	87.19
787	880	695	787	13.22	15.64	10.32	13.22	86.67	65.46	33.96	50.00	45.04	0.27	0.24	0.24	0.24	101.70	101.70	87.19	101.70
787	880	695	880	12.72	16.44	13.12	16.44	86.67	68.83	31.39	45.75	31.39	0.27	0.24	0.24	0.24	101.70	101.70	101.70	101.70
787	880	787	324	13.22	15.64	13.22	4.88	86.67	63.69	33.96	45.04	50.00	0.27	0.24	0.24	0.24	101.70	101.70	101.70	43.65
787	880	787	695	13.22	15.64	13.22	10.32	86.67	65.46	33.96	45.04	50.00	0.27	0.24	0.24	0.24	101.70	101.70	101.70	87.19
787	880	787	787	13.22	15.64	13.22	13.22	86.67	63.69	33.96	45.04	45.04	0.27	0.24	0.24	0.24	101.70	101.70	101.70	101.70
787	880	787	880	13.72	16.44	15.14	16.44	86.67	60.80	31.39	35.58	31.39	0.27	0.24	0.24	0.24	101.70	101.70	101.70	101.70
787	880	880	324	12.66	16.44	16.44	5.58	86.67	49.45	31.39	31.39	50.00	0.24	0.24	0.24	0.24	101.70	101.70	101.70	43.65
787	880	880	695	12.66	16.44	16.44	13.12	86.67	69.26	31.39	31.39	45.75	0.27	0.24	0.24	0.24	101.70	101.70	101.70	101.70
787	880	880	787	13.72	16.44	16.44	15.14	86.67	60.80	31.39	42.02	35.58	0.27	0.24	0.26	0.24	101.70	101.70	101.70	101.70
787	880	880	880	12.66	17.14	17.14	17.14	86.67	49.45	29.01	40.66	29.01	0.24	0.24	0.26	0.24	101.70	101.70	101.70	101.70
880	324	324	324	15.64	4.88	4.88	4.88	86.67	35.27	50.00	50.00	50.00	0.24	0.24	0.24	0.24	101.70	43.65	43.65	43.65
880	324	324	695	15.64	4.88	4.88	10.32	86.67	35.27	50.00	50.00	50.00	0.24	0.24	0.24	0.24	101.70	43.65	43.65	90.91
880	324	324	787	15.64	4.88	4.88	13.22	86.67	33.96	50.00	50.00	45.04	0.24	0.24	0.24	0.24	101.70	43.65	43.65	101.70
880	324	324	880	15.64	4.88	4.88	15.64	86.67	35.27	50.00	50.00	35.27	0.24	0.24	0.24	0.24	101.70	43.65	43.65	101.70
880	324	695	324	15.64	4.88	10.32	4.88	86.67	35.27	50.00	50.00	50.00	0.24	0.24	0.24	0.24	101.70	43.65	90.91	43.65
880	324	695	695	15.64	4.88	10.32	10.32	86.67	35.27	50.00	50.00	50.00	0.24	0.24	0.24	0.24	101.70	43.65	90.91	90.91
880	324	695	787	15.64	4.88	10.32	13.22	86.67	53.57	50.00	50.00	45.04	0.27	0.24	0.24	0.24	101.70	43.65	87.19	101.70
880	324	695	880	15.64	4.88	10.32	15.64	86.67	63.79	50.00	50.00	35.27	0.28	0.24	0.24	0.24	101.70	43.65	90.91	101.70
880	324	787	324	15.64	4.88	13.22	4.88	86.67	33.96	50.00	45.04	50.00	0.24	0.24	0.24	0.24	101.70	43.65	101.70	43.65
880	324	787	695	15.64	4.88	13.22	10.32	86.67	53.57	50.00	45.04	50.00	0.27	0.24	0.24	0.24	101.70	43.65	101.70	87.19
880	324	787	787	15.64	4.88	13.22	13.22	86.67	52.20	50.00	45.04	45.04	0.27	0.24	0.24	0.24	101.70	43.65	101.70	101.70
880	324	787	880	13.9	5.58	15.14	16.44	86.67	59.84	50.00	35.58	31.39	0.27	0.24	0.24	0.24	101.70	43.65	101.70	101.70
880	324	880	324	15.64	4.88	15.64	4.88	86.67	45.16	50.00	45.16	50.00	0.25	0.24	0.25	0.24	115.26	43.65	101.70	43.65

880	324	880	695	15.64	4.88	15.64	10.32	86.67	63.79	50.00	45.16	50.00	0.28	0.24	0.25	0.24	101.70	43.65	101.70	90.91
880	324	880	787	13.9	5.58	16.44	15.14	86.67	59.84	50.00	42.02	35.58	0.27	0.24	0.26	0.24	101.70	43.65	101.70	101.70
880	324	880	880	15.72	5.58	16.44	16.44	86.67	34.88	50.00	42.02	31.39	0.24	0.24	0.25	0.24	101.70	43.65	101.70	101.70
880	695	324	324	15.64	10.32	4.88	4.88	86.67	35.27	50.00	50.00	50.00	0.24	0.24	0.24	0.24	101.70	90.91	43.65	43.65
880	695	324	695	15.64	10.32	4.88	10.32	86.67	35.27	50.00	50.00	50.00	0.24	0.24	0.24	0.24	101.70	90.91	43.65	90.91
880	695	324	787	15.64	10.32	4.88	13.22	86.67	53.57	50.00	50.00	45.04	0.27	0.24	0.24	0.24	101.70	87.19	43.65	101.70
880	695	324	880	15.64	10.32	4.88	15.64	86.67	63.79	50.00	50.00	35.27	0.28	0.24	0.24	0.24	101.70	90.91	43.65	101.70
880	695	695	324	15.64	10.32	10.32	4.88	86.67	35.27	50.00	50.00	50.00	0.24	0.24	0.24	0.24	101.70	90.91	90.91	43.65
880	695	695	695	15.64	10.32	10.32	10.32	86.67	35.27	50.00	50.00	50.00	0.24	0.24	0.24	0.24	101.70	90.91	90.91	90.91
880	695	695	787	15.64	10.32	10.32	13.22	86.67	53.57	50.00	50.00	45.04	0.27	0.24	0.24	0.24	101.70	87.19	87.19	101.70
880	695	695	880	15.64	10.32	10.32	15.64	86.67	63.79	50.00	50.00	35.27	0.28	0.24	0.24	0.24	101.70	90.91	90.91	101.70
880	695	787	324	15.64	10.32	13.22	4.88	86.67	53.57	50.00	45.04	50.00	0.27	0.24	0.24	0.24	101.70	87.19	101.70	43.65
880	695	787	695	15.64	10.32	13.22	10.32	86.67	53.57	50.00	45.04	50.00	0.27	0.24	0.24	0.24	101.70	87.19	101.70	87.19
880	695	787	787	15.64	10.32	13.22	13.22	86.67	53.57	50.00	45.04	45.04	0.27	0.24	0.24	0.24	101.70	87.19	101.70	101.70
880	695	787	880	13.9	13.12	15.14	16.44	86.67	65.43	45.75	35.58	31.39	0.28	0.24	0.24	0.24	101.70	101.70	101.70	101.70
880	695	880	324	15.64	10.32	15.64	4.88	86.67	63.79	50.00	35.27	50.00	0.28	0.24	0.24	0.24	101.70	90.91	101.70	43.65
880	695	880	695	15.64	10.32	15.64	10.32	86.67	63.79	50.00	45.16	50.00	0.28	0.24	0.25	0.24	101.70	90.91	101.70	90.91
880	695	880	787	13.9	13.12	16.44	15.14	86.67	64.46	45.75	42.02	35.58	0.28	0.24	0.26	0.24	101.70	101.70	101.70	101.70
880	695	880	880	15.72	13.12	16.44	16.44	86.67	61.04	46.98	42.02	31.39	0.28	0.24	0.25	0.24	101.70	101.70	101.70	101.70
880	787	324	324	15.64	13.22	4.88	4.88	86.67	33.96	45.04	50.00	50.00	0.24	0.24	0.24	0.24	101.70	101.70	43.65	43.65
880	787	324	695	15.64	13.22	4.88	10.32	86.67	53.57	45.04	50.00	50.00	0.27	0.24	0.24	0.24	101.70	101.70	43.65	87.19
880	787	324	787	15.64	13.22	4.88	13.22	86.67	52.20	45.04	50.00	45.04	0.27	0.24	0.24	0.24	101.70	101.70	43.65	101.70
880	787	324	880	13.9	15.14	5.58	16.44	86.67	59.84	35.58	50.00	31.39	0.27	0.24	0.24	0.24	101.70	101.70	43.65	101.70
880	787	695	324	15.64	13.22	10.32	4.88	86.67	53.57	45.04	50.00	50.00	0.27	0.24	0.24	0.24	101.70	101.70	87.19	43.65
880	787	695	695	15.64	13.22	10.32	10.32	86.67	53.57	45.04	50.00	50.00	0.27	0.24	0.24	0.24	101.70	101.70	87.19	87.19
880	787	695	787	15.64	13.22	10.32	13.22	86.67	53.57	45.04	50.00	45.04	0.27	0.24	0.24	0.24	101.70	101.70	87.19	101.70

