

Optimization of Traffic Signal Coordination System on Congestion: A Case Study

MAHMOOD MAHMOODI NESHELI, OTHMAN CHE PUAN AND ARASH
MORADKHANI ROSHANDEH

Department of Geotechnics and Transportation
Universiti Teknologi of Malaysia, UTM
81310, Skudai, Johor Bahru
MALAYSIA

mmmahmood2@siswa.utm.my, othmancp@utm.my, mrrash2@siswa.utm.my

Abstract: Signal coordination is perceived by many agencies as an advantageous improvement to the community or corridor in consideration. In many cases, signal coordination techniques have proven to be successful in improving the quality of life and mobility through the area. This study determines the coordination system pattern of traffic signal for four consecutive intersections spaced at 780 m distance. Data for vehicles movement were collected using video camera during morning and evening peak hour with congested conditions. For evaluation of the possible coordination of signalized intersections a simulation model, TRANSYT7F, was used. The results show after coordinating, the amount of delay, travel time, and queue reduce.

Key-words: Congestion, Coordination System, Delay, Intelligent Transportation Systems, Maximum Back of Queue, Travel Time

1 Introduction

Intelligent Transportation Systems (ITS), which apply advanced technologies to surface transportation systems, are widely viewed as the solution to the transportation problems that our society faces. ITS applications, in which technology is used to increase the operating efficiency and capacity of transportation infrastructure, can supplement or even replace infrastructure development, providing more effective mobility solutions at less of a cost to society. Urban traffic control is a major area in which ITS can be applied [1].

Traffic signal coordination is a method of timing groups of traffic signals along a major roadway to provide for a smooth flow of traffic with minimal stops. The goal of coordination is to get the greatest number of vehicles through a system a group of coordinated traffic signals with the fewest number of stops. While it would be ideal if every vehicle entering the system could proceed through without stopping, this is not possible even in a well-spaced, well-designed system. Coordinated traffic signals also result in less stop-and-go traffic. This can reduce driver frustration and stress levels, and may reduce a driver's potential to take risks on the road [2].

Improvement of traffic signal timing and using traffic signal coordination is one of the most important strategies for reducing delay, travel time and queue length in urban area. The comparison of corridor or network optimization for pre-timed signal system using different software was done many times by many

authors [3]. The coordinated actuated corridor or network optimization became more necessary than before because more detectors are being installed on intersections. But there were not many software that are able to deal with actuated coordinated signals. Recent version of some software has improvement in actuated signal simulation and optimization; therefore, it is possible to get more realistic simulation results on actuated signal intersections.

At a higher level, however, traffic signals can part of a broader control strategy. In this case, signal controllers are used as tools for managing traffic flow, either along a corridor or throughout a network, to provide a more efficient use of the urban street network. ITS applications for transit, or Advanced Public Transportation Systems (APTS), have the same goals, namely improvements of efficiency without the need for major infrastructure enhancements [4]. One such application is Bus Rapid Transit (BRT), a transit concept that uses buses to provide a high level of service usually associated with rail transit. The reason that rail transit can provide such a high level of service, however, is that it operates on a right-of-way that is fixed and exclusive. This is typically not the case for city buses, which instead operate on a shared right-of-way in an open and more chaotic system. In such an environment, buses face delays caused by interactions with other vehicles and by the presence of traffic signals at intersections. These two factors can have a significant negative impact on operations [5].

One method of addressing these operational challenges is by the use of infrastructure solutions such as exclusive bus lanes. While often effective in reducing delays due to congestion, these solutions can be prohibitively expensive or, in many urban areas, infeasible due to inadequate street space. Another method is the use of control strategies, which use the existing traffic signal control system to give priority to transit vehicles. This convergence of APTS and urban traffic control is known as transit signal priority. Transit signal priority strategies can be categorized into two basic types: passive and active. Passive priority strategies are those that use static signal settings to favor streets with transit routes. These rely on signal timing plans that are prepared offline and are designed to impede transit vehicles as little as possible. Active priority measures are those which employ dynamic detection and response to transit vehicles, altering signal settings in real-time in order to reduce delay.

Implementing transit signal priority can offer many challenges. One major concern is how to implement transit priority within the existing signal control system. Another is determining what impacts the priority implementation will have on other traffic. Most fundamental, however, is the question of what benefits the priority implementation offers and whether these benefits outweigh the costs. In these cases, simulation can be used to evaluate a proposed strategy before it is implemented determining whether field implementation will have beneficial results. Traffic simulation is an ideal tool for these evaluations, as it simulates vehicle movements at a detailed level, modeling interactions with other vehicles and response to traffic control devices.

