Optimization and Evaluation for TIME-OF-DAY Signal Timing of Arterial Traffic

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Abstract: Traffic signal control is one of the most cost-effective means of improving urban mobility. With the recent progress in the ITS (Intelligent Transportation System) and the installation of the Real Time Traffic Control System, traffic signal controlling is conducted online and in real time. Normally, time-of-day (TOD) Signal Control is used with the system, but no definite methodologies have been proposed for efficient TOD Timing Plan. Therefore, methods and processes are needed for optimizing the traffic signal timing plan in order to improve the efficiency of the traffic signal system.

This paper study on the optimization of TOD Signal Timing for arterial roads, the application effects of the signal time were assessed in the field. We defined a method to separate TOD breakpoints and optimize TOD intervals for improved traffic signal time. The proposed approach was implemented on an arterial consisting of ten coordinated signalized intersections. In the study results, the proposed TOD Timing Plan outperformed the previous signal time.

Key Words: Traffic Signal Control, TOD Timing Plan, Signal Optimization, Assessment

1. INTRODUCTION

TOD signal control in an optimal condition is undoubtedly one of the most cost-effective means of improving mobility in an urban environment. Due to the temporal nature of traffic demand, especially according to the time of day, traffic engineers have to develop multiple signal timing plans to adjust to these changes over a 24-hr cycle. This signal timing plan is called time-of-day (TOD) control. Although not as responsive to variable traffic demands as adaptive or "real-time" control systems, the TOD mode is commonly used due to its lack of reliance on detectors, and hence any need for the costly installation and maintenance of sophisticated vehicle sensor hardware. In addition, the TOD mode is often used as a backup to more advanced control systems. Despite the inadequacies in assuming that traffic flows remain constant during a given time interval, frequent changes in signal timings may be too
disruptive to drivers. Thus, the TOD mode can be a consistent manner of signal timing that is conducive to driver expectancies.

Despite this significance, a TOD Timing Plan rests on the engineer’s experience or is simply divided into the two cases of peak period and non-peak period. Furthermore, despite being a good criterion for setting the TOD breakpoints, traffic volume hasn’t been clearly defined and the progression problem can arise in the absence of any consideration for changes in the heavier direction traffic in both directions. Therefore, these defects of existing TOD planning methods are compensated in this paper and the process of the TOD Timing Plan is defined. The proposed approach is implemented on an arterial of real signalized intersections and the effects are evaluated.

A Field Survey and Floating Car Test was held for three days from April 2 to April 4, 2010, in order to check weekday and weekend traffic patterns in dong2-street of Seoul. The surveyors conducted a Pre-Survey of 10 intersections in dong2-street and gathered data on traffic volume, link speed and Maximum queue length.

Using the Pre-Survey data, we determined the Sub-Area (SA) by quantitative and qualitative analysis, implemented the TOD Timing Plan, computed the optimized signal time of the TOD time periods, and evaluated the effects of the improved signal time by micro simulation program. After applying the new TOD Timing Plan in the test site, we conducted a post survey for three days from July 9 to July 11, 2010, monitored the change of traffic patterns, and assessed the result of the Pre-Post Survey.

The study objectives are to define a standard process that identifies the optimal TOD Timing Plan for urban signal systems and to evaluate the performance of the new TOD Plan through a field survey.

![Diagram](attachment:image.png)

**Figure 1 : The study course**

2. REVIEW OF PREVIOUS RESEARCH

TOD Signal time typically includes separating a day into two time periods: unsaturated (off-peak) and oversaturated (peak). Current signalization practice recognizes that the variation in volumes at a typical urban intersection warrants the consideration of several, distinct time periods within a 24-hour day. A number of researchers have attempted to optimize the TOD breakpoints and analyze the improved effect of TOD Signal time.

Hua and Faghri (2) described a dynamic programming (DP) method for identifying time
interval. The DP method is based on finding an optimal set of control parameters, including the cycle length, splits (portion of the cycle allocated to each phase) and offset (difference between start times at adjacent intersections, thereby enabling coordination), for a given time interval. The DP method can produce a set of optimal signal timings, but only at considerable computational expense. Hua and Faghri also described a neural network approach to identifying appropriate time intervals.