880	787	695	880	13.9	15.14	13.12	16.44	86.67	65.43	35.58	45.75	31.39	0.28	0.24	0.24	0.24	101.70	101.70	101.70	101.70
880	787	787	324	15.64	13.22	13.22	4.88	86.67	52.20	45.04	45.04	50.00	0.27	0.24	0.24	0.24	101.70	101.70	101.70	43.65
880	787	787	695	15.64	13.22	13.22	10.32	86.67	53.57	45.04	45.04	50.00	0.27	0.24	0.24	0.24	101.70	101.70	101.70	87.19
880	787	787	787	15.64	13.22	13.22	13.22	86.67	52.20	45.04	45.04	45.04	0.27	0.24	0.24	0.24	101.70	101.70	101.70	101.70
880	787	787	880	15	15.14	15.14	16.44	86.67	54.71	35.58	35.58	31.39	0.27	0.24	0.24	0.24	101.70	101.70	101.70	101.70
880	787	880	324	13.9	15.14	16.44	5.58	86.67	59.84	35.58	31.39	50.00	0.27	0.24	0.24	0.24	101.70	101.70	101.70	43.65
880	787	880	695	13.9	15.14	16.44	13.12	92.82	65.43	35.58	42.02	38.46	0.28	0.24	0.26	0.22	101.70	101.70	101.70	101.70
880	787	880	787	15	15.14	16.44	15.14	92.82	54.71	35.58	42.02	35.58	0.27	0.24	0.26	0.22	101.70	101.70	101.70	101.70
880	787	880	880	15	15.14	17.14	17.14	92.82	54.71	35.58	40.66	29.01	0.27	0.24	0.26	0.24	101.70	101.70	101.70	101.70
880	880	324	324	15.64	15.64	4.88	4.88	86.67	35.27	35.27	50.00	50.00	0.24	0.24	0.24	0.24	101.70	101.70	43.65	43.65
880	880	324	695	15.64	15.64	4.88	10.32	86.67	63.79	35.27	50.00	50.00	0.28	0.24	0.24	0.24	101.70	101.70	43.65	90.91
880	880	324	787	13.9	16.44	5.58	15.14	86.67	59.84	31.39	50.00	35.58	0.27	0.24	0.24	0.24	101.70	101.70	43.65	101.70
880	880	324	880	15.72	16.44	5.58	16.44	86.67	34.88	31.39	50.00	31.39	0.24	0.24	0.24	0.24	101.70	101.70	43.65	101.70
880	880	695	324	15.64	15.64	10.32	4.88	86.67	63.79	35.27	50.00	50.00	0.28	0.24	0.24	0.24	101.70	101.70	90.91	43.65
880	880	695	695	15.64	15.64	10.32	10.32	86.67	63.79	35.27	50.00	50.00	0.28	0.24	0.24	0.24	101.70	101.70	90.91	90.91
880	880	695	787	13.9	16.44	13.12	15.14	86.67	65.43	31.39	45.75	35.58	0.28	0.24	0.24	0.24	101.70	101.70	101.70	101.70
880	880	695	880	15.72	16.44	13.12	16.44	86.67	63.46	31.39	46.98	31.39	0.28	0.24	0.24	0.24	101.70	101.70	101.70	101.70
880	880	787	324	13.9	16.44	15.14	5.58	86.67	59.84	31.39	35.58	50.00	0.27	0.24	0.24	0.24	101.70	101.70	101.70	43.65
880	880	787	695	13.9	16.44	15.14	13.12	86.67	65.43	31.39	35.58	45.75	0.28	0.24	0.24	0.24	101.70	101.70	101.70	101.70
880	880	787	787	15	16.44	15.14	15.14	86.67	54.71	31.39	35.58	35.58	0.27	0.24	0.24	0.24	101.70	101.70	101.70	101.70
880	880	787	880	15	17.14	15.14	17.14	86.67	54.71	29.01	35.58	29.01	0.27	0.24	0.24	0.24	101.70	101.70	101.70	101.70
880	880	880	324	15.72	16.44	16.44	5.58	91.34	44.84	42.02	42.02	41.24	0.25	0.25	0.25	0.23	101.70	101.70	101.70	43.65
880	880	880	695	15.72	16.44	16.44	13.12	99.29	61.04	31.39	42.02	41.24	0.28	0.24	0.25	0.23	115.26	115.26	115.26	101.70
880	880	880	787	15	17.14	17.14	15.14	102.35	54.71	29.01	40.66	35.58	0.27	0.24	0.26	0.22	119.56	119.56	119.56	101.70
880	880	880	880	15.72	17.14	17.14	17.14	107.89	44.84	28.00	39.27	28.00	0.25	0.24	0.25	0.24	115.26	115.26	115.26	115.26
324	324	880	1112	5.5	5.58	17.14	20.24	86.67	50.00	50.00	28.00	50.62	0.24	0.24	0.24	0.29	43.65	43.65	101.70	101.70

324	324	1112	324	4.88	4.88	21.56	4.88	86.67	50.00	50.00	12.50	50.00	0.24	0.24	0.24	0.24	43.65	43.65	101.70	43.65
324	324	1112	695	4.88	4.88	21.56	10.32	86.67	50.00	50.00	12.50	50.00	0.24	0.24	0.24	0.24	43.65	43.65	101.70	91.54
324	324	1112	787	4.88	4.88	21.56	13.22	86.67	50.00	50.00	32.20	45.04	0.24	0.24	0.27	0.24	43.65	43.65	101.70	101.70
324	324	1112	880	5.5	5.58	20.24	16.28	86.67	50.00	50.00	50.62	32.17	0.24	0.24	0.29	0.24	43.65	43.65	101.70	101.70
324	695	1112	695	4.88	10.32	21.56	10.32	86.67	50.00	50.00	31.25	50.00	0.24	0.24	0.27	0.24	43.65	72.67	101.70	72.67
324	695	1112	787	5.42	13.12	20.24	15.14	86.67	50.00	39.60	52.56	31.25	0.24	0.24	0.29	0.24	43.65	101.70	101.70	101.70
695	695	1112	695	10.32	10.32	21.56	10.32	86.67	50.00	50.00	43.43	50.00	0.24	0.24	0.28	0.24	91.54	91.54	101.70	91.54
695	324	1112	880	12.4	5.58	20.24	17.14	86.67	50.00	50.00	50.62	28.00	0.24	0.24	0.29	0.24	90.91	43.65	101.70	101.70
695	695	1112	880	12.4	5.58	20.24	17.14	86.67	50.00	50.00	50.62	28.00	0.24	0.24	0.29	0.24	90.91	90.91	101.70	101.70
787	787	1112	787	15.14	15.14	20.24	15.14	86.67	35.58	35.58	50.89	35.58	0.24	0.24	0.29	0.24	101.70	101.70	101.70	101.70
787	787	1112	880	15.14	15.14	20.24	15.14	86.67	35.58	35.58	50.89	35.58	0.24	0.24	0.29	0.24	101.70	101.70	101.70	101.70
787	324	1112	880	15.14	5.58	20.24	17.14	86.67	35.58	50.00	50.89	29.01	0.24	0.24	0.29	0.24	101.70	43.65	101.70	101.70
787	695	1112	880	15.14	13.12	20.24	17.14	86.67	35.58	45.75	50.89	29.01	0.24	0.24	0.29	0.24	101.70	101.70	101.70	101.70
880	324	1112	880	17.14	5.58	20.94	17.14	86.67	28.00	50.00	46.56	28.00	0.24	0.24	0.29	0.24	101.70	43.65	101.70	101.70
880	695	1112	880	17.14	13.12	20.94	17.14	86.67	28.00	46.98	46.56	28.00	0.24	0.24	0.29	0.24	101.70	101.70	101.70	101.70
880	787	1112	880	17.14	13.12	20.94	17.14	92.82	40.66	45.75	45.18	29.01	0.26	0.24	0.29	0.24	101.70	101.70	101.70	101.70
880	880	1112	880	16.44	17.86	21.66	17.86	107.89	42.02	24.51	41.24	24.51	0.25	0.24	0.28	0.24	115.26	115.26	115.26	115.26
1112	324	1112	324	21.66	5.58	21.66	5.58	86.67	43.60	50.00	43.60	50.00	0.29	0.24	0.29	0.24	159.75	43.65	101.70	43.65
1112	324	1112	695	21.66	5.58	21.66	13.12	86.67	43.58	50.00	43.58	47.18	0.29	0.24	0.29	0.24	101.70	43.65	101.70	101.70
1112	324	1112	787	21.66	5.58	21.66	15.86	86.67	40.09	50.00	40.09	32.37	0.29	0.24	0.29	0.24	101.70	43.65	101.70	101.70
1112	695	1112	695	21.66	13.12	21.66	13.12	86.67	43.58	47.18	43.58	47.18	0.29	0.24	0.29	0.24	101.70	101.70	101.70	101.70
1112	695	1112	787	21.66	13.12	21.66	15.86	86.67	40.09	45.35	40.09	32.37	0.29	0.24	0.29	0.24	101.70	101.70	101.70	101.70
1112	787	1112	787	21.66	15.86	21.66	15.86	97.18	40.81	33.31	40.81	32.20	0.29	0.24	0.29	0.22	101.70	101.70	101.70	101.70
1112	880	1112	324	20.94	18.58	22.38	5.58	91.34	46.56	33.53	21.53	41.24	0.29	0.25	0.25	0.23	101.70	101.70	101.70	43.65
1112	880	1112	695	20.94	18.58	22.38	13.12	108.99	41.24	21.08	40.11	19.47	0.28	0.24	0.28	0.20	115.26	115.26	115.26	101.70
1112	880	1112	787	23.84	20.82	25.28	18.94	114.87	32.65	12.50	27.79	22.10	0.28	0.24	0.28	0.22	119.56	119.56	119.56	101.70

1112	880	1112	880	25.28	20.82	25.28	20.82	120.55	26.06	12.50	26.06	12.50	0.28	0.24	0.28	0.24	115.26	115.26	115.26	115.26
1112	1112	1112	324	25.28	25.28	25.28	6.9	106.67	26.06	26.06	26.06	12.50	0.29	0.29	0.29	0.19	101.70	101.70	101.70	43.65
1112	1112	1112	695	28.1	28.82	28.82	19.52	133.33	12.50	12.50	12.50	12.50	0.25	0.24	0.24	0.19	159.75	159.75	159.75	101.70
1112	1112	1112	787	30.24	30.96	30.96	23.1	133.33	12.50	12.50	12.50	12.50	0.24	0.24	0.24	0.22	159.75	159.75	159.75	101.70
1112	1112	1112	880	32.3	33.04	33.04	27.2	138.00	12.50	12.50	12.50	12.50	0.24	0.24	0.24	0.24	159.75	159.75	159.75	115.26
1112	1112	1112	1112	35.82	35.82	35.82	35.82	153.33	12.50	12.50	12.50	12.50	0.24	0.24	0.24	0.24	159.75	159.75	159.75	159.75