2 Literature Review

In general, the inflow on any intersection in an arterial road is limited by the capacities and green times of the different links on the upstream intersection. In order to maximize the possibility that vehicles passing an intersection upstream will arrive at each intersection downstream during the green phase, the traffic signals within an arterial road can be coordinated.

Attempts are often made to place traffic signals on a coordinated system so that drivers encounter long strings of green lights. The distinction between coordinated signals and synchronized signals is very important. Synchronized signals all change at the same time and are only used in special instances or in older systems. Coordinated systems are controlled from a master controller and are set up so lights "cascade" in sequence so platoons of vehicles can proceed through a continuous series of green lights. A graphical

representation of phase state on a two-axis plane of distance versus time clearly shows a "green band" that has been established based on signalized intersection spacing and expected vehicle speeds. In some countries (e.g. Germany, France and The Netherlands), this "green band" system is used to limit speeds in certain areas. Lights are timed in such a way that motorists can drive through without stopping if their speed is lower than a given limit, mostly 50 km/h in urban areas [6].

Such systems were commonly used in urban areas of the United States since the 1940s, but are less common today. In modern coordinated signal systems, it is possible for drivers to travel long distances without encountering a red light. This coordination is done easily only on one-way streets with fairly constant levels of traffic. Two-way streets are often arranged to correspond with rush hours to speed the heavier volume direction. On the other hand, some traffic signals are coordinated to prevent drivers from encountering a long string of green lights. This practice discourages high volumes of traffic by inducing delay yet preventing congestion. Speed is self-regulated in coordinated signal systems; drivers travelling too fast will arrive on a red indication and end up stopping, drivers travelling too slowly will not arrive at the next signal in time to utilize the green indication [7].

2.1 Principle of traffic signal coordination

An offset is defined as the time difference in the beginning of green between adjacent traffic control signals and is expressed in seconds. Traffic signal coordination is a method of establishing relationships between adjacent traffic control signals using offsets. Traffic signal coordination reduces delay and unnecessary stops at traffic signals. The benefit of traffic signal coordination is based on the relationship between the prevailing speed of vehicles on the main street, the spacing of/distance between traffic signals, the hourly traffic volume on a major street, hourly traffic volumes on the side streets, and number of non-signalized intersections along the roadway system [8].

Travel speed along a roadway system is dependent on the signal spacing and the cycle length at traffic signals. Travel speeds are lower when traffic signals are closely spaced and operate under a short cycle length. Conversely, higher travel speeds are a result of long cycle lengths and large spacing between intersections. Traffic signal coordination can be achieved at short signal spacing, such as at 0.25 mile, as long as the traffic volumes are low and short cycles 70 second or less can be used. As arterial and cross-street traffic volumes increase, longer cycle lengths must be used in order to increase capacity by minimizing lost time. As a result,

cycle lengths of 90 to 120 seconds are commonly used in those areas. A spacing of 0.5 miles will enable traffic flow at a wide range of speeds, with cycle lengths ranging from 60 to 120 seconds [6].

2.2 Need for Traffic Signal Coordination

Traffic signal coordination is typically needed to process traffic efficiently through a group of intersections. This is an attempt to utilize the existing roadway infrastructure by insuring optimum travel speeds while reducing delay. Traffic coordination may delay or even eliminate the need for roadway widening. Since traffic signal coordination attempts to reduce the number of stops and slow down of traffic, there is a reduction in accident potential. In addition to traffic and safety concerns, the need for signal coordination may be justified by high levels of vehicle emissions and poor air quality.

An engineering study may be required to determine the need for traffic signal coordination. The need is based on a detailed investigation of the existing conditions which include travel speeds and delay, traffic volumes and accident experience [9].

2.3 Types of Coordinated Signal Systems

A signal system can be defined as a group of traffic signals that are coordinated. The selection of a type of signal system is based upon the available budgetary resources and the applicability of that system in the given area [10].

The most common signal systems are Urban Traffic Control Systems (UTCS), Closed-Loop Systems, Time-Based Coordination (TBC) Systems, and traffic adaptive signal control systems. The TBC system operates on a time clock that is used to take actions automatically based upon the time of day and day of week. In contrast, both UTCS and the Closed-Loop systems react to real-world conditions as they are happening, based on actual traffic volume and signal timing data stored in the system.

In UTCS and Closed-Loop systems, traffic signals are interconnected using different types of cables or communication mechanisms. Electrical cables are the most commonly used method of signal system interconnection. Fiber-optic cables are slowly getting recognition in signal systems. Connecting cables are not needed in the TBC system, as adjacent intersections are coordinated by the timing of their individual controlling clocks.