A recent study proposed the use of statistical clustering algorithms to determine such TOD breakpoints (3). The study results indicated that statistical methods produce fairly good clusters; however, situations arise in which “unclean” clusters or isolated clusters are formed. Unlike the majority of the clusters, these isolated clusters do not follow an intuitive TOD scheme. As a result, traffic engineers have to manually assign the adjacent cluster or a special algorithm has to be developed to refine the clusters. Park et al. (4) pointed out that unclean clusters are inevitable because of the nature of statistical clustering algorithms, which do not include the TOD variable. They then proposed a heuristic clustering technique on the basis of a genetic algorithm (GA) that removes such unclean clusters and offers comparable performance. Park et al. (4) recommended that the proposed heuristic be implemented several times to select the most intuitive TOD breakpoints, since the process occasionally generates irrational TOD breakpoints.

Smith and Scherer (5) defined the TOD Timing Plan using the data mining tool. Park and Lee (6) presented the development and evaluation of a procedure for determining optimal breakpoints for TOD-based coordinated actuated traffic signal operation using the simulation program. The proposed procedure uses a feature vector of optimal cycle length per time interval instead of the traffic volume itself. Initial breakpoints determined by the proposed feature vector are used in the greedy search algorithm to obtain optimal breakpoints. By using the greedy search algorithm, the number of evaluations in the search is dramatically reduced when compared to an exhaustive search or other common heuristic search methods such as a GA.

3. METHODS FOR TOD SIGNAL TIMING PLAN

■ Data Gathering

In order to make the signal plan, all the traffic data at critical points of the main street over a 24-hr period are collected. This research gathered traffic volume, speed and occupancy using an inductive loop detector. The data gathering period was either 15 min or 30 min, which is useful to describe the traffic volumes in terms of traffic condition. With the 15 min data (traffic volume) and in the case of a wide gap between two intersections, the traffic volume is likely to change drastically for almost every cycle, making it difficult to determine the breakpoints of the TOD signal time. Therefore, the 30 min data of the field survey were used.

■ Set-up of a Sub-Area (SA)

For efficient signal management and progression control, engineers typically group intersections of a similar traffic condition into an SA by considering the road shape, transition of traffic pattern and direction of main streets. The progression effect may vary depending on the composition of the SA. So, we established a standard for SA based on the quantitative and qualitative criteria.
Table 1 Standards for SA grouping

<table>
<thead>
<tr>
<th>Quantitative</th>
<th>Qualitative</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The continuity of traffic pattern</td>
<td>1. The function of signal controller</td>
</tr>
<tr>
<td>2. The right of management</td>
<td>2. The grade of road</td>
</tr>
<tr>
<td>3. Check the construction</td>
<td>3. The Geometric Structures of Roads</td>
</tr>
<tr>
<td>4. The midblock interruption</td>
<td>4. The space between signalized intersections</td>
</tr>
<tr>
<td></td>
<td>5. Coupling Index</td>
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</tbody>
</table>

Figure 2 An example of SA grouping

Method for Identifying TOD breakpoints

Traffic engineers manually collect traffic survey data for a day, plot the aggregated volumes, and determine the TOD breakpoints based on the engineer’s experience and judgment. However, this approach may not be efficient due to its inability to accommodate rapid changes in daily traffic. So, we need the methodology for TOD breakpoints.

Traffic Signal Timing plans under multiple TOD intervals are affected by the implementation of a new timing plan as the progression bandwidth along an arterial could be disrupted, which causes a transition cost. Therefore, the number and length of the TOD intervals are as important as finding the optimal signal timing plan for the TOD Signal Control. For efficient signal control, the optimal breakpoints must be determined by analyzing the traffic pattern on each SA. The following analysis procedure of traffic pattern, shown in Fig. 3, is proposed to determine the optimal breakpoints for TOD-based traffic signal operations.
Step 1. Analyze and convert the traffic volume for the unit time interval in each SA. Traffic volume data is an important element input in the breakpoint and the traffic signal timing optimization. The 15-min traffic volume and occupancy of the main street on a weekday and on the weekend are used. If the 15-min data have large fluctuations, the 30-min data should be applied. The traffic volume provides a reliable estimate of demand when traffic is well below the saturation flow. But as the traffic passing over a detector approaches saturated levels, queues tend to build up and the traffic flow measured by the detector is only that which is allowed to pass through the intersection during the green phase. Thus, the volume is a good measure of demand until saturated conditions occur. At that time, the volume tends to level off to a value that reflects intersection approach capacity rather than traffic demand. Then the traffic volume is translated into VPLUSKO value.