Table B.1: The output data of the FLM for all 289 studied scenarios

Inputs								Outputs																	
								Difference: (FLM-SYNCHRO)									% Difference: 100*(FLM-SYNCHRO)/ SYNCHRO								
Volumes Terms				DSC Terms				Cycle (sec)	Green Times (sec)				Final Green Times (FLM)– Green time (SYNCHRO) (sec)				Cycle (sec)	Green Times (sec)				Final Green Times (FLM)– Green time (SYNCHRO)/ Green time (SYNCHRO) (sec)			
H	W	N	S	E	W	N	S		E	W	N	S	E	W	N	S		E	W	N	S	E	W	N	S
L	L	L	L	L	L	L	L	6.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	8.3	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
L	L	L	M	L	L	L	L	6.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	8.3	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
L	L	L	MH	L	L	L	L	6.7	1.7	1.7	1.7	1.7	2.1	2.1	2.1	0.3	8.3	10.4	10.4	10.4	10.4	13.2	13.2	13.2	2.0
L	L	L	H	L	L	L	L	6.7	1.7	1.7	1.7	1.7	3.1	3.1	3.1	-2.5	8.3	10.4	10.4	10.4	10.4	19.2	19.2	19.2	-15.9
L	L	M	L	L	L	M	L	6.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	8.3	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
L	L	M	M	L	L	M	L	6.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	8.3	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
L	L	M	MH	L	L	M	L	6.7	1.7	1.7	1.7	1.7	2.1	2.1	2.1	0.3	8.3	10.4	10.4	10.4	10.4	13.2	13.2	13.2	2.0
L	L	M	H	L	L	M	L	6.7	1.7	1.7	1.7	1.7	3.1	3.1	3.1	-2.5	8.3	10.4	10.4	10.4	10.4	19.2	19.2	19.2	-15.9
L	L	MH	L	L	L	L	L	6.7	1.7	1.7	1.7	1.7	2.1	2.1	0.3	2.1	8.3	10.4	10.4	10.4	10.4	13.2	13.2	2.0	13.2
L	L	MH	M	L	L	L	L	6.7	1.7	1.7	1.7	1.7	2.1	2.1	0.3	2.1	8.3	10.4	10.4	10.4	10.4	13.2	13.2	2.0	13.2
L	L	MH	MH	L	L	L	L	6.7	1.7	1.7	1.7	1.7	2.6	2.6	0.7	0.7	8.3	10.4	10.4	10.4	10.4	16.2	16.2	4.7	4.7
L	L	MH	H	L	L	L	L	6.7	1.4	1.4	1.4	2.5	2.6	2.6	0.8	0.7	8.3	8.6	8.6	8.6	15.9	16.3	16.3	4.8	4.2
L	L	H	L	L	L	M	L	6.7	1.7	1.7	1.7	1.7	3.1	3.1	-2.5	3.1	8.3	10.4	10.4	10.4	10.4	19.2	19.2	-15.9	19.2
L	L	H	M	L	L	M	L	6.7	1.7	1.7	1.7	1.7	3.1	3.1	-2.5	3.1	8.3	10.4	10.4	10.4	10.4	19.2	19.2	-15.9	19.2
L	L	H	MH	L	L	M	L	6.7	1.4	1.4	2.5	1.4	2.6	2.6	0.7	0.8	8.3	8.6	8.6	15.9	8.6	16.3	16.3	4.2	4.8
L	L	H	H	L	L	M	L	6.7	1.2	1.2	2.1	2.1	2.6	2.6	0.8	0.8	8.3	7.7	7.7	13.2	13.2	16.0	16.0	4.8	4.8
L	M	L	L	L	M	L	L	6.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	8.3	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
L	M	L	M	L	M	L	L	6.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	8.3	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4

L	M	L	MH	L	M	L	L	6.7	1.7	1.7	1.7	1.7	2.1	2.1	2.1	0.3	8.3	10.4	10.4	10.4	10.4	13.2	13.2	13.2	2.0
L	M	L	H	L	M	L	L	6.7	1.7	1.7	1.7	1.7	3.1	3.1	3.1	-2.5	8.3	10.4	10.4	10.4	10.4	19.2	19.2	19.2	-15.9
L	M	M	L	L	M	M	L	6.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	8.3	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
L	M	M	M	L	M	M	L	6.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	8.3	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
L	M	M	MH	L	M	M	L	6.7	1.7	1.7	1.7	1.7	2.1	2.1	2.1	0.3	8.3	10.4	10.4	10.4	10.4	13.2	13.2	13.2	2.0
L	M	M	H	L	M	M	L	6.7	1.7	1.7	1.7	1.7	3.1	3.1	3.1	-2.5	8.3	10.4	10.4	10.4	10.4	19.2	19.2	19.2	-15.9
L	M	MH	L	L	M	L	L	6.7	1.7	1.7	1.7	1.7	2.1	2.1	0.3	2.1	8.3	10.4	10.4	10.4	10.4	13.2	13.2	2.0	13.2
L	M	MH	M	L	M	L	L	6.7	1.7	1.7	1.7	1.7	2.1	2.1	0.3	2.1	8.3	10.4	10.4	10.4	10.4	13.2	13.2	2.0	13.2
L	M	MH	MH	L	M	L	L	6.7	1.7	1.7	1.7	1.7	2.6	2.6	0.7	0.7	8.3	10.4	10.4	10.4	10.4	16.2	16.2	4.7	4.7
L	M	MH	H	L	M	L	L	6.7	1.7	1.7	1.7	1.7	3.7	3.7	1.8	-2.6	8.3	10.4	10.4	10.4	10.4	23.4	23.4	11.1	-16.2
L	M	H	L	L	M	M	L	6.7	1.7	1.7	1.7	1.7	3.1	3.1	-2.5	3.1	8.3	10.4	10.4	10.4	10.4	19.2	19.2	-15.9	19.2
L	M	H	M	L	M	M	L	6.7	1.5	1.5	2.2	1.5	2.3	2.3	-0.2	2.3	8.3	9.3	9.3	13.8	9.3	14.4	14.4	-1.5	14.4
L	M	H	MH	L	M	M	L	6.7	1.4	1.4	2.4	1.4	2.8	2.8	0.0	1.0	8.3	8.9	8.9	14.9	8.9	17.7	17.7	0.1	6.1
L	M	H	H	L	M	M	L	6.7	1.7	1.7	1.7	1.7	4.7	4.7	-1.4	-1.4	8.3	10.4	10.4	10.4	10.4	29.5	29.5	-8.7	-8.7
L	MH	L	L	L	L	L	L	6.7	1.7	1.7	1.7	1.7	2.1	0.3	2.1	2.1	8.3	10.4	10.4	10.4	10.4	13.2	2.0	13.2	13.2
L	MH	L	M	L	L	L	L	6.7	1.7	1.7	1.7	1.7	2.1	0.3	2.1	2.1	8.3	10.4	10.4	10.4	10.4	13.2	2.0	13.2	13.2
L	MH	L	MH	L	L	L	L	6.7	1.7	1.7	1.7	1.7	2.6	0.7	2.6	0.7	8.3	10.4	10.4	10.4	10.4	16.2	4.7	16.2	4.7
L	MH	L	H	L	L	L	L	6.7	1.7	1.7	1.7	1.7	3.7	1.8	3.7	-2.6	8.3	10.4	10.4	10.4	10.4	23.4	11.1	23.4	-16.2
L	MH	M	L	L	L	M	L	6.7	1.7	1.7	1.7	1.7	2.1	0.3	2.1	2.1	8.3	10.4	10.4	10.4	10.4	13.2	2.0	13.2	13.2
L	MH	M	M	L	L	M	L	6.7	1.7	1.7	1.7	1.7	2.1	0.3	2.1	2.1	8.3	10.4	10.4	10.4	10.4	13.2	2.0	13.2	13.2
L	MH	M	MH	L	L	M	L	6.7	1.7	1.7	1.7	1.7	2.6	0.7	2.6	0.7	8.3	10.4	10.4	10.4	10.4	16.2	4.7	16.2	4.7
L	MH	M	H	L	L	M	L	6.7	1.7	1.7	1.7	1.7	3.7	1.8	3.7	-2.6	8.3	10.4	10.4	10.4	10.4	23.4	11.1	23.4	-16.2
L	MH	MH	L	L	L	L	L	6.7	1.7	1.7	1.7	1.7	2.6	0.7	0.7	2.6	8.3	10.4	10.4	10.4	10.4	16.2	4.7	4.7	16.2
L	MH	MH	M	L	L	L	L	6.7	1.7	1.7	1.7	1.7	2.6	0.7	0.7	2.6	8.3	10.4	10.4	10.4	10.4	16.2	4.7	4.7	16.2

L	MH	MH	MH	L	L	L	L	6.7	1.7	1.7	1.7	1.7	3.1	1.2	1.2	1.2	8.3	10.4	10.4	10.4	10.4	19.3	7.5	7.5	7.5
L	MH	MH	H	L	L	L	L	6.7	1.7	1.7	1.7	1.7	4.3	2.3	2.3	-2.2	8.3	10.4	10.4	10.4	10.4	26.9	14.3	14.3	-13.8
L	MH	H	L	L	L	M	L	6.7	1.7	1.7	1.7	1.7	3.7	1.8	-2.6	3.7	8.3	10.4	10.4	10.4	10.4	23.4	11.1	-16.2	23.4
L	MH	H	M	L	L	M	L	6.7	1.7	1.7	1.7	1.7	3.7	1.8	-2.6	3.7	8.3	10.4	10.4	10.4	10.4	23.4	11.1	-16.2	23.4
L	MH	H	MH	L	L	M	L	6.7	1.7	1.7	1.7	1.7	4.3	2.3	-2.2	2.3	8.3	10.4	10.4	10.4	10.4	26.9	14.3	-13.8	14.3
L	MH	H	H	L	L	M	L	-3.3	-1.3	0.7	-1.3	-1.3	5.0	0.1	-4.2	-4.2	-3.7	-7.0	3.9	-7.0	-7.0	26.3	0.5	-22.2	-22.2
L	H	L	L	L	M	L	L	6.7	1.7	1.7	1.7	1.7	3.1	-2.5	3.1	3.1	8.3	10.4	10.4	10.4	10.4	19.2	-15.9	19.2	19.2
L	H	L	M	L	M	L	L	6.7	1.7	1.7	1.7	1.7	3.1	-2.5	3.1	3.1	8.3	10.4	10.4	10.4	10.4	19.2	-15.9	19.2	19.2
L	H	L	MH	L	M	L	L	6.7	1.7	1.7	1.7	1.7	3.7	-2.6	3.7	1.8	8.3	10.4	10.4	10.4	10.4	23.4	-16.2	23.4	11.1
L	H	L	H	L	M	L	L	6.7	1.7	1.7	1.7	1.7	4.7	-1.4	4.7	-1.4	8.3	10.4	10.4	10.4	10.4	29.5	-8.7	29.5	-8.7
L	H	M	L	L	M	M	L	6.7	1.7	1.7	1.7	1.7	3.1	-2.5	3.1	3.1	8.3	10.4	10.4	10.4	10.4	19.2	-15.9	19.2	19.2
L	H	M	M	L	M	M	L	6.7	1.7	1.7	1.7	1.7	3.1	-2.5	3.1	3.1	8.3	10.4	10.4	10.4	10.4	19.2	-15.9	19.2	19.2
L	H	M	MH	L	M	M	L	6.7	1.7	1.7	1.7	1.7	3.7	-2.6	3.7	1.8	8.3	10.4	10.4	10.4	10.4	23.4	-16.2	23.4	11.1
L	H	M	H	L	M	M	L	6.7	1.7	1.7	1.7	1.7	4.7	-1.4	4.7	-1.4	8.3	10.4	10.4	10.4	10.4	29.5	-8.7	29.5	-8.7
L	H	MH	L	L	M	L	L	6.7	1.7	1.7	1.7	1.7	3.7	-2.6	1.8	3.7	8.3	10.4	10.4	10.4	10.4	23.4	-16.2	11.1	23.4
L	H	MH	M	L	M	L	L	6.7	1.7	1.7	1.7	1.7	3.7	-2.6	1.8	3.7	8.3	10.4	10.4	10.4	10.4	23.4	-16.2	11.1	23.4
L	H	MH	MH	L	M	L	L	6.7	1.7	1.7	1.7	1.7	4.3	-2.2	2.3	2.3	8.3	10.4	10.4	10.4	10.4	26.9	-13.8	14.3	14.3
L	H	MH	H	L	M	L	L	-3.3	-1.3	-1.3	0.7	-1.3	4.8	-4.0	-0.1	-4.0	-3.7	-7.0	-7.0	3.9	-7.0	25.3	-21.3	-0.3	-21.3
L	H	H	L	L	M	M	L	6.7	1.7	1.7	1.7	1.7	4.7	-1.4	-1.4	4.7	8.3	10.4	10.4	10.4	10.4	29.5	-8.7	-8.7	29.5
L	H	H	M	L	M	M	L	6.7	1.7	1.7	1.7	1.7	4.7	-1.4	-1.4	4.7	8.3	10.4	10.4	10.4	10.4	29.5	-8.7	-8.7	29.5
L	H	H	MH	L	M	M	L	-3.3	-1.3	-1.3	-1.3	0.7	4.8	-4.0	-4.0	-0.1	-3.7	-7.0	-7.0	-7.0	3.9	25.3	-21.3	-21.3	-0.3
L	H	H	H	L	M	M	L	-3.3	0.7	-1.3	-1.3	-1.3	7.5	-3.6	-3.6	-3.6	-3.7	3.9	-7.0	-7.0	-7.0	44.2	-19.0	-19.0	-19.0

