PEAK HOUR VOLUME SIGNAL WARRANT BY DELAY MODELS FOR T INTERSECTIONS

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Abstract: Existing signal warrants do not consider the type of intersection configuration. In this research, a signal warrant for T intersections was proposed to control the intersection efficiently. The minimization of average stopped delay at intersection was used as a measure of effectiveness for signalization. The major findings are as follows: (1) the delay at T intersections can be represented an exponential function consisting of two independent variables of major and minor street volume. (2) the signal warrant volume for T intersections is higher than the volume proposed by the US Manual on Uniform Traffic Control Devices because of phase reduction at T intersections, and (3) when the plotted point representing the peak hour volume on the major street(the total for both approach) and minor street approach is above the threshold volume suggested in this study, the peak hour volume signal warrant for T intersections is satisfied.

1. INTRODUCTION

An intersection can create conflicts among traffic flows on each approach. It can also create conflicts between vehicles and pedestrians at crosswalks. Operating an intersection efficiently and safely is very important. Control of intersections can be divided into two categories: signalized and unsignalized control.
The objective of intersection control is not only to minimize delay but also to reduce accidents and increase capacity. However, excessive delay results from unnecessary signal control of low traffic volumes.

Our signal warrants for intersections are published in the "Manual on Installation of Traffic Safety Devices"(1996) published by the police. We follow the warrant suggested by this manual. Although there are signal warrants for traffic volume, pedestrian, school zone and permitted left-turn in this manual, most of these warrants use the same value as recommended in the US MUTCD(FHWA,1988). In addition, the existing manual has no separate warrants for different types of intersection, including four-leg and three-leg intersections. Because each type of intersection has different characteristics, individual warrants are necessary. To improve this situation, this study collected and analyzed field data in Korea and proposes the signal warrant for T intersections. The collected data in this research includes major and minor street traffic volume and the number of stopped vehicles in signalized and unsignalized T intersections.

The objective of this paper is to propose the new signal warrants for T intersections using a peak hour volume signal warrant. To achieve this objective, field data was collected at 6 signalized and 6 unsignalized T intersections at level terrain. In this study, three types of intersections were analyzed according to the number of lanes for approach. The first type has one lane each in both major and minor approaches. The second type is where the major approach has two lanes and minor approach has one lane. The third type has two lanes each in both approaches. These three types of intersections are referred to in this paper as 1*1, 2*1 and 2*2, respectively.

2. LITERATURE REVIEW AND PROBLEM IDENTIFICATION

2.1 Literature Review

Among the signal warrants suggested by the "Manual on Installation of Traffic Safety Devices " in Korea, the warrants related to traffic volume were reviewed in detail. These warrants include : traffic volume warrant, pedestrian volume warrant and permitted left-turn warrant. The traffic volume warrant uses the same threshold as prescribed in the US MUTCD. Based on the manual intersection signal is warranted if the traffic volumes exceed the threshold volumes during 8 or more hours in an average day. For example, this warrant suggests an intersection in which major and minor streets have only one lane should be signalized when major street volume(in both directions) exceeds 500vph and minor street volume exceeds 150vph.

According to a study on signal warrants(focused on traffic volume) published by Road Traffic Safety Association (RTSA)(1996), intersections should be signalized when major and minor street volumes are in the range of 900-1,200 vph and 300-500vph respectively. In this study the warrants are proposed for the types of intersection(┼ or ┬) and the number of approaches. The recommendation is to signalize a 3-leg intersection when the 2-lane major street and 1-lane minor street reach traffic volumes of 900vph and 400vph respectively. The major findings of the study are shown in Table1.

Table 1. Signal warrant proposed by RTSA study

Classification	3-leg intersection			4-leg intersection		
	1*1	2*1	2*2	1*1	2*1	2*2
Total traffic volume		1300		1400	1500	1600
Major directional volume		900		900	1200	1200
Minor directional volume		400		500	300	400

There are 11 warrants in the US MUTCD. The warrants related to traffic volume are as follows : minimum vehicular volume, interruption of continuous traffic, four-hour volumes, peak-hour delay and peak-hour volume. Table 2 shows the minimum threshold vehicular volumes. Interruption of continuous traffic is suggested when the traffic volume on the major street is so heavy that the traffic on the minor intersecting street suffers excessive delay or hazard in entering or crossing the major street. The warrant is satisfied when for each of any 8 hours of an average day, the traffic volumes given in the Table 3 exist on the major street and on the higher volume minor street approach to the intersection, and the signal installation will not seriously disrupt progressive traffic flow.