\[
VPLUSKO = \text{Volume} + K \times \text{Occupancy} \quad \text{(which is proportional to demand)}
\]

Where, \(K\) : weight factor of volume and occupancy (User Define \(\approx 20\))

Combining volume and occupancy in the equation for VPLUSKO provides a function that increases as demand increases even when saturation occurs. The actual value of VPLUSKO is not important, because it is used to compare the survey data with the traffic conditions. However, it is important that a weighting factor be incorporated into the equation that ensures that occupancy (which can have a practical range of values between 0 percent and 50 percent) has an impact on the value of VPLUSKO that is equivalent to the impact of volume (which can range between 0 vehicles per hour and 1,200 vehicles per hour). For this reason, a value of 20 has been used for \(K\). (Ed- this paragraph is perfectly written in entirety)

Step 2. Determine the number of initial breakpoints
This work is very important for the non-hierarchical clustering analysis (K-Mean Clustering Method). However, there is no definite method for determining the \(K\)-value (the number of initial breakpoints). Although the number of clusters can be analyzed using methods such as
semi-partial R-square, pseudo-F, pseudo-t square and cubic clustering criterion, errors can arise and the result is too dependent on the analyzer's subjective views. Therefore, the number of initial breakpoints was decided in this study using the inflection point and cross points in the vertical direction of a VPLUSKO plot.

Step 3. Conduct the statistical analysis program to finalize the breakpoints
The K-means method, developed by MacQueen (7), is one of the most popular non-hierarchical clustering algorithms and has been used in many other technical disciplines, including multi objective optimization (8) and real-time intersection level of service determination (9). The algorithm is straightforward:
1) Partition the data items into K initial clusters.
2) Proceed through the list of items, and assign each to the cluster having the nearest "centroid" or mean. Recalculate the centroids for the cluster receiving the new item and for the cluster losing the item.
3) Repeat 2) above until no further assignments can occur.
The statistical analysis program (SPSS) was used to conduct this algorithm. These initial breakpoints do not have to be perfect as they are further refined in step 5. Hence, the initial breakpoints have to be calibrated by steps 4 and 5.

Step 4. Calibrate the initial breakpoints considering the minimum transition time
The minimum transition time was determined as less than 1 hour on the field application, since the frequent traffic signal changes induced shocks and delays to the traffic flows. If it is determined within 1 hour, the initial breakpoint moves to the adjacent TOD interval of a similar traffic pattern or condition.

Step 5. Calibrate for the changes of the heavier direction pattern.
In the case of a change in the heavier direction of traffic volume, inspection of the VPLUSKO plot reveals that a breakpoint must be added at the time that the curve on the graph changes.

![Figure 4 The result of TOD Timing Plan](image)

- **Optimize the traffic signal of each TOD interval**

In order to calculate traffic control variables (cycle, split, phase order, offset), a traffic signal timing plan for each time segment can be obtained from commercial traffic signal timing optimization software packages such as PASSER or TRANSYT-7F. The following procedure shows the process of signal optimization.
4. EVALUATION

In order to evaluate the performance of the newly developed TOD Timing Plan, the VISSIM model was used. A simulation was executed with 10 intersections on the test site as the destination for a day. Using the VISVAP function, TOD control was exerted over the traffic for 24 hours of a weekday and over the weekend. The time headway, start-up lost time, average free speed, etc., were calibrated. To measure the efficiency of the intersection, the average link delay was selected as MOE (Measure Of Effect). The average link delay was calculated using the difference between a vehicle’s travel time and the free-flow travel time.