M	L	L	L	M	L	L	L	6.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	8.3	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
M	L	L	M	M	L	L	L	6.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	8.3	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
M	L	L	MH	M	L	L	L	6.7	1.7	1.7	1.7	1.7	2.1	2.1	2.1	0.3	8.3	10.4	10.4	10.4	10.4	13.2	13.2	13.2	2.0
M	L	L	H	M	L	L	L	6.7	1.7	1.7	1.7	1.7	3.1	3.1	3.1	-2.5	8.3	10.4	10.4	10.4	10.4	19.2	19.2	19.2	-15.9
M	L	M	L	M	L	M	L	6.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	8.3	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
M	L	M	M	M	L	M	L	6.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	8.3	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
M	L	M	MH	M	L	M	L	6.7	1.7	1.7	1.7	1.7	2.1	2.1	2.1	0.3	8.3	10.4	10.4	10.4	10.4	13.2	13.2	13.2	2.0
M	L	M	H	M	L	M	L	6.7	1.7	1.7	1.7	1.7	3.1	3.1	3.1	-2.7	8.3	10.4	10.4	10.4	10.4	19.4	19.4	19.4	-16.7
M	L	MH	L	M	L	L	L	6.7	1.7	1.7	1.7	1.7	2.1	2.1	0.3	2.1	8.3	10.4	10.4	10.4	10.4	13.2	13.2	2.0	13.2
M	L	MH	M	M	L	L	L	6.7	1.7	1.7	1.7	1.7	2.1	2.1	0.3	2.1	8.3	10.4	10.4	10.4	10.4	13.2	13.2	2.0	13.2
M	L	MH	MH	M	L	L	L	6.7	1.7	1.7	1.7	1.7	2.6	2.6	0.7	0.7	8.3	10.4	10.4	10.4	10.4	16.2	16.2	4.7	4.7
M	L	MH	H	M	L	L	L	6.7	1.7	1.7	1.7	1.7	3.7	3.7	1.8	-2.6	8.3	10.4	10.4	10.4	10.4	23.4	23.4	11.1	-16.2
M	L	H	L	M	L	M	L	6.7	1.7	1.7	1.7	1.7	3.1	3.1	-2.5	3.1	8.3	10.4	10.4	10.4	10.4	19.2	19.2	-15.9	19.2
M	L	H	M	M	L	M	L	6.7	1.7	1.7	1.7	1.7	3.1	3.1	-2.5	3.1	8.3	10.4	10.4	10.4	10.4	19.2	19.2	-15.9	19.2
M	L	H	MH	M	L	M	L	6.7	1.4	1.4	2.5	1.4	2.6	2.6	0.7	0.8	8.3	8.6	8.6	15.9	8.6	16.3	16.3	4.2	4.8
M	L	H	H	M	L	M	L	6.7	1.4	1.4	2.3	1.4	3.6	3.6	1.7	-2.2	8.3	9.0	9.0	14.6	9.0	22.4	22.4	10.5	-13.7
M	M	L	L	M	M	L	L	6.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	8.3	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
M	M	L	M	M	M	L	L	6.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	8.3	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
M	M	L	MH	M	M	L	L	6.7	1.7	1.7	1.7	1.7	2.1	2.1	2.1	0.3	8.3	10.4	10.4	10.4	10.4	13.2	13.2	13.2	2.0
M	M	L	H	M	M	L	L	6.7	1.7	1.7	1.7	1.7	3.1	3.1	3.1	-2.5	8.3	10.4	10.4	10.4	10.4	19.2	19.2	19.2	-15.9
M	M	M	L	M	M	M	L	6.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	8.3	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
M	M	M	M	M	M	M	L	6.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	8.3	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4
M	M	M	MH	M	M	M	L	6.7	1.7	1.7	1.7	1.7	2.1	2.1	2.1	0.3	8.3	10.4	10.4	10.4	10.4	13.2	13.2	13.2	2.0
M	M	M	H	M	M	M	L	6.7	1.7	1.7	1.7	1.7	2.7	2.7	2.7	-1.4	8.3	10.4	10.4	10.4	10.4	16.8	16.8	16.8	-8.6

M	M	MH	L	M	M	L	L	6.7	1.7	1.7	1.7	1.7	2.1	2.1	0.3	2.1	8.3	10.4	10.4	10.4	10.4	13.2	13.2	2.0	13.2
M	M	MH	M	M	M	L	L	6.7	1.7	1.7	1.7	1.7	2.1	2.1	0.3	2.1	8.3	10.4	10.4	10.4	10.4	13.2	13.2	2.0	13.2
M	M	MH	MH	M	M	L	L	6.7	1.7	1.7	1.7	1.7	2.6	2.6	0.7	0.7	8.3	10.4	10.4	10.4	10.4	16.2	16.2	4.7	4.7
M	M	MH	H	M	M	L	L	6.7	1.7	1.7	1.7	1.7	3.7	3.7	1.8	-2.6	8.3	10.4	10.4	10.4	10.4	23.4	23.4	11.1	-16.2
M	M	H	L	M	M	M	L	6.7	1.7	1.7	1.7	1.7	2.0	2.0	0.7	2.0	8.3	10.4	10.4	10.4	10.4	12.4	12.4	4.4	12.4
M	M	H	M	M	M	M	L	6.7	1.4	1.4	2.3	1.4	2.1	2.1	0.4	2.1	8.3	9.0	9.0	14.6	9.0	13.2	13.2	2.2	13.2
M	M	H	MH	M	M	M	L	6.7	1.4	1.4	2.5	1.4	2.6	2.6	0.7	0.8	8.3	8.6	8.6	15.9	8.6	16.3	16.3	4.2	4.8
M	M	H	H	M	L	L	L	6.7	1.4	1.4	2.3	1.4	3.6	3.6	1.7	-2.2	8.3	9.0	9.0	14.6	9.0	22.4	22.4	10.5	-13.7
M	MH	L	L	M	L	L	L	6.7	1.7	1.7	1.7	1.7	2.1	0.3	2.1	2.1	8.3	10.4	10.4	10.4	10.4	13.2	2.0	13.2	13.2
M	MH	L	M	M	L	L	L	6.7	1.7	1.7	1.7	1.7	2.1	0.3	2.1	2.1	8.3	10.4	10.4	10.4	10.4	13.2	2.0	13.2	13.2
M	MH	L	MH	M	L	L	L	6.7	1.7	1.7	1.7	1.7	2.6	0.7	2.6	0.7	8.3	10.4	10.4	10.4	10.4	16.2	4.7	16.2	4.7
M	MH	L	H	M	L	M	L	6.7	1.7	1.7	1.7	1.7	3.7	1.8	3.7	-2.6	8.3	10.4	10.4	10.4	10.4	23.4	11.1	23.4	-16.2
M	MH	M	L	M	L	M	L	6.7	1.7	1.7	1.7	1.7	2.1	0.3	2.1	2.1	8.3	10.4	10.4	10.4	10.4	13.2	2.0	13.2	13.2
M	MH	M	M	M	L	M	L	6.7	1.7	1.7	1.7	1.7	2.1	0.3	2.1	2.1	8.3	10.4	10.4	10.4	10.4	13.2	2.0	13.2	13.2
M	MH	M	MH	M	L	M	L	6.7	1.7	1.7	1.7	1.7	2.6	0.7	2.6	0.7	8.3	10.4	10.4	10.4	10.4	16.2	4.7	16.2	4.7
M	MH	M	H	M	L	L	L	6.7	1.7	1.7	1.7	1.7	3.7	1.8	3.7	-2.6	8.3	10.4	10.4	10.4	10.4	23.4	11.1	23.4	-16.2
M	MH	MH	L	M	L	L	L	6.7	1.7	1.7	1.7	1.7	2.6	0.7	0.7	2.6	8.3	10.4	10.4	10.4	10.4	16.2	4.7	4.7	16.2
M	MH	MH	M	M	L	L	L	6.7	1.7	1.7	1.7	1.7	2.6	0.7	0.7	2.6	8.3	10.4	10.4	10.4	10.4	16.2	4.7	4.7	16.2
M	MH	MH	MH	M	L	L	L	6.7	1.7	1.7	1.7	1.7	3.1	1.2	1.2	1.2	8.3	10.4	10.4	10.4	10.4	19.3	7.5	7.5	7.5
M	MH	MH	H	M	L	M	L	6.7	1.7	1.7	1.7	1.7	4.3	2.3	2.3	-2.2	8.3	10.4	10.4	10.4	10.4	26.9	14.3	14.3	-13.8
M	MH	H	L	M	L	M	L	6.7	1.7	1.7	1.7	1.7	3.7	1.8	-2.6	3.7	8.3	10.4	10.4	10.4	10.4	23.4	11.1	-16.2	23.4
M	MH	H	M	M	L	M	L	6.7	1.4	1.4	2.5	1.4	2.6	0.8	0.7	2.6	8.3	8.6	8.6	15.9	8.6	16.3	4.8	4.2	16.3
M	MH	H	MH	M	L	M	L	6.7	1.4	1.4	2.5	1.4	3.1	1.2	1.1	1.2	8.3	8.6	8.6	15.9	8.6	19.4	7.6	7.0	7.6
M	MH	H	H	M	M	L	L	6.7	1.4	1.4	2.5	1.4	4.3	2.3	2.2	-2.2	8.3	8.6	8.6	15.9	8.6	27.1	14.5	13.9	-13.7