Traffic-adaptive signal control systems are designed to develop coordination patterns in real-time based on traffic flow data gathered, processed, and communicated

to a central computers. The traffic flow data is gathered using a detector located in each lane at the signalized intersection.

2.4 Advantages and Disadvantages of Traffic Signal Coordination

Signal coordination is perceived by many agencies as an advantageous improvement to the community or corridor in consideration. In many cases, signal coordination techniques have proven to be successful in improving the quality of life and mobility through the area. Project experience from around the United States has indicated that interconnecting previously uncoordinated signals and providing newly optimized timing plans and a central master control system can result in a reduction in travel time ranging from 10 percent to 20 percent [9].

2.4.1 Some of the Advantages of Traffic Signal Coordination

Traffic signal coordination has some advantages that are dedicated as follow:

- (i) Improves mobility and access through the area;
- (ii) Reduces vehicle accidents in the area;
- (iii) Reduces energy and fuel consumption;
- (iv) Reduces stops;
- (v) May control travel speeds;
- (vi) Provides environmental benefits from reduced vehicle emissions; and,
- (vii) Ability to monitor daily traffic operations (UTCS and Closed-Loop).

2.4.2 Some of the Disadvantages of Traffic Signal Coordination

Beside of any advantage for using the one system or method there are some disadvantages. Disadvantages of coordination system are as follow.

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

3 Aim and Objectives

The aim of this study is to implement a traffic control coordination system within a macroscopic simulation environment, thus there is a case study for the evaluation

of traffic congestion. A simulation model, TRANSYT7F, was used to evaluate the possible coordination of signalized intersections. A comparison of the traffic parameters after modeling system is performed, and recommendations for improvement and further study are offered. To achieve this aim, the study was carried out based on the following objectives:

To evaluate travel time, speed, delay and maximum back of queue in the case study, and Comparison of the traffic parameters performance after modeling the system with software.

4 Methodology

For implementing this study some data like traffic flow at each intersection during A.M. and P.M. peak hour, maximum back of queue and control delay at each approach and travel time between intersections were collected.

4.1 Field Data

Field data were collected at four signalized intersections that were located successively in the case study. At each site the video cameras were set up. The total intersection traffic volumes were grouped into 15-minute time periods.

In addition to the total intersection volumes and the maximum back of queue length data, the saturation flow rates for the critical approaches were measured. The Highway Capacity Manual method for measuring saturation flow rates was used. Consistent with ideal values in TRANSYT7F and Chapter 16 of the Highway Capacity Manual [11].

These intersections are located in the vicinity of Johor Bahru. Video cameras were set up at each of the locations during the A.M. and P.M. peak hour period. Data were collected for the heaviest traveled weekday peak hour conditions. Each of these locations were videotaped for a minimum one hour. On certain intersection approaches where the traffic volumes were heavy and back of queues long, an additional dedicated camera was assigned to tape the approach.

The traffic volume, delays, vehicle classifications, and maximum back of queue were obtained for most approach lane groups at each of the intersection locations. These data were collected by cycle for 16 cycles. Signal timing is not fixed over the study period since some signals analyzed are actuated and some are pretimed. Cycle lengths, signal phases and offsets were measured before and after each analysis period and they were unchanged.

4.1.1 Queue

TRANSYT7F calculates the maximum back of queue. This calculation includes any vehicles which join to the back of the queue after the signal indication has turned green and the front of the queue is moving. The queue lengths calculated are the queues that occur due to the given flow rates and they do not build over time [12]. Therefore, it is assumed that the queues have cleared at the end of each cycle and there are no residual vehicles. TRANSYT-7F also reports a queue capacity value for each link based upon a user input value such as a left turn storage length or it is calculated by TRANSYT-7F based upon the link length. This value can then be compared to the estimated queue lengths to determine where spillover may occur. For measuring queue the reference lane at each intersection was considered. During the peak hour the number of vehicle in queue was measured.

4.1.2 Travel Time

The delay experienced by a motorist is made up of a number of factors that relate to control, geometrics, traffic, and congestion. Total delay is the difference between the travel time actually experienced and the reference travel time that would result during base conditions, in the absence of congestion, control, traffic, or geometric delay. To estimate the travel time, one technique, floating car method, was used. Some checkpoints involved all intersections were selected to measure the travel time. This measurement was done during evening and morning peak hour.

4.1.3 Delay

The values derived from the delay calculations represent the average control delay experienced by all vehicles that arrive in the analysis period, including delays incurred beyond the analysis period when the lane group is oversaturated. Delay that practically measured was according to HCM (2000) chapter 16, appendix A. The measuring procedure of delay in TRANSYT is according to HCM too. The average control delay per vehicle is estimated for each lane group and aggregated for each approach and for the intersection as a whole. LOS is directly related to the control delay value. The criteria are listed in HCM (2000).