To demonstrate the effects of the proposed algorithm, three scenarios were compared using the VISSIM model: firstly, the present signal state that was operated on test site, secondly, the present TOD pattern and optimized signal time that were applied to the optimum cycle and green split that is calculated through the PASSER model, and thirdly, the new TOD Timing Plan of the proposed method. The second scenario was added in order to test the effect of the new breakpoints.

<table>
<thead>
<tr>
<th>Table 2 Analysis Scenarios</th>
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<tbody>
<tr>
<td><strong>Scenarios</strong></td>
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<tr>
<td>1. old TOD + old Phase</td>
</tr>
<tr>
<td>2. old TOD + new Phase</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>3. new TOD + new Phase</td>
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We evaluated the algorithm based on the average link delay (sec) of the vehicles in the intersection in order to determine the link performance. A smaller delay with higher speed indicates better performance of the new TOD Timing Plan.

Figure 6 shows the total average delay of the vehicles of all approaches for a day. The new TOD Timing Plan had a greater effect on the average link delay than the other scenarios over the 24-hr period. The signal timing optimization (Scenario 2) reduced the
vehicle’s delay time by an average of 7% compared with the present signal time, and by 16% in scenario 3 with the new TOD Timing Plan. The new methodology was demonstrated to be more effective and it reduced the vehicle’s delay in most intersections at the test site.

Figure 6 Average delay on each day

5. CASE STUDY

Ten coordinated signalized intersections on dong2-street, Seoul, were used for the case study. The Pre-field survey was conducted for three days from April 2 to April 4, 2010, and the Post-field survey was conducted for monitoring from July 1 to July 12, 2010.

Table 3 Checklist to Survey

<table>
<thead>
<tr>
<th>Check List</th>
<th>Survey Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intersection volume</td>
<td>Using the Loop Detector and video equipment</td>
</tr>
<tr>
<td>Average Travel Speed</td>
<td>video equipment or Car Plate Survey,</td>
</tr>
<tr>
<td></td>
<td>Field Survey by GPS Equipment</td>
</tr>
<tr>
<td>Length of queue</td>
<td>Field Survey by surveyors</td>
</tr>
<tr>
<td>Average Stops</td>
<td>Field Survey by GPS Equipment</td>
</tr>
</tbody>
</table>

The Pre-Post survey analysis revealed that the traffic volume was reduced by about 7% from April to July. The vehicles’ average speed was increased about 16%, and the largest increase was 38% in the time-based analysis.

Figure 7 The result of Pre-Post survey analysis
In Figure 9, the vehicle’s average stops was reduced by an average of 13% and a maximum of 34%, and the queue length of the main street was decreased by about 13% by applying the new TOD Timing Plan.

![Figure 8 Average queue length](image)

This field application demonstrated the capability of the new method for TOD Timing to decrease vehicle delay, stops and queue length that are related to traffic signal progression for arterial.

**6. CONCLUSIONS AND FUTURE RESEARCH**

Although establishing a Signal Timing Plan for effective TOD control is a very important process, no standard methodology and process for TOD Timing Plan have yet been demonstrated. Therefore, this study developed a procedure for determining TOD breakpoints and demonstrated that the proposed procedure produces optimal breakpoints. A method was defined for setting the SA, which is the default element of the signal plan, using the k-mean method, and determining the initial breakpoints of the TOD Timing Plan based on the time series data. This solved the problem that the initial breakpoints were determined only on the basis of the traffic volume and a 3-step calibration process was presented. Through the proposed methodology, signal optimization was conducted for each TOD interval and the effectiveness was verified by using the simulation S/W (VISSIM).

In the results from a case study applied to a field site, the average vehicle’s speed was increased by about 16% and the average stops and queue length were decreased by about 13%. Especially, the signal operating efficiency was improved at the non-peak time.

Future research should focus on developing a methodology for determining the number of clusters, since too many traffic signal transitions induce shocks in the traffic flow. The present research analysis determined the proper number of breakpoints and suggested the minimum transition period by considering the traffic flow delay.

**7. REFERENCES**