M	H	L	L	M	M	L	L	6.7	1.7	1.7	1.7	1.7	3.1	-2.5	3.1	3.1	8.3	10.4	10.4	10.4	10.4	19.2	-15.9	19.2	19.2
M	H	L	M	M	M	L	L	6.7	1.7	1.7	1.7	1.7	3.1	-2.5	3.1	3.1	8.3	10.4	10.4	10.4	10.4	19.2	-15.9	19.2	19.2
M	H	L	MH	M	M	L	L	6.7	1.7	1.7	1.7	1.7	3.7	-2.6	3.7	1.8	8.3	10.4	10.4	10.4	10.4	23.4	-16.2	23.4	11.1
M	H	L	H	M	M	M	L	6.7	1.7	1.7	1.7	1.7	4.7	-1.4	4.7	-1.4	8.3	10.4	10.4	10.4	10.4	29.5	-8.7	29.5	-8.7
M	H	M	L	M	M	M	L	6.7	1.7	1.7	1.7	1.7	3.1	-2.5	3.1	3.1	8.3	10.4	10.4	10.4	10.4	19.2	-15.9	19.2	19.2
M	H	M	M	M	M	M	L	6.7	1.7	1.7	1.7	1.7	3.1	-2.5	3.1	3.1	8.3	10.4	10.4	10.4	10.4	19.2	-15.9	19.2	19.2
M	H	M	MH	M	M	L	L	6.7	1.7	1.7	1.7	1.7	3.7	-2.6	3.7	1.8	8.3	10.4	10.4	10.4	10.4	23.4	-16.2	23.4	11.1
M	H	M	H	M	M	L	L	6.7	1.7	1.7	1.7	1.7	4.7	-1.4	4.7	-1.4	8.3	10.4	10.4	10.4	10.4	29.5	-8.7	29.5	-8.7
M	H	MH	L	M	M	L	L	6.7	1.7	1.7	1.7	1.7	3.7	-2.6	1.8	3.7	8.3	10.4	10.4	10.4	10.4	23.4	-16.2	11.1	23.4
M	H	MH	M	M	M	L	L	6.7	1.7	1.7	1.7	1.7	3.7	-2.6	1.8	3.7	8.3	10.4	10.4	10.4	10.4	23.4	-16.2	11.1	23.4
M	H	MH	MH	M	M	M	L	6.7	1.7	1.7	1.7	1.7	4.3	-2.2	2.3	2.3	8.3	10.4	10.4	10.4	10.4	26.9	-13.8	14.3	14.3
M	H	MH	H	L	L	M	L	-3.3	-1.3	-1.3	0.7	-1.3	4.8	-4.0	-0.1	-4.0	-3.7	-7.0	-7.0	3.9	-7.0	25.3	-21.3	-0.3	-21.3
M	H	H	L	L	L	M	L	6.7	1.7	1.7	1.7	1.7	4.7	-1.4	-1.4	4.7	8.3	10.4	10.4	10.4	10.4	29.5	-8.7	-8.7	29.5
M	H	H	M	L	L	M	L	6.7	1.7	1.7	1.7	1.7	4.7	-1.4	-1.4	4.7	8.3	10.4	10.4	10.4	10.4	29.5	-8.7	-8.7	29.5
M	H	H	MH	L	L	M	L	-3.3	-1.3	-1.3	-1.3	0.7	4.8	-4.0	-4.0	-0.1	-3.7	-7.0	-7.0	-7.0	3.9	25.3	-21.3	-21.3	-0.3
M	H	H	H	M	L	M	L	-3.3	0.7	-1.3	-1.3	-1.3	7.5	-3.6	-3.6	-3.6	-3.7	3.9	-7.0	-7.0	-7.0	44.2	-19.0	-19.0	-19.0
MH	L	L	L	M	L	M	M	6.7	1.7	1.7	1.7	1.7	0.3	2.1	2.1	2.1	8.3	10.4	10.4	10.4	10.4	2.0	13.2	13.2	13.2
MH	L	L	M	M	M	M	M	6.7	1.7	1.7	1.7	1.7	0.3	2.1	2.1	2.1	8.3	10.4	10.4	10.4	10.4	2.0	13.2	13.2	13.2
MH	L	L	MH	M	M	M	M	6.7	1.7	1.7	1.7	1.7	0.7	2.6	2.6	0.7	8.3	10.4	10.4	10.4	10.4	4.7	16.2	16.2	4.7
MH	L	L	H	M	M	M	M	6.7	1.7	1.7	1.7	1.7	1.8	3.7	3.7	-2.6	8.3	10.4	10.4	10.4	10.4	11.1	23.4	23.4	-16.2
MH	L	M	L	L	L	L	M	6.7	1.7	1.7	1.7	1.7	0.3	2.1	2.1	2.1	8.3	10.4	10.4	10.4	10.4	2.0	13.2	13.2	13.2
MH	L	M	M	L	L	L	M	6.7	1.7	1.7	1.7	1.7	0.3	2.1	2.1	2.1	8.3	10.4	10.4	10.4	10.4	2.0	13.2	13.2	13.2

MH	L	M	MH	L	L	M	M	6.7	3.2	1.2	1.2	1.2	6.0	0.8	0.8	-0.9	8.3	19.7	7.3	7.3	7.3	37.3	4.9	4.9	-5.5
MH	L	M	H	L	L	M	M	6.7	3.2	1.2	1.2	1.2	7.2	1.7	1.7	-4.0	8.3	19.7	7.3	7.3	7.3	45.0	10.7	10.7	-24.8
MH	L	MH	L	L	L	L	M	6.7	1.7	1.7	1.7	1.7	0.7	2.6	0.7	2.6	8.3	10.4	10.4	10.4	10.4	4.7	16.2	4.7	16.2
MH	L	MH	M	L	L	L	M	6.7	3.2	1.2	1.2	1.2	6.0	0.8	-0.9	0.8	8.3	19.7	7.3	7.3	7.3	37.3	4.9	-5.5	4.9
MH	L	MH	MH	L	L	M	M	6.7	3.0	1.2	1.2	1.2	6.1	1.3	-0.4	-0.4	8.3	18.8	7.6	7.6	7.6	38.1	8.4	-2.4	-2.4
MH	L	MH	H	L	L	M	M	6.7	3.0	1.2	1.2	1.2	7.4	2.3	0.5	-3.5	8.3	18.8	7.6	7.6	7.6	46.0	14.6	3.2	-22.2
MH	L	H	L	L	M	L	M	6.7	1.7	1.7	1.7	1.7	1.8	3.7	-2.6	3.7	8.3	10.4	10.4	10.4	10.4	11.1	23.4	-16.2	23.4
MH	L	H	M	L	M	L	M	6.7	3.2	1.2	1.2	1.2	7.2	1.7	-4.0	1.7	8.3	19.7	7.3	7.3	7.3	45.0	10.7	-24.8	10.7
MH	L	H	MH	L	M	M	M	6.7	2.7	0.9	2.1	0.9	6.1	1.4	-0.4	-0.4	8.3	16.9	5.9	13.0	5.9	38.2	8.5	-2.8	-2.3
MH	L	H	H	L	M	M	M	-3.3	-2.6	1.4	-0.5	-1.6	0.2	4.4	-1.8	-6.2	-3.7	-13.1	8.6	-2.4	-8.6	1.1	27.8	-9.6	-32.5
MH	M	L	L	L	M	L	M	6.7	1.7	1.7	1.7	1.7	0.3	2.1	2.1	2.1	8.3	10.4	10.4	10.4	10.4	2.0	13.2	13.2	13.2
MH	M	L	M	L	M	L	M	6.7	1.7	1.7	1.7	1.7	0.3	2.1	2.1	2.1	8.3	10.4	10.4	10.4	10.4	2.0	13.2	13.2	13.2
MH	M	L	MH	L	M	M	M	6.7	3.2	1.2	1.2	1.2	6.0	0.8	0.8	-0.9	8.3	19.7	7.3	7.3	7.3	37.3	4.9	4.9	-5.5
MH	M	L	H	L	L	L	M	6.7	3.2	1.2	1.2	1.2	7.2	1.7	1.7	-4.0	8.3	19.7	7.3	7.3	7.3	45.0	10.7	10.7	-24.8
MH	M	M	L	L	L	L	M	6.7	1.7	1.7	1.7	1.7	0.3	2.1	2.1	2.1	8.3	10.4	10.4	10.4	10.4	2.0	13.2	13.2	13.2
MH	M	M	M	L	L	M	M	6.7	1.7	1.7	1.7	1.7	0.3	2.1	2.1	2.1	8.3	10.4	10.4	10.4	10.4	2.0	13.2	13.2	13.2
MH	M	M	MH	L	L	M	M	6.7	3.2	1.2	1.2	1.2	6.0	0.8	0.8	-0.9	8.3	19.7	7.3	7.3	7.3	37.3	4.9	4.9	-5.5
MH	M	M	H	L	L	L	M	6.7	3.2	1.2	1.2	1.2	7.2	1.7	1.7	-4.0	8.3	19.7	7.3	7.3	7.3	45.0	10.7	10.7	-24.8
MH	M	MH	L	L	L	L	M	6.7	3.2	1.2	1.2	1.2	6.0	0.8	-0.9	0.8	8.3	19.7	7.3	7.3	7.3	37.3	4.9	-5.5	4.9
MH	M	MH	M	L	L	M	M	6.7	3.2	1.2	1.2	1.2	6.0	0.8	-0.9	0.8	8.3	19.7	7.3	7.3	7.3	37.3	4.9	-5.5	4.9
MH	M	MH	MH	L	L	M	M	6.7	3.2	1.2	1.2	1.2	6.5	1.2	-0.5	-0.5	8.3	19.7	7.3	7.3	7.3	40.7	7.4	-3.2	-3.2
MH	M	MH	H	L	M	L	M	6.7	3.2	1.2	1.2	1.2	7.8	2.2	0.4	-3.7	8.3	19.7	7.3	7.3	7.3	48.7	13.6	2.3	-22.9
MH	M	H	L	L	M	L	M	6.7	3.2	1.2	1.2	1.2	7.2	1.7	-4.0	1.7	8.3	19.7	7.3	7.3	7.3	45.0	10.7	-24.8	10.7