Table 2. Minimum Vehicular Volume

Number of lanes for moving traffic on each approach		Vehicles per hour on major street (total of both approach)	Vehicles per hour on higher-volume minor-street approach (one direction only)
Major street	Minor street		
1	1	500	150
2 or more	1	600	150
2 or more	2 or more	600	200
1	2 or more	500	200

Table 3. Interruption of Continuous Traffic

Number of lanes for moving traffic on each approach		Vehicles per hour on major street (total of both approach)	Vehicles per hour on higher-volume minor-street approach (one direction only)
Major street	Minor street		
1	1	750	75
2 or more	1	900	75
2 or more	2 or more	900	100
1	2 or more	750	100

Peak hour delay warrant is satisfied when :
(1) The total delay experienced by the traffic on one minor street approach(one direction only) controlled by a STOP sign equals or exceeds 4 vehicle-hours for a one-lane approach and 5 vehicle-hours for a two-lane approach,
(2) The volume on the same minor street approach(one direction only) equals or exceeds 100vph for one moving lane of traffic or 150 vph for two moving lanes, and
(3) The total entering volume serviced during the hour equals or exceeds 800vph for an intersection with four(or more) approaches or 650vph for intersections with three approaches-this is the only mention about intersection with three approaches.
Table 4 summarizes these peak-hour delay warrants;

Table 4. Peak Hour Delay

Classification	One-lane approach	Two-lane approach
The total delay experienced by the traffic on one minor street approach(one direction only) controlled by STOP sign	4 veh hour or more	5 veh hour or more
The volume on the minor street approach	100 veh/h or more	150veh/h more

2.2 Problem Identification

The preceding analysis indicates that a signal warrant for T intersections is needed. Most existing signal warrants have no comments or explanations for T intersections.
The RTSA study has warrants only for 2*1 intersections. The US MUTCD(U.S.) merely states that signalization is desirable when total entering volume is 650vph(or more) in an hour for T intersection. In other countries, it appears that there are no separate signal warrants for different types of intersection. Therefore, a separate signal warrant is necessary to control T intersections effectively.

3. DATA COLLECTION AND REDUCTION

To get good results, it is necessary to compare traffic data from the same intersection under signalized and unsignalized control conditions. However this is very difficult to implement because of safety risks. Therefore, to collect the field data under the most similar traffic conditions, the following points were considered when selecting intersections:

- Level terrain, good sight distance
- the major street meets minor street at a right angle
- no left-turn bay
- some amount of delay for comparison
- similar land-use condition
- isolated intersection

The field data for this research is shown in Table 5. In the case of signalized intersections, each category is based on the configuration of an intersection with the same signal timing and phase. The signal system observed at sites is found to be optimum with respect to the cycle length, phasing and green split. Table 6 shows the range of traffic volumes observed on the major and minor streets under signalized and unsignalized conditions.

Table 5. Collected Field Data

Unsignalized intersection	Signalized intersection
Traffic volume on each approach Stopped vehicle on each approach Geometry of intersection	Traffic volume on each approach Stopped vehicle on each approach Geometry of intersection Signal timing and phase

Table 6. Range of Traffic Volumes for Each Type of Intersections

Class of intersection		Range of traffic volume	
		Major street volume (both direction) (vph)	Minor street volume (vph)
1*1	Signal	496～1421	24～284
	Unsignal	336～1680	60～396
2*1	Signal	774～1640	168～412
	Unsignal	604～1508	30～500
2*2	Signal	820～1656	140～908
	Unsignal	616～1612	104～324

The data collected for this research was traffic volume on each approach and the number of stopped vehicles. For calculating intersection delay, we used the method suggested by the US Highway Capacity Manual(TRB,1994) as follows;

(1) Record a count over a certain time interval of the number of vehicles stopped on the intersection approach.
(2) The total count of stopped vehicles during all intervals multiplied by the length of the time interval provides the stopped delay estimate.
(3) Dividing this delay estimate by the number of vehicles departing the approach provides an estimate of stopped delay per vehicle.