4.2 Case Study Description

Selection of the study area is based on road sections that are spaced less than 270 meters for two signalized intersections. This study requires area where there is straight path with series junctions. The Bukit Indah is one of the most important areas in Skudai, Johor Bahru, Malaysia. The network is extremely congested, and has heavy traffic, resulting from a varied mix of commuters and travelers.

4.3 Simulating Model

Using TRANSYT7F for evaluating traffic signal network is one of the ways to achieve delay and queue in the system. In this study current traffic was evaluated with simulating the system in the software, it means the base case was simulated according to the uncoordinated traffic signal. Next step of simulation was applied for coordination system. Also optimization and estimation the system to accomplish minimum delay were done. Modeling a network in software requires detailed input data. These data are included traffic flow in each lane and movement, traffic signal data such as cycle time, kind of control (actuated or pretimed) peak hourly factor (PHF) for each lane, geometric data, saturation flow and etc.

4.3.1 Disutility Index

This is a measure of disadvantageous operation; that is, stops, delay, fuel consumption, etc. Unless the disutility index (DI) has specifically been defined as excess fuel consumption, its value has no intrinsic meaning, since it is simply a linear combination of delay and stops, whose units differ. An excess maximum back of queue penalty can optionally be included within the disutility index.

Note that "Disutility Index (DI)" was the optimization objective function for this run, and average delay is a significant component of the DI.

In general, TRANSYT-7F always attempts to maximize the PI (Performance Index), unless the disutility index (DI) has been selected as the PI. Since the DI can be a combination of delay, stops, queuing, and fuel consumption, this value must be minimized. Other objective functions that involve progression or throughput must be maximized.

The DI is a combination of vehicle delay, stops, and fuel consumption. Weighting factors are available in order to place more emphasis on any of these three DI components if desired. Delay-only optimization results in excessive stops and fuel consumption. Excess fuel consumption (minimization) is considered to be a good compromise between bandwidth and delay-based optimization. Although the DI has been shown over the years to be a practical and effective combination of minimizing delay and stops, it does not necessarily produce a wide bandwidth (TRANSYT7F, 2005).

4.3.2 Genetic Algorithm Optimization

Genetic algorithm (G.A.) optimization is a theoretical improvement over the traditional hill-climb optimization technique that has been employed by TRANSYT-7F for many years. G.A. has the ability to avoid becoming trapped in a "local optimum" solution, and is mathematically best qualified to locate the "global optimum" solution. For a discussion on the meaning of

local and global optimum solutions, refer to the documentation on Hill- Climb Optimization.

While running G.A. optimization, the T7F10 interface continuously displays the optimal function value and the average function value. The optimal function value represents the best performance index value when considering all candidate timing plans in that particular generation. The average function value is the average performance index value from all candidate solutions in that particular generation. (TRANSYT 7F, 2005).

4.4 Optimization

The primary qualities of the TRANSYT-7F optimization process include the availability of multiple search techniques (hill-climb and genetic algorithm), numerous optimization objective functions (e.g., involving combinations of progression opportunities, delay, stops, fuel consumption, throughput, and queuing), extensive ability to customize the optimization process, and the ability to optimize all signal settings (cycle length, phasing sequence, splits, and offsets). When using genetic algorithm optimization, it is now possible to allow offset optimization at certain intersections but not others. In addition, genetic algorithm optimization now holds the offset constant at the master controller, if a master controller has been defined [13].

Phase sequences may consist of numerous combinations of protected and permitted movements. While any phase sequence may be specified in TRANSYT, the traffic engineer must exercise professional judgment as to which sequences are most practical (or safe) for the intersections under consideration. Phasing sequence optimization is primarily effective at improving progression for coordinated intersections [14].

TRANSYT-7F explicitly optimizes phasing sequences, phase lengths (splits), and offsets for a given cycle length. Optimization consists of a series of trial simulation runs, using the TRANSYT-7F simulation engine. Each simulation run is assigned a unique signal timing plan by the optimization "umbrella", or processor. The optimizer typically applies the hill-climb and/or genetic algorithm searching strategies. The trial simulation run resulting in the best performance is reported as optimal. To determine the best cycle length, an evaluation of a user-specified range of cycle lengths may also be made. Prior the optimization project, field studies related to travel times as well as advance considerations for a signal timing review process is recommended[15].

4.5 Estimation

The estimation module is capable of computing traffic-actuated phase times with precision included are an improved green time reallocation algorithm, comprehensive critical link search, and improved treatment of stochastic effects. The end result is that performance estimates generated by TRANSYT-7F, after computing actuated phase times under the new methodology, are more realistic. The actuated estimation module can be used to determine maximum green times for implementation in the field [13].