MH	M	H	M	L	M	M	M	6.7	2.8	0.9	2.0	0.9	6.0	0.8	-0.9	0.8	8.3	17.8	5.6	12.7	5.6	37.5	5.0	-5.9	5.0
MH	M	H	MH	L	M	M	M	6.7	2.8	0.9	2.0	0.9	6.5	1.2	-0.6	-0.5	8.3	17.8	5.6	12.7	5.6	40.8	7.6	-3.6	-3.1
MH	M	H	H	L	M	L	M	-3.3	-1.2	0.9	-1.0	-2.1	6.0	1.2	-3.2	-7.2	-3.7	-5.8	5.6	-5.1	-11.1	29.9	7.2	-17.1	-38.0
MH	MH	L	L	L	M	L	M	6.7	1.7	1.7	1.7	1.7	0.7	0.7	2.6	2.6	8.3	10.4	10.4	10.4	10.4	4.7	4.7	16.2	16.2
MH	MH	L	M	L	M	M	M	6.7	3.2	1.2	1.2	1.2	6.0	-0.9	0.8	0.8	8.3	19.7	7.3	7.3	7.3	37.3	-5.5	4.9	4.9
MH	MH	L	MH	M	L	L	M	6.7	3.0	1.2	1.2	1.2	6.1	-0.4	1.3	-0.4	8.3	18.8	7.6	7.6	7.6	38.1	-2.4	8.4	-2.4
MH	MH	L	H	M	L	L	M	6.7	3.0	1.2	1.2	1.2	7.4	0.5	2.3	-3.5	8.3	18.8	7.6	7.6	7.6	46.0	3.2	14.6	-22.2
MH	MH	M	L	M	L	M	M	6.7	3.2	1.2	1.2	1.2	6.0	-0.9	0.8	0.8	8.3	19.7	7.3	7.3	7.3	37.3	-5.5	4.9	4.9
MH	MH	M	M	M	L	M	M	6.7	3.2	1.2	1.2	1.2	6.0	-0.9	0.8	0.8	8.3	19.7	7.3	7.3	7.3	37.3	-5.5	4.9	4.9
MH	MH	M	MH	M	L	L	M	6.7	3.2	1.2	1.2	1.2	6.5	-0.5	1.2	-0.5	8.3	19.7	7.3	7.3	7.3	40.7	-3.2	7.4	-3.2
MH	MH	M	H	M	L	L	M	6.7	3.2	1.2	1.2	1.2	7.8	0.4	2.2	-3.7	8.3	19.7	7.3	7.3	7.3	48.7	2.3	13.6	-22.9
MH	MH	MH	L	M	L	M	M	6.7	3.0	1.2	1.2	1.2	6.1	-0.4	-0.4	1.3	8.3	18.8	7.6	7.6	7.6	38.1	-2.4	-2.4	8.4
MH	MH	MH	M	M	L	M	M	6.7	3.2	1.2	1.2	1.2	6.5	-0.5	-0.5	1.2	8.3	19.7	7.3	7.3	7.3	40.7	-3.2	-3.2	7.4
MH	MH	MH	MH	M	M	L	M	6.7	3.0	1.2	1.2	1.2	6.6	0.0	0.0	0.0	8.3	18.8	7.6	7.6	7.6	41.5	0.1	0.1	0.1
MH	MH	MH	H	M	M	L	M	6.7	3.0	1.2	1.2	1.2	8.0	1.0	1.0	-3.2	8.3	18.8	7.6	7.6	7.6	49.9	6.0	6.0	-20.1
MH	MH	H	L	M	M	M	M	6.7	3.0	1.2	1.2	1.2	7.4	0.5	-3.5	2.3	8.3	18.8	7.6	7.6	7.6	46.0	3.2	-22.2	14.6
MH	MH	H	M	M	M	M	M	6.7	2.8	0.9	2.0	0.9	6.5	-0.5	-0.6	1.2	8.3	17.8	5.6	12.7	5.6	40.8	-3.1	-3.6	7.6
MH	MH	H	MH	M	M	L	M	6.7	2.7	0.9	2.1	0.9	6.7	0.0	-0.1	0.0	8.3	16.9	5.9	13.0	5.9	41.7	0.2	-0.3	0.2
MH	MH	H	H	M	M	L	M	-3.3	-0.3	-0.1	-0.9	-2.1	6.3	-2.2	-1.5	-5.9	-3.7	-1.6	-0.4	-4.8	-10.9	33.2	-12.9	-8.0	-31.2
MH	H	L	L	M	M	M	M	6.7	1.7	1.7	1.7	1.7	1.8	-2.6	3.7	3.7	8.3	10.4	10.4	10.4	10.4	11.1	-16.2	23.4	23.4
MH	H	L	M	M	L	L	M	6.7	3.2	1.2	1.2	1.2	7.2	-4.0	1.7	1.7	8.3	19.7	7.3	7.3	7.3	45.0	-24.8	10.7	10.7
MH	H	L	MH	M	L	L	M	6.7	3.0	1.2	1.2	1.2	7.4	-3.5	2.3	0.5	8.3	18.8	7.6	7.6	7.6	46.0	-22.2	14.6	3.2

MH	H	L	H	M	L	M	M	-3.3	-2.3	-1.3	1.7	-1.3	1.5	-5.3	5.8	-5.3	-3.7	-11.7	-7.0	10.4	-7.0	7.7	-28.0	36.1	-28.0
MH	H	M	L	M	L	L	M	6.7	3.2	1.2	1.2	1.2	7.2	-4.0	1.7	1.7	8.3	19.7	7.3	7.3	7.3	45.0	-24.8	10.7	10.7
MH	H	M	M	M	L	L	M	6.7	3.2	1.2	1.2	1.2	7.2	-4.0	1.7	1.7	8.3	19.7	7.3	7.3	7.3	45.0	-24.8	10.7	10.7
MH	H	M	MH	M	L	M	M	6.7	3.2	1.2	1.2	1.2	7.8	-3.7	2.2	0.4	8.3	19.7	7.3	7.3	7.3	48.7	-22.9	13.6	2.3
MH	H	M	H	M	M	L	M	-3.3	-0.8	-1.8	1.2	-1.8	7.4	-6.5	2.2	-6.5	-3.7	-4.2	-9.6	7.3	-9.6	37.1	-34.2	13.9	-34.2
MH	H	MH	L	M	M	L	M	6.7	3.0	1.2	1.2	1.2	7.4	-3.5	0.5	2.3	8.3	18.8	7.6	7.6	7.6	46.0	-22.2	3.2	14.6
MH	H	MH	M	M	M	M	M	6.7	3.2	1.2	1.2	1.2	7.8	-3.7	0.4	2.2	8.3	19.7	7.3	7.3	7.3	48.7	-22.9	2.3	13.6
MH	H	MH	MH	L	L	M	M	6.7	3.0	1.2	1.2	1.2	8.0	-3.2	1.0	1.0	8.3	18.8	7.6	7.6	7.6	49.9	-20.1	6.0	6.0
MH	H	MH	H	M	M	M	L	-3.3	0.0	-1.8	0.2	-1.8	8.0	-5.1	-1.2	-5.1	-3.7	0.1	-9.4	1.3	-9.4	42.1	-26.6	-7.1	-26.6
MH	H	H	L	M	M	M	M	-3.3	-2.3	-1.3	-1.3	1.7	1.5	-5.3	-5.3	5.8	-3.7	-11.7	-7.0	-7.0	10.4	7.7	-28.0	-28.0	36.1
MH	H	H	M	M	M	M	L	-3.3	-0.8	-1.8	-1.8	1.2	7.5	-6.5	-6.5	2.2	-3.7	-4.2	-9.6	-9.6	7.3	37.6	-34.3	-34.3	13.7
MH	H	H	MH	L	L	M	M	-3.3	-0.3	-2.1	-0.9	-0.1	6.3	-5.9	-1.5	-2.2	-3.7	-1.6	-10.9	-4.8	-0.4	33.2	-31.2	-8.0	-12.9
MH	H	H	H	L	L	M	M	-3.3	-2.6	-0.6	0.5	-0.6	3.6	-4.2	1.4	-4.2	-3.7	-13.1	-3.5	3.0	-3.5	18.0	-23.1	7.8	-23.1
H	L	L	L	L	L	M	M	6.7	1.7	1.7	1.7	1.7	-2.5	3.1	3.1	3.1	8.3	10.4	10.4	10.4	10.4	-15.9	19.2	19.2	19.2
H	L	L	M	M	M	M	M	6.7	1.7	1.7	1.7	1.7	-2.5	3.1	3.1	3.1	8.3	10.4	10.4	10.4	10.4	-15.9	19.2	19.2	19.2
H	L	L	MH	L	L	L	M	6.7	1.7	1.7	1.7	1.7	-2.6	3.7	3.7	1.8	8.3	10.4	10.4	10.4	10.4	-16.2	23.4	23.4	11.1
H	L	L	H	M	M	M	M	6.7	1.7	1.7	1.7	1.7	-1.4	4.7	4.7	-1.4	8.3	10.4	10.4	10.4	10.4	-8.7	29.5	29.5	-8.7
H	L	M	L	M	M	M	M	6.7	1.7	1.7	1.7	1.7	-2.5	3.1	3.1	3.1	8.3	10.4	10.4	10.4	10.4	-15.9	19.2	19.2	19.2
H	L	M	M	M	M	M	M	6.7	1.7	1.7	1.7	1.7	-2.5	3.1	3.1	3.1	8.3	10.4	10.4	10.4	10.4	-15.9	19.2	19.2	19.2
H	L	M	MH	L	M	M	M	6.7	3.2	1.2	1.2	1.2	3.1	1.8	1.8	0.0	8.3	19.7	7.3	7.3	7.3	19.1	11.2	11.2	0.2
H	L	M	H	L	M	M	M	6.7	3.9	0.9	0.9	0.9	6.6	1.8	1.8	-3.5	8.3	24.6	5.7	5.7	5.7	41.5	10.9	10.9	-21.8
H	L	MH	L	M	M	M	M	6.7	1.7	1.7	1.7	1.7	-2.6	3.7	1.8	3.7	8.3	10.4	10.4	10.4	10.4	-16.2	23.4	11.1	23.4