4. ESTIMATION OF DELAY MODEL BY REGRESSION ANALYSIS

The delay model for signalized and unsignalized intersections are estimated for each type of intersection. In addition, the delay models are tested to determine whether or not they are statistically significant. The Statistical Analysis Software(SAS) Package was used to estimate the models. The multiple linear stepwise regression technique in SAS was used.

In this paper, "x" denotes major street volume(in both direction) and "y" denotes minor street volume. Both are independent variables. Combinations of "x" and "y" , such as "xy", "y/x", "1/xy" etc., were used to select the variables. By this procedure the average stopped delay models were established. The variable "D" denotes the average stopped delay. The delay model represents a form of exponential function with two independent variables : major and minor street volume.

The T intersection consists of three approaches. We plotted the data into 3-dimendions in order to identify the relationship between major street volume(x); minor street volume(y) and average stopped delay(D).

4.1 Delay Models

The delay model estimated by regression analysis for each types of intersection has an exponential function form. Table 7 shows the delay models for each type of intersection. As an example, we explain the fitness of the model for just 1*1 unsignalized intersection. An R-square value of 0.92 indicates that the estimated delay is well suited to observed data. Among the combination of variables, "x" and "xy" were selected. The estimated parameter for "x" and "xy" are 0.001909 and 0.000004591 respectively. The t-statistics for each independent variable which indicate whether we can reject the null hypothesis H0:β =0 are both significant at 14.131 and 7.352. Therefore the null hypothesis that "x" and "xy" are not related to the delay can be rejected with a 0.01 significant level.

Table 7. Delay Models

Intersections		Delay model
1*1	Signal	Dsig=exp(0.602545+0.000664x+0.000001931xy)
	Unsignal	Dnosig=exp(-1.584378+0.001909x+0.000004591xy)
2*1	Signal	Dsig=exp(0.758125+0.00078x+0.000001676xy)
	Unsignal	Dnosig=exp(-1.291426+0.001391x+0.000004631xy)
2*2	Signal	Dsig=exp(0.674241+0.001191x+0.000001301xy)
	Unsignal	Dnosig=exp(-2.150302+0.002016x+0.000004468xy)

※The range of x and y is presented in Table 6.

Table 8. Statistics for Each Delay Model

Signalized intersection				
Intersection		1*1	2*1	2*2
F-value		78.629	205.883	89.995
Prob>F		0.0001	0.0001	0.0001
t-value (prob>T)	Constant	5.848(0.0001)	7.453(0.0001)	2.669(0.0102)
	X	4.850(0.0001)	5.733(0.0001)	5.373(0.0001)
	Xy	4.443(0.0001)	6.128(0.0001)	7.631(0.0001)
R-square		0.7409	0.8821	0.7826
Adj. R-square		0.7315	0.8779	0.7739
Unsignalized intersection				
Intersection		1*1	2*1	2*2
F-value		319.913	265.068	505.748
Prob>F		0.0001	0.0001	0.0001
t-value (prob>T)	Constant	-14.960(0.0001)	-6.210(0.0001)	-19.810(0.0001)
	X	14.131(0.0001)	8.224(0.0001)	12.650(0.0001)
	Xy	7.352(0.0001)	21.153(0.0001)	8.566(0.0001)
R-square		0.9208	0.9023	0.9529
Adj. R-square		0.9180	0.8988	0.9510

Figure 1 shows residual analysis for each estimated model.