4.6 Calibration of TRANSYT7F

The process of comparing model parameters with real-world data is to ensure that the model realistically represents the traffic environment. The objective is to minimize the discrepancy between model results and measurements or observations [11]. Before using the model to simulate the traffic flow, it has to be calibrated, so that it gives a good estimate of the results. For this study, amount of delay is the most important measure of effectiveness, because it was found to be directly proportional to the traffic performance in the system. In order to estimate the traffic performance correctly, the model should be able to estimate the value of delay correctly. In order to calibrate the value of delay, travel time and maximum back of queue obtained from the TRANSYT7F model is compared to the delay, travel time and maximum back of queue obtained from the field studies.

5 Results and Analysis

5.1 Delay

Delay that measured in the case study is control delay. Control delay is the portion of the total delay attributed to traffic signal operation for signalized intersections. According to appendix A, HCM (2000), field measurement of intersection control delay was obtained at each approach of all intersections during morning and evening peak hours. Therefore 32 samples from 16 approaches control delay during peak period were measured.

5.2 Queue and Travel Time

Traffic stream for the site in the morning and evening peak hour is different. Traffic flow in the morning from Johor Bahru to Jusco has maximum amount and in the evening this flow is inverse. The value of queue in the morning from the Johor Bahru to Jusco and Jusco to Johor Bahru are 19 vehs per lane, and 21 vehs per lane respectively at major routes. It depicts high amount of maximum back of queue in the system when there is congestion. The results of travel time show there is significant difference between running speed and journey speed (more than 50%). It shows there is long delay in the case study.

5.3 Calibration of TRANSYT7F

Scatter plot to determine R-squared value for field data and TRANSYT7F results were used. Correlation of model with TRANSYT, based on all three experiments, are illustrated in Fig. 1, Fig. 2 and Fig. 3. For travel time just major approaches were considered, for control delay and maximum back of queue data of all approaches at each intersection were considered. It seems that the goodness of fit (R^2) of the calibration was obtained.

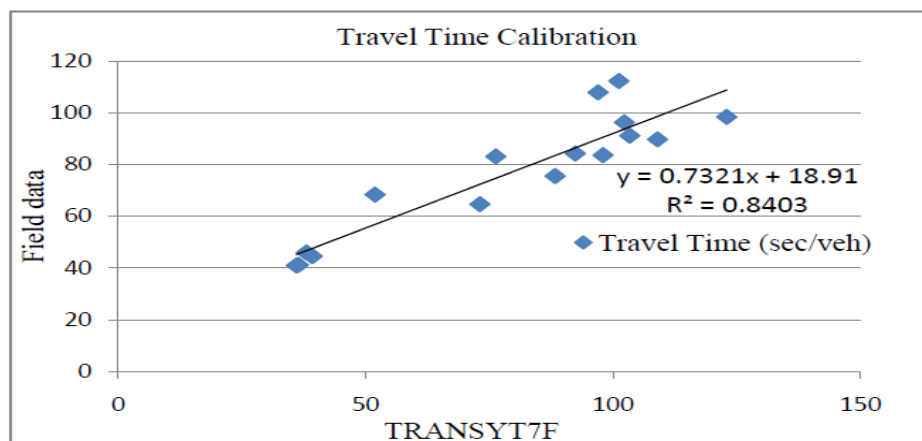
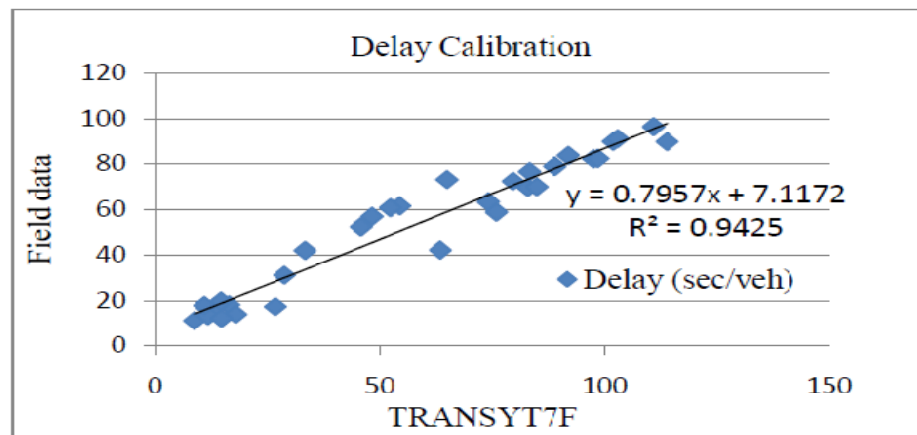


Figure 1. Travel time calibration



5.4 Evaluation of Performance of System without Coordination

Objective of this part is modeling the base case condition to obtain current traffic performance. The first study was done without coordination in the system. Results show for the whole system, the high amount of travel times, delay and maximum back of queue are experienced during the peak period by most of the travelers. However, disutility Index (DI) shows the travel time and delay are larger indicating that these routes are highly congested. Delay obtained 65.1 sec/veh (A.M.) and 68.3 sec/veh (P.M.), with refer to (HCM, 2000) dictate level of service (LOS) E. Also travel time achieved 396 veh-hr/hr (A.M.) and 419 veh-hr/hr (P.M.).