H	L	MH	M	M	L	M	M	6.7	3.2	1.2	1.2	1.2	3.1	1.8	0.0	1.8	8.3	19.7	7.3	7.3	7.3	19.1	11.2	0.2	11.2
H	L	MH	MH	M	M	M	M	6.7	3.0	1.2	1.2	1.2	3.2	2.4	0.6	0.6	8.3	18.8	7.6	7.6	7.6	19.9	14.9	3.5	3.5
H	L	MH	H	M	M	L	M	-3.3	-3.0	1.2	0.2	-1.8	1.9	4.0	-2.8	-6.5	-3.7	-13.6	7.6	1.3	-9.4	8.7	24.9	-16.3	-34.0
H	L	H	L	M	M	M	M	6.7	2.1	1.2	2.1	1.2	0.8	2.6	0.8	2.6	8.3	13.2	7.7	13.2	7.7	4.8	16.0	4.8	16.0
H	L	H	M	M	M	M	M	6.7	3.7	0.7	1.6	0.7	5.6	0.9	-0.7	0.9	8.3	23.1	4.4	9.8	4.4	34.8	5.7	-4.5	5.7
H	L	H	MH	M	M	M	M	-3.3	-3.3	0.9	-0.9	-0.1	0.6	2.9	-3.2	-3.6	-3.7	-15.0	5.9	-4.8	-0.4	2.5	17.8	-16.6	-21.1
H	L	H	H	M	M	M	M	-3.3	-2.6	1.4	-0.7	-1.6	-4.4	6.3	-0.2	-5.0	-3.7	-12.8	9.0	-3.5	-8.2	-22.1	39.5	-1.3	-26.2
H	M	L	L	L	L	L	M	6.7	1.7	1.7	1.7	1.7	-2.5	3.1	3.1	3.1	8.3	10.4	10.4	10.4	10.4	-15.9	19.2	19.2	19.2
H	M	L	M	L	L	L	M	6.7	1.7	1.7	1.7	1.7	-2.5	3.1	3.1	3.1	8.3	10.4	10.4	10.4	10.4	-15.9	19.2	19.2	19.2
H	M	L	MH	L	L	L	M	6.7	3.2	1.2	1.2	1.2	3.1	1.8	1.8	0.0	8.3	19.7	7.3	7.3	7.3	19.1	11.2	11.2	0.2
H	M	L	H	L	L	L	M	6.7	3.9	0.9	0.9	0.9	6.6	1.8	1.8	-3.5	8.3	24.6	5.7	5.7	5.7	41.5	10.9	10.9	-21.8
H	M	M	L	L	L	M	M	6.7	1.7	1.7	1.7	1.7	-2.5	3.1	3.1	3.1	8.3	10.4	10.4	10.4	10.4	-15.9	19.2	19.2	19.2
H	M	M	M	L	M	L	M	6.7	1.7	1.7	1.7	1.7	-2.5	3.1	3.1	3.1	8.3	10.4	10.4	10.4	10.4	-15.9	19.2	19.2	19.2
H	M	M	MH	L	M	L	M	6.7	3.2	1.2	1.2	1.2	3.1	1.8	1.8	0.0	8.3	19.7	7.3	7.3	7.3	19.1	11.2	11.2	0.2
H	M	M	H	L	L	L	M	6.7	3.9	0.9	0.9	0.9	6.6	1.8	1.8	-3.5	8.3	24.6	5.7	5.7	5.7	41.5	10.9	10.9	-21.8
H	M	MH	L	L	L	M	M	6.7	3.2	1.2	1.2	1.2	3.1	1.8	0.0	1.8	8.3	19.7	7.3	7.3	7.3	19.1	11.2	0.2	11.2
H	M	MH	M	L	L	L	M	6.7	3.2	1.2	1.2	1.2	3.1	1.8	0.0	1.8	8.3	19.7	7.3	7.3	7.3	19.1	11.2	0.2	11.2
H	M	MH	MH	L	L	M	M	6.7	3.2	1.2	1.2	1.2	3.5	2.2	0.4	0.4	8.3	19.7	7.3	7.3	7.3	22.2	14.0	2.7	2.7
H	M	MH	H	L	M	L	M	-3.3	-2.2	1.0	0.0	-2.0	4.0	2.1	-2.9	-6.5	-3.7	-10.2	6.0	-0.2	-10.7	18.0	13.4	-17.0	-34.5
H	M	H	L	L	M	L	M	6.7	3.9	0.9	0.9	0.9	6.6	1.8	-3.5	1.8	8.3	24.6	5.7	5.7	5.7	41.5	10.9	-21.8	10.9
H	M	H	M	M	L	L	M	6.7	3.7	0.7	1.6	0.7	5.6	0.9	-0.7	0.9	8.3	23.1	4.4	9.8	4.4	34.8	5.7	-4.5	5.7
H	M	H	MH	M	L	L	M	-3.3	-2.7	0.7	-1.1	-0.3	2.3	1.2	-3.2	-3.6	-3.7	-12.3	4.7	-5.9	-1.5	10.2	7.6	-16.8	-21.2
H	M	H	H	M	L	L	M	-3.3	-0.4	0.7	-1.4	-2.3	3.8	2.3	-2.6	-6.8	-3.7	-2.2	4.7	-7.3	-11.9	18.9	14.4	-13.9	-35.6
H	MH	L	L	M	L	L	M	6.7	1.7	1.7	1.7	1.7	-2.6	1.8	3.7	3.7	8.3	10.4	10.4	10.4	10.4	-16.2	11.1	23.4	23.4

H	MH	L	M	L	L	L	M	6.7	3.2	1.2	1.2	1.2	3.1	0.0	1.8	1.8	8.3	19.7	7.3	7.3	7.3	19.1	0.2	11.2	11.2
H	MH	L	MH	L	L	M	M	6.7	3.0	1.2	1.2	1.2	3.2	0.6	2.4	0.6	8.3	18.8	7.6	7.6	7.6	19.9	3.5	14.9	3.5
H	MH	L	H	L	M	L	M	-3.3	-3.0	0.2	1.2	-1.8	1.9	-2.8	4.0	-6.5	-3.7	-13.6	1.3	7.6	-9.4	8.7	-16.3	24.9	-34.0
H	MH	M	L	L	M	L	M	6.7	3.2	1.2	1.2	1.2	3.1	0.0	1.8	1.8	8.3	19.7	7.3	7.3	7.3	19.1	0.2	11.2	11.2
H	MH	M	M	L	M	M	M	6.7	3.2	1.2	1.2	1.2	3.1	0.0	1.8	1.8	8.3	19.7	7.3	7.3	7.3	19.1	0.2	11.2	11.2
H	MH	M	MH	L	L	M	M	6.7	3.2	1.2	1.2	1.2	3.5	0.4	2.2	0.4	8.3	19.7	7.3	7.3	7.3	22.2	2.7	14.0	2.7
H	MH	M	H	L	L	M	M	-3.3	-2.2	0.0	1.0	-2.0	4.0	-2.9	2.1	-6.5	-3.7	-10.2	-0.2	6.0	-10.7	18.0	-17.0	13.4	-34.5
H	MH	MH	L	L	M	L	M	6.7	3.0	1.2	1.2	1.2	3.2	0.6	0.6	2.4	8.3	18.8	7.6	7.6	7.6	19.9	3.5	3.5	14.9
H	MH	MH	M	L	M	L	M	6.7	3.2	1.2	1.2	1.2	3.5	0.4	0.4	2.2	8.3	19.7	7.3	7.3	7.3	22.2	2.7	2.7	14.0
H	MH	MH	MH	L	M	M	M	6.7	3.0	1.2	1.2	1.2	3.7	1.0	1.0	1.0	8.3	18.8	7.6	7.6	7.6	23.1	6.2	6.2	6.2
H	MH	MH	H	L	M	M	M	-3.3	-2.0	0.2	0.2	-1.8	3.6	-1.0	-1.0	-4.9	-3.7	-9.5	1.3	1.3	-9.4	17.1	-5.9	-5.9	-25.8
H	MH	H	L	M	L	L	M	-3.3	-3.0	0.2	-1.8	1.2	1.9	-2.8	-6.5	4.0	-3.7	-13.6	1.3	-9.4	7.6	8.7	-16.3	-34.0	24.9
H	MH	H	M	M	L	L	M	2.8	-0.5	1.4	0.7	1.2	5.7	-1.9	-1.2	0.3	3.1	-2.3	8.5	3.6	7.5	25.9	-11.4	-6.4	1.7
H	MH	H	MH	M	L	M	M	2.8	-0.3	1.7	1.0	0.5	4.0	-0.7	0.2	-0.7	3.1	-1.6	10.1	5.2	2.7	19.2	-4.2	1.2	-4.2
H	MH	H	H	M	L	L	M	2.8	-0.7	1.4	1.7	0.4	5.3	0.1	1.5	-4.1	3.1	-3.2	8.3	9.2	2.3	25.1	0.5	8.5	-22.6
H	H	L	L	M	L	L	M	6.7	1.7	1.7	1.7	1.7	-1.4	-1.4	4.7	4.7	8.3	10.4	10.4	10.4	10.4	-8.7	-8.7	29.5	29.5
H	H	L	M	M	L	M	M	6.7	3.9	0.9	0.9	0.9	6.6	-3.5	1.8	1.8	8.3	24.6	5.7	5.7	5.7	41.5	-21.8	10.9	10.9
H	H	L	MH	M	M	L	M	-3.3	-3.0	-1.8	1.2	0.2	1.9	-6.5	4.0	-2.8	-3.7	-13.6	-9.4	7.6	1.3	8.7	-34.0	24.9	-16.3
H	H	L	H	M	M	L	M	-3.3	-2.3	-1.3	1.7	-1.3	-3.3	-4.0	7.9	-4.0	-3.7	-11.7	-7.0	10.4	-7.0	-16.5	-20.9	49.5	-20.9
H	H	M	L	M	M	M	M	6.7	3.9	0.9	0.9	0.9	6.6	-3.5	1.8	1.8	8.3	24.6	5.7	5.7	5.7	41.5	-21.8	10.9	10.9
H	H	M	M	M	L	M	M	6.7	3.9	0.9	0.9	0.9	6.6	-3.5	1.8	1.8	8.3	24.6	5.7	5.7	5.7	41.5	-21.8	10.9	10.9
H	H	M	MH	M	M	M	M	-3.3	-2.2	-2.0	1.0	0.0	4.0	-6.5	2.1	-2.9	-3.7	-10.2	-10.7	6.0	-0.2	18.0	-34.5	13.4	-17.0