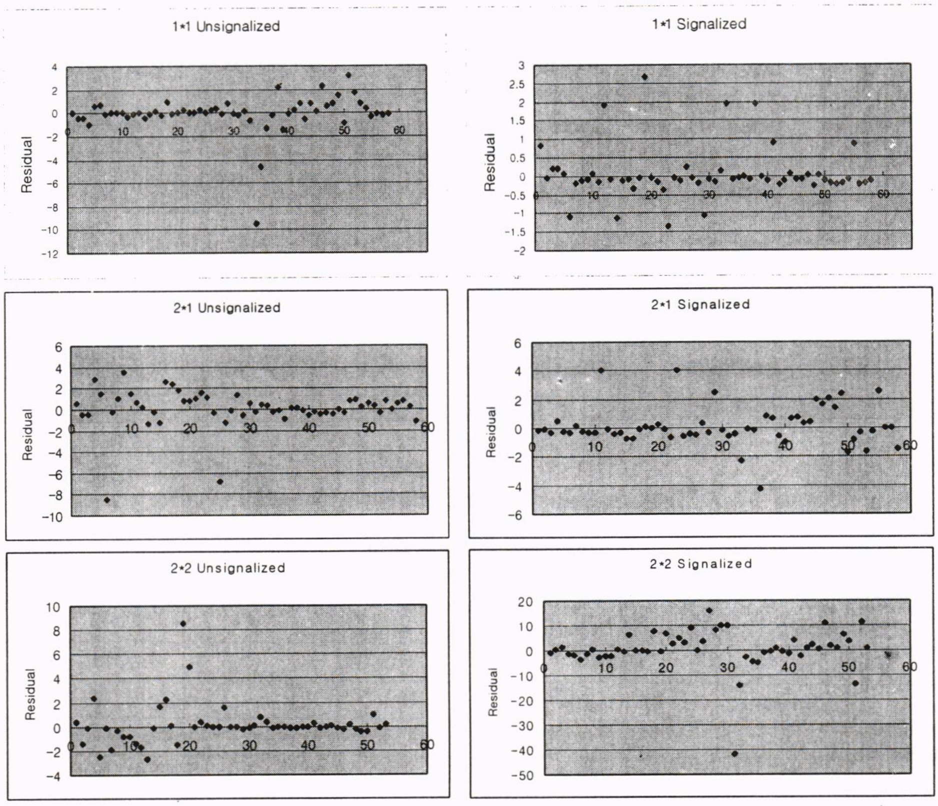


Figure 1. Residual Analysis for Estimated Delay Models

4.2 Statistical Examination of the Delay Model

To examine the delay model's fitness, following steps were taken.

(Step 1)
We checked whether the regression lines are reasonably fitted for real data or not. For this check, with the 0.05 significant level, when the value of Prob>F is 0.05 or less we can reject the null hypothesis that there is no regression relation.

(Step 2)
We examined whether the signs of independent variables are rational or not. The parameters for independent variables should have a positive sign because delay increases with traffic volume.

(Step 3)
We examined whether the independent variables selected for delay model are significant or not by finding the t-statistics as in (Step1).

In (Step1), the values of (Prob>F) of the estimated models is 0.0001, therefore, we can reject the null hypothesis with the 0.05 significant level and say there is significant relation in the delay models. Because all signs of independent variables are positive, the variables are reasonable according to (Step2). Finally, the constant for 2*2 signalized intersection has only 0.012 and other constants parameters is 0.001. Therefore we can reject the null hypothesis(H0:β =0) with 0.05 significant level. As a result of our examination, we found all independent variables in delay models to be statistically significant According to this examination, the established delay model in this research can be regarded as a reasonable model representing the characteristics of field data.

5. PROPOSED SIGNAL WARRANTS

Figure 2 shows the 3-D figures representing the relationship between traffic volumes and delay for signalized and unsignalized intersections. The figure compares the delays of a signalized intersection with that of an unsignalized intersection. If the delay of an unsignalized intersection is higher than that of signalized intersection, signal control should be used at unsignalized intersections. Therefore, we compare the delay between signalized and unsignalized intersections by using the delay model estimated in this research. If we draw the two delay models for each type of signalized and unsignalized intersection in the same space as shown in Figure 2, two curved surfaces representing delay models intersect each other. In the upper area of this line, the delay for unsignalized intersection is higher than that of signalized intersection. This line is the signal warrant line.

The curve formula consists of two variables. The first variable(x) is the major street volume in both directions, and the second variable(y) is the minor street volume. From this formula we can find major and minor street volumes which have the same delay. These traffic volumes on each street are peak hour volume signal warrant to minimize delay.

