Evaluation of Effect of Traffic Signal Coordination System on Congestion

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Abstract: A lot of effort has been concentrated on the development of various tools for the optimization of transportation systems. The potential benefits of studying coordination systems of traffic signal are already known in traffic flow analysis, modeling and traffic engineering design. However, presently there is a lack of information on coordination system on Malaysian roads. 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. A simulation model, TRANSYT7F, was used to evaluate the possible coordination of signalized intersections. For calibration TRANSYT7F results, delay, maximum back of queue and travel time practically were measured. The results show after coordinating, the amount of delay, travel time, and queue reduce.

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

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.

2 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.
3 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.

3.1 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 [4].

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.

3.1.1 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 [5]. 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 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.

3.1.2 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.

3.1.3 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).

3.2 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.

3.3 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.

3.4 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 [6].

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 [7].

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[8].

3.6 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 [4]. 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.

4 Results and Analysis

4.1 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.

4.2 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 Bahro 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 depict 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.

4.3 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.

4.4 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.).

4.5 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 314 veh-veh/hr, from 396 veh-veh/hr, an improvement of about 21% and 325 veh-veh/hr from 419 veh-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 65.1 sec/veh has been changed to 35.6 sec/veh and 68.3 comes down to 37.2 sec/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.

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

4.6.1 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.

4.6.2 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.

<table>
<thead>
<tr>
<th>System Performance</th>
<th>Uncoordinated</th>
<th>Coordinated</th>
</tr>
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<tbody>
<tr>
<td>Average Delay (sec/veh)&amp; LOS</td>
<td>A.M.</td>
<td>P.M.</td>
</tr>
<tr>
<td>Travel Time (veh/hr)</td>
<td>396</td>
<td>419</td>
</tr>
<tr>
<td>System Speed (km/hr)</td>
<td>11.2</td>
<td>10.9</td>
</tr>
<tr>
<td>Performance Index (DI)</td>
<td>233.7</td>
<td>251.2</td>
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</tbody>
</table>

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 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 65.1 sec/veh comes down to 35.6 sec/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.

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References