H	H	M	H	L	L	M	M	-3.3	-0.1	-2.1	0.9	-2.1	5.9	-6.2	3.2	-6.2	-3.7	-0.3	-11.0	5.7	-11.0	29.4	-32.6	19.8	-32.6
H	H	MH	L	L	M	M	M	-3.3	-3.0	-1.8	0.2	1.2	1.9	-6.5	-2.8	4.0	-3.7	-13.6	-9.4	1.3	7.6	8.7	-34.0	-16.3	24.9
H	H	MH	M	L	M	M	M	-3.3	-2.2	-2.0	0.0	1.0	4.0	-6.5	-2.9	2.1	-3.7	-10.2	-10.7	-0.2	6.0	18.0	-34.5	-17.0	13.4
H	H	MH	MH	L	M	M	M	-3.3	-2.0	-1.8	0.2	0.2	3.6	-4.9	-1.0	-1.0	-3.7	-9.5	-9.4	1.3	1.3	17.1	-25.8	-5.9	-5.9
H	H	MH	H	L	M	M	M	-3.3	-2.0	-0.8	0.2	-0.8	5.1	-4.2	0.0	-4.2	-3.7	-9.5	-4.3	1.3	-4.3	24.1	-23.2	-0.3	-23.2
H	H	H	L	M	L	M	M	1.3	-0.7	0.3	0.3	1.4	-0.1	-0.4	-0.4	2.3	1.5	-3.5	1.6	1.6	8.9	-0.7	-2.1	-2.1	14.1
H	H	H	M	M	M	M	M	9.3	3.3	1.0	2.0	3.0	8.9	-4.1	0.9	3.6	10.3	16.7	5.2	10.6	18.5	44.7	-21.7	4.8	22.2
H	H	H	MH	M	M	M	M	12.4	2.2	3.0	4.5	2.6	8.5	-2.3	4.0	2.2	13.7	10.6	16.9	24.8	15.4	40.6	-13.0	21.9	13.0
H	H	H	H	M	M	L	M	17.9	3.5	4.4	5.5	4.4	9.4	0.4	7.8	0.4	19.9	17.7	24.4	30.8	24.4	47.1	2.0	43.1	2.0
L	L	H	VH	M	M	M	M	-3.3	-0.3	0.7	-1.3	-2.6	2.8	3.8	-6.9	-3.0	-3.7	-1.5	4.7	-7.0	-11.2	16.4	23.6	-38.5	-12.9
L	L	VH	L	M	M	M	M	6.7	1.7	1.7	1.7	1.7	5.7	5.7	-10.6	5.7	8.3	10.4	10.4	10.4	10.4	35.9	35.9	-66.0	35.9
L	L	VH	M	M	L	M	M	6.7	1.7	1.7	1.7	1.7	5.7	5.7	-10.6	5.7	8.3	10.4	10.4	10.4	10.4	35.9	35.9	-66.0	35.9
L	L	VH	MH	M	L	M	M	6.7	1.2	1.2	3.2	1.2	3.9	3.9	-3.2	2.0	8.3	7.3	7.3	19.7	7.3	24.6	24.6	-19.8	12.2
L	L	VH	H	M	M	M	M	-3.3	-0.3	0.7	-2.6	-1.3	2.3	3.3	-3.4	-5.6	-3.7	-1.5	4.7	-11.2	-7.0	13.7	20.8	-14.9	-30.9
L	M	VH	M	M	M	M	M	6.7	1.2	1.2	3.1	1.2	3.5	3.5	-3.8	3.5	8.3	7.5	7.5	19.3	7.5	21.8	21.8	-23.9	21.8
L	M	VH	MH	M	M	L	M	-3.3	-1.3	0.7	-2.6	-0.3	2.4	0.1	-1.6	-4.3	-3.7	-7.0	4.7	-11.2	-1.5	13.2	0.9	-6.9	-25.1
M	M	VH	M	M	M	M	M	6.7	0.9	0.9	4.0	0.9	2.3	2.3	-0.1	2.3	8.3	5.6	5.6	24.8	5.6	14.2	14.2	-0.8	14.2
M	L	VH	H	M	M	M	M	-3.3	-0.3	0.7	-2.6	-1.3	2.8	3.8	-3.0	-6.9	-3.7	-1.5	4.7	-11.2	-7.0	16.4	23.6	-12.9	-38.5
M	M	VH	H	M	M	L	M	-3.3	-0.3	0.7	-2.6	-1.3	2.8	3.8	-3.0	-6.9	-3.7	-1.5	4.7	-11.2	-7.0	16.4	23.6	-12.9	-38.5
MH	MH	VH	MH	M	M	M	M	-3.3	-0.3	-0.3	-2.6	-0.3	-1.0	-1.0	-0.2	-1.0	-3.7	-1.5	-1.5	-11.2	-1.5	-6.2	-6.2	-0.8	-6.2
MH	MH	VH	H	L	M	M	M	-3.3	-0.3	-0.3	-2.6	-0.3	-1.0	-1.0	-0.2	-1.0	-3.7	-1.5	-1.5	-11.2	-1.5	-6.2	-6.2	-0.8	-6.2
MH	L	VH	H	L	M	M	M	-3.3	-0.3	0.7	-2.6	-1.3	-1.8	5.4	-1.3	-5.6	-3.7	-1.5	4.7	-11.2	-7.0	-10.6	33.4	-5.5	-31.2

MH	M	VH	H	M	M	M	M	-3.3	-0.3	0.7	-2.6	-1.3	-1.4	4.1	-0.7	-5.3	-3.7	-1.5	4.7	-11.2	-7.0	-8.3	25.3	-3.0	-29.4
H	L	VH	H	M	M	M	M	-3.3	-1.3	0.7	-1.6	-1.3	-5.0	7.2	-0.4	-5.0	-3.7	-7.0	4.7	-7.1	-7.0	-27.9	44.8	-2.0	-27.9
H	M	VH	H	M	M	M	M	-3.3	-1.3	0.7	-1.6	-1.3	-4.8	6.2	0.0	-4.8	-3.7	-7.0	4.7	-7.1	-7.0	-26.5	38.8	0.0	-26.5
H	MH	VH	H	M	L	M	M	2.8	1.1	1.9	-0.1	-0.1	1.4	5.9	-0.4	-4.1	3.1	6.3	12.0	-0.7	-0.5	8.1	36.8	-1.8	-22.9
H	H	VH	H	M	M	M	M	17.9	3.9	4.8	4.4	4.8	10.2	0.0	7.6	0.0	19.9	20.5	28.1	21.2	28.1	53.6	0.2	36.4	0.2
VH	L	VH	L	M	M	M	M	-3.3	-1.6	-0.1	-1.6	-0.1	-4.5	2.9	-4.5	2.9	-3.7	-7.5	-0.5	-7.5	-0.5	-21.6	18.0	-21.6	18.0
VH	L	VH	M	M	M	M	M	-3.3	-1.6	-0.1	-1.6	-0.1	-4.3	3.2	-4.3	2.1	-3.7	-7.5	-0.5	-7.5	-0.5	-20.4	19.8	-20.4	13.0
VH	L	VH	MH	L	L	M	M	-3.3	-1.6	-0.1	-1.6	-0.1	-3.6	5.7	-3.6	-1.9	-3.7	-7.5	-0.5	-7.5	-0.5	-17.0	35.9	-17.0	-12.1
VH	M	VH	M	L	L	M	M	-3.3	-1.6	-0.1	-1.6	-0.1	-4.0	2.4	-4.0	2.4	-3.7	-7.5	-0.5	-7.5	-0.5	-19.2	14.8	-19.2	14.8
VH	M	VH	MH	M	L	M	M	-3.3	-1.6	-0.1	-1.6	-0.1	-3.1	4.3	-3.1	-1.5	-3.7	-7.5	-0.5	-7.5	-0.5	-14.6	26.9	-14.6	-9.5
VH	MH	VH	MH	M	M	M	M	7.2	1.8	2.7	1.8	0.8	1.5	2.4	1.5	1.8	8.0	8.8	17.0	8.8	4.8	7.2	14.9	7.2	11.0
VH	H	VH	L	M	M	M	M	1.3	-0.5	2.5	-1.5	0.7	2.6	1.7	-8.6	5.7	1.5	-2.2	15.9	-7.3	4.6	11.6	10.5	-43.2	35.9
VH	H	VH	M	M	M	M	M	19.0	4.1	6.4	6.1	2.4	9.5	0.1	10.6	-1.1	21.1	18.8	39.8	30.7	14.8	43.0	0.5	53.0	-7.2
VH	H	VH	MH	M	M	M	M	4.9	-0.9	2.5	1.1	2.1	6.0	-8.0	2.9	4.0	4.4	-3.1	12.1	4.3	11.0	21.3	-38.1	11.2	21.0
VH	H	VH	H	M	M	M	L	10.6	2.2	3.1	2.2	3.1	9.3	-4.1	9.3	-4.1	9.6	8.3	14.8	8.3	14.8	35.9	-19.3	35.9	-19.3
VH	VH	VH	L	H	H	H	M	-3.3	-1.1	-1.1	-1.1	-0.1	0.1	0.1	0.1	-3.5	-3.0	-4.2	-4.2	-4.2	-0.4	0.2	0.2	0.2	-21.9
VH	VH	VH	M	H	H	H	M	3.3	-0.1	-0.3	-0.3	4.0	-2.7	-1.7	-1.7	9.3	2.6	-0.3	-0.9	-0.9	19.9	-8.3	-5.4	-5.4	46.7
VH	VH	VH	MH	M	M	M	M	-6.7	-3.9	-2.9	-2.9	3.0	-4.7	-3.7	-3.7	5.3	-4.8	-11.4	-8.7	-8.7	12.4	-13.7	-11.1	-11.1	22.2
VH	VH	VH	H	H	H	H	M	-12.0	-5.5	-4.5	-4.5	2.5	-5.5	-4.5	-4.5	2.5	-8.0	-15.3	-12.9	-12.9	8.9	-15.3	-12.9	-12.9	8.9
VH	VH	VH	VH	H	H	H	H	-6.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-1.7	-4.2	-4.6	-4.6	-4.6	-4.6	-4.6	-4.6	-4.6	-4.6

Table B.2: Estimated Difference between the FLM and SYNCHRO Green Times and Cycle Outputs.