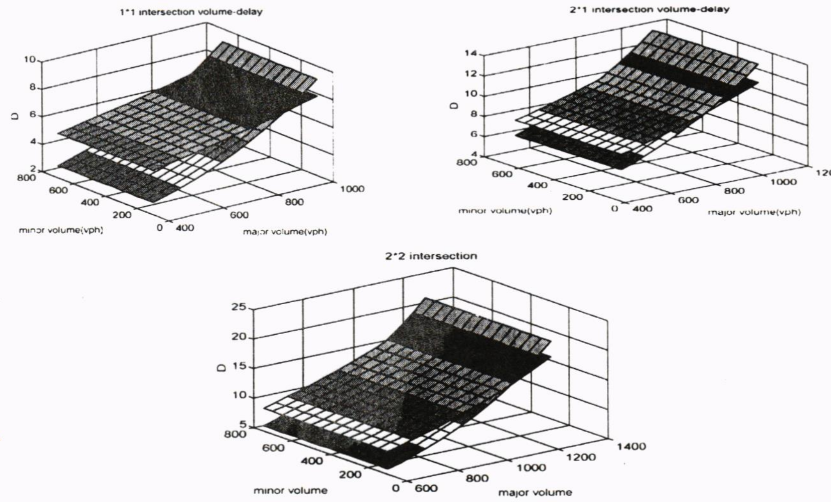


Figure 2. Comparisons of Delay Models for Signalized and Unsignalized Intersections

In Table 7, we summarized the delay models for each type of intersections. For each intersection if we equate Dsig with Dnosig, we can find the signal warrant line as a function of "x" and "y" .The equations for the lines are summarized in Table 9.

Table 9. Formula of Signal Warrant Line

1*1	x=2.18693/(0.001245+0.00000266y)
2*1	x=2.049551/(0.000611+0.000002955y)
2*2	x=2.824543/(0.000825+0.000003167y)

Figure 3 is a plot of these curves. With this figure we can identify the area where signal control is more appropriate for minimizing delay.

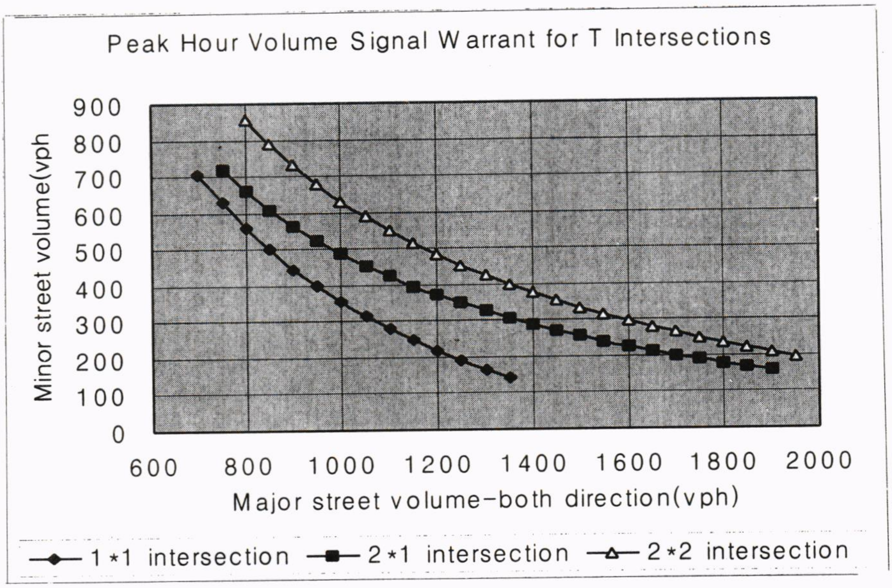
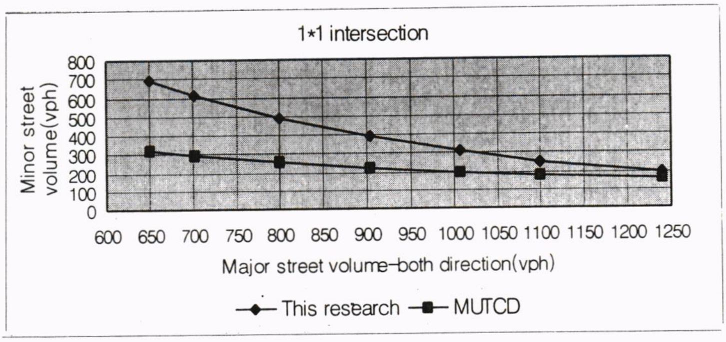