5.5 Evaluation of Performance of System with Coordination

Simulation of the system with coordination mode and with the help of optimization (genetic algorithm) and estimation of maximum green time for finding the best

cycle time to reduce delay and minimize it, was applied in TRANSYT7F. This coordination provides information about the links that are affected by the congestion. The results for the whole segment of system show that the amount of delay, travel time and disutility index (DI) reduced. The benefits of coordination are clearly visible. For the whole segments, the maximum average travel time comes down to 314veh-veh/hr, from 396veh-veh/hr, an improvement of about 21% and 325veh-veh/hr from 419veh-veh/hr, an improvement about 22% during the morning and evening peak hours respectively. From the results, we can see that control delay faced by the vehicles has come down significantly, where 65.1sec/veh has been changed to 35.6sec/veh and 68.3 comes down to 37.2sec/veh during A.M. and P.M. peak hours respectively that indicates LOS D. Average travel times for the peak hour period decreases during the whole duration. With the help of coordination system, maximum back of queue per link in major lane also comes down by a significant value.

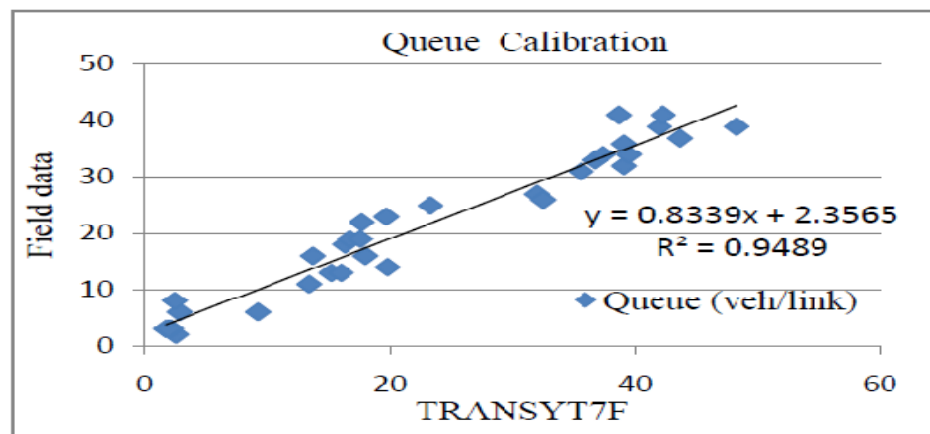


Figure 3. Queue calibration

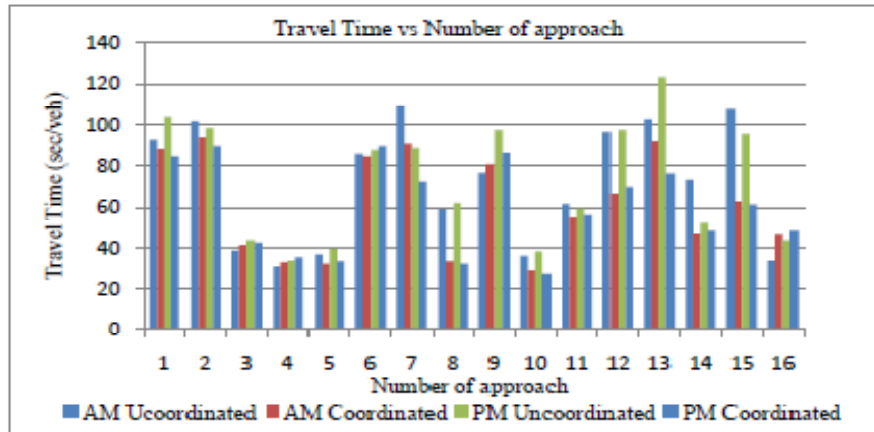


Figure 4. Travel time vs number of approach

5.6 Comparison

This section compares the results obtained from different scenarios, travel time, control delay and the maximum back of queue for each approach.