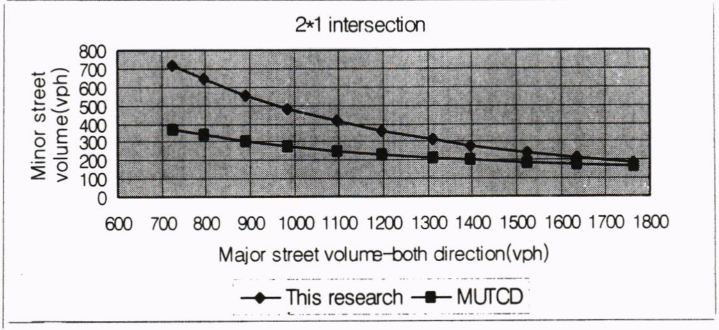
Figure 3. Peak Hour Volume Signal Warrant for T Intersections

When the plotted point representing the major and minor street volumes for peak hour of an average day is above the warrant line, signal control at T intersection is more efficient than no signal control with regard to the minimization of delay.

6. COMPARISON BETWEEN THE PROPOSED WARRANT AND MUTCD'S WARRANT

Our findings are compared with 4-leg intersection warrants in US MUTCD since MUTCD does not have separate warrants for T intersections. The warrants proposed in this study are higher compared with the MUTCD's threshold volumes. The main reason for this can be summarized as follows:
The number of phases for a T intersection is less than that of a 4-leg intersection.
Drivers generally don't obey the "STOP" signs as they try to clear the intersection slowly without stopping.





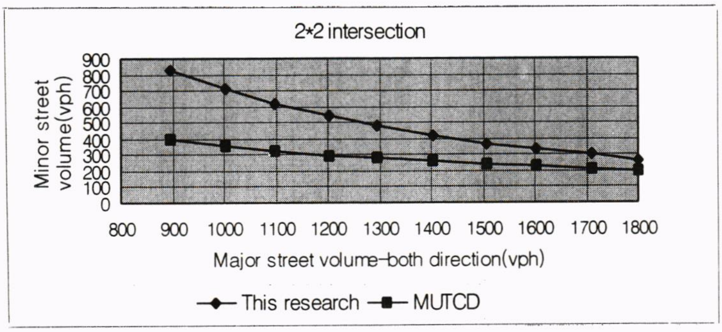


Figure 4. Comparisons between Proposed warrant and MUTCD's

7. CONCLUSION AND RECOMMEDATIONS

Existing signal warrants do not consider the type of intersection configuration. In this research, a separate signal warrant for T intersections was proposed to control the intersection efficiently.

7.1 Conclusion

The purpose of this study is to develop a peak hour volume signal warrant for T intersections based on delay data observed at signalized and unsignalized T intersections. The minimization of average stopped delay at intersection is used as a measure of effectiveness for signalization. The major findings are as follows;

(1) The delay model at T intersection represents an exponential function form of consisting of two independent variables of major and minor street volumes. The basic form of the delay model is $D=\exp(a+bx+cxy)$, where D= average stopped delay, x= major street volume and y =minor street volume.
(2) The signal warrant volumes for T intersections obtained from this study are higher than those in the US MUTCD because of phase reduction at T intersections.
(3) When the plotted point representing the peak hour volume on the major street(the total of both approach) and minor street approach on an average day is above the warrant line suggested in this study, the peak hour volume signal warrant for T intersections is satisfied. The basic form of the warrant line is $x=\alpha/(\beta+\gamma y)$, where x= major street volume and y= minor street volume.

7.2 Recommendations

(1) To control intersections efficiently, a separate signal warrant should be used for each type of intersection(┼ or ┬ type).
(2) We recommend that the results presented be accepted as a reference when signal warrants are updated.
(3) A study of signal warrants besides the peak hour volume warrant implemented in this research should be carried out for type T intersections.

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