5.6.1 Comparison Base on Travel Time and Delay

Table 1 summarizes the travel times, average delay, system speed and performance index during A.M. and P.M. peak hours for whole segment of the route. As can be observed from these results, using a coordination system can significantly improve all parameters. It may be observed that using coordination system can save about 21% and 22% vehicle hours for travel time during the peak hours in the morning and evening respectively.

It leads to increase the system speed. Without coordination system occurrence increases the delay as well. Coordination system usage can bring this down by about 45% during peak hours that means improve the level of service to D. Fig. 4 and Fig. 5 show the amount of travel time and delay at both systems during the peak hours at each approach. All obtained result will be represented by performance index.

Table 1. Summary of the Result of Uncoordinated and Coordinated During the A.M and P.M Peak Hour.

System Performance	Uncoordinated		Coordinated	
	A.M	P.M	A.M	P.M
Average Delay (sec/veh)& LOS	65.1 E	68.3 E	35.6 D	37.2 D
Travel Time (veh-hr/hr)	396	419	314	325
System Speed (km/hr)	11.2	10.9	15.1	14.7
Performance Index (DI)	233.7	251.2	186.4	194.3

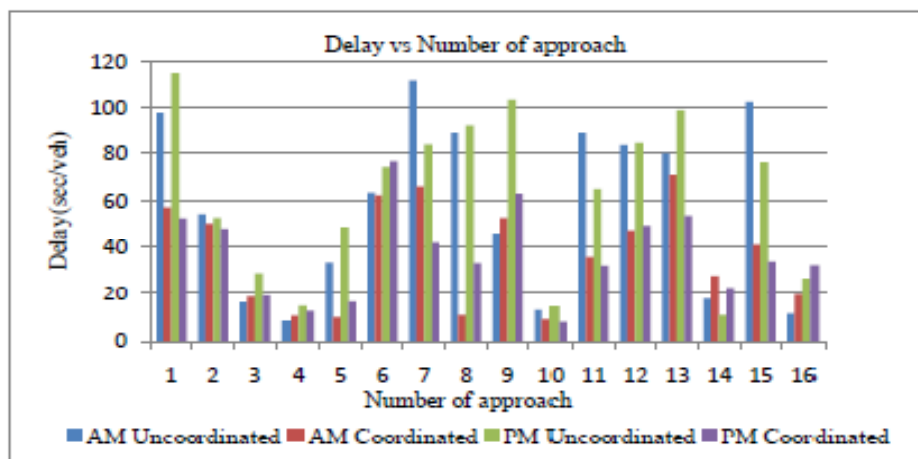


Figure 5. Delay vs number of approach

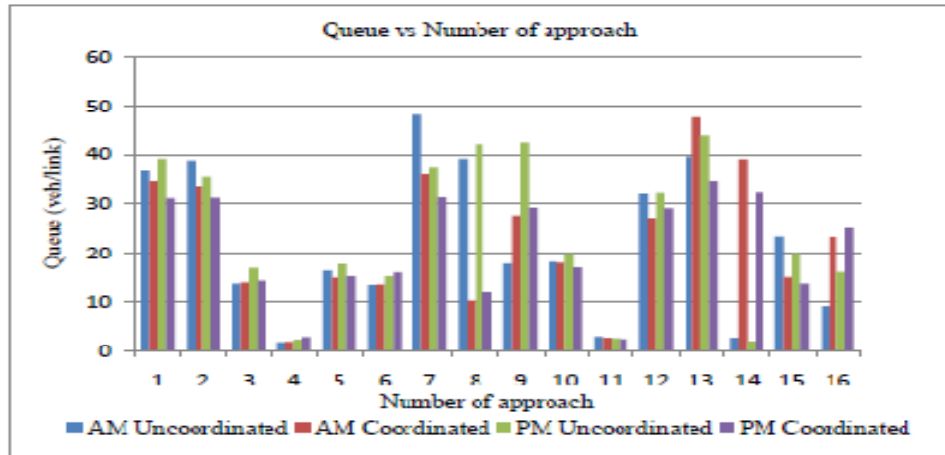


Figure 6. Queue vs number of approach

For the whole segment, the performance index (DI) comes down to 186.4, from 233.7, an improvement of about 20% and 194.3 from 251.2, an improvement about 23% during the morning and evening peak hours respectively.

5.6.2 Comparison Base on maximum Back of Queue (Veh/Link)

The comparison based on the maximum back of queue within various ranges of travel times and delay for whole segment of route during peak hours at all approaches is shown in Fig. 6. The impact of the coordination system is obvious from the fact that there is a significant reduction in the value of queue with major approaches.

6 Conclusion

1. Because of consecutive short distance signalized intersections in the site, the performance of traffic parameters are not appropriate, so one of the methods for improving the network performance is coordinating traffic signal at intersections.
2. Maximum traffic flow in the morning is from southbound and in the evening is from northbound. During the A.M. and P.M. peak hours drivers have experienced long queue in mentioned approaches. In addition the amount of traffic flow in the evening peak hour is more than morning peak hour.
3. One of the most important measurements of effectiveness in traffic studies is the delay to vehicles in the system. Delay represents indirect costs to the motorist in terms of lost time, discomfort and frustration, and a direct cost in terms of fuel consumption during idling. Excessive delay at signalized intersections reflects inefficiency in the

signal timing, coordinating system leads to reduce delay and reduction in the overall system number of stops.

4. Simulating system with TRANSYT7F shows when intersections are uncoordinated, the amount of delay, queue, travel time and system speed are almost near to practical measuring.
5. The value of delay, maximum back of queue, travel time and speed that obtained from practical measurement in the site show the level of service in the case study is E and drivers have experienced long delay, long travel time and low speed for passing the system.
6. During the evening and morning peak hour after applying coordinating system obvious effect has been seen, where average delay from 68.3 sec/veh decreases to 37.2 sec/veh and from 65.1sec/veh comes down to 35.6sec/veh respectively. It means LOS has been improved from E in uncoordinated system to D in coordinated one. This leads to increase speed from 10.9 km/hr to 14.7 km/hr and 11.2 km/hr to 15.1 km/hr during P.M. and A.M. peak hour respectively.

Also for the whole system, performance index (DI) improved about 23% for evening and about 20% for morning peak hour.

7. In a coordinated signal system the cycle length is constant for all controllers during any given control period. In this study the capability of TRANSYT-7F (optimization and estimation model) has been used for evaluating a range of cycle lengths and advising of a "best" cycle length for investigation along with the system.

A general conclusion from the evaluation is that the effectiveness of coordination traffic signal is obvious for the site that was investigated, but it is

specific in every site and condition. Therefore, results from one application may not necessarily apply in different situations. For this reason, in one case study simulation is a valuable tool for the design and evaluation of different strategies, as it can be used to determine if and how such strategies can be most effectively implemented.

Acknowledgment:

The authors are thankful to MOSTI through RMC of Universiti Teknologi Malaysia (UTM) and UTM for providing financial aid to carry out this research.

References:

- [1] Angus P. Davol, *Modeling of Traffic Signal Control and Transit Signal Priority Strategies in a Microscopic Simulation Laboratory*, Master Thesis, Massachusetts Institute of Technology, September 2001.
- [2] McShane, W.R., Roess, R.P., Prassas, E.S., *Traffic Engineering*. 2nd. ed. Prentice Hall, New Jersey, 1998.
- [3] Dong Nyong KIM, Evaluation on Simulation Models For Urbancorridor Signal Optimizations, *Proceedings of the Eastern Asia Society for Transportation Studies*, Vol.4, October, 2003.
- [4] Booz Allen Hamilton., *Assessment of benefits relative to costs of ITS facilities*, VicRoads, Melbourne., 2003.
- [5] Roger R. Stough, George., *Intelligent Transportation Systems, Cases and Policies*.USA: Mason University., 2001.
- [6] McShane, W.R., Roess, R.P., Prassas, E.S., *Traffic Engineering*. 3rd. ed. Prentice Hall, New Jersey., 2004.
- [7] Nicholas J. Garber, Lester A. Hoel., "*Traffic and Highway Engineering*". West Publishing Co., 1999.
- [8] Richard Whelan., (1995). *Smart Highways, Smart Cars*. Boston: Artech House
- [9] Traffic Engineering Handbook, Institute of Transportation Engineers, 5th Edition, 1999.
- [10] Fred L. Orcutt Jr., *The Traffic Signal Book*, Prentice Hall, Englewood Cliffs, N.J., 1993.
- [11] TRB, Highway Capacity Manual. *Transportation Research Board*. National Research Council, Washington, D.C., 2000.
- [12] Wallace, Charles, Chang, Edmond, Messer, Carroll, and Courage, Kenneth, *Methodology for Optimizing Signal Timing: PASSER II-90 Users Guide*, Office of Traffic Operations and Intelligent Vehicle/Highway Systems – Federal Highway Administration, Volume 3, December 1991.
- [13] *TRANSYT-7F User's Guide*, U.S. Department of Transportation, University of Florida, 2005.
- [14] McTrans, *Highway Capacity Software*. *Transportation Research Center*. University of Florida, Newsletter, Volume 21 Fall 2000.
- [15] Avery, D.J., *A Design Review Process for the Development of Traffic Signal Timing Plans*, Masters Report, University of Florida Transportation Research Center, 1991.