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□論 文□

Determination of Intersection Level of Service Based on Intersection Delay Measures

交叉路遲滯測定値에 의한 交叉路 서비스水準決定에 관한 研究

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要 約

1965年에 출판된 高速道路容量敎範(Highway Capacity Manual)은 高速道路, 都市 및 地方道路의 容量과 서비스水準을 판단하는데 기본서 역할을 해왔다. 都市內 신호등이 있는 交叉路의 서비스水準은 負荷率(load factor) 개념을 이용하여 算定해 왔다. 그러나 푸른 신호주기동안 車輛의 交叉路利用度를 기준으로 하는 負荷率 개념은 서비스 水準의 測定値로서 한계가 있고 또 그동안 信號體系가 많이 改善되었고 運轉者의 通行行態가 크게 變化하여 1970年代 중반부터 限界通行分析法(Critical Movement Analysis)과 車輛의 交叉路遲滯時間 測定法(Intersection Delay)등과 같은 새로운 技法이 소개되었다.

本 論文은 최근에 많이 이용되고 있는 交叉路遲滯時間測定法의 有用性을 검증하기 위해 15個 交叉路의 車輛通行量을 기준으로 하여 V/C 比를 계산하는 限界通行分析法에 의한 測定値와 比較, 分析하였다. 그 결과 交叉路의 서비스水準을 測定하는데 兩者의 方法에 의한 測定値가 크게 다르지 않음을 발견하였다. 즉 都市內 신호등이 있는 交叉路施設을 改善하기 위해 대략적인 交叉路 서비스水準을 測定할 경우 調査人員 및 費用이 많이 所要되는 限界通行分析法보다 調査가 간편하고 費用이 적게 드는 交叉路遲滯時間測定法이 有用함을 밝혔다.

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I. Introduction

Looking at the development of capacity analysis, the 1965 Highway Capacity Manual (HCM) was the principal document used during the 1960's and 1970's for capacity and level of service both in the United States and other countries. The 1965 HCM was based on the concept that the amount of vehicular traffic through an intersection was a function of; 1) various physical and operating characteristics of the roadways, 2) environmental conditions which have a bearing on the experience and actions of the driver, 3) characteristics of the traffic stream, and 4) traffic control measures.[1] The level of service concept was introduced and used as a means for estimating the physical capacity as well as the operational aspect of an intersection approach.

The 1965 HCM was based primarily on data from pretimed signal systems which were in widespread use during the 1950's. Little information was available on the effects of signal coordination, actuated and multiphase signal systems used extensively on intersections since the mid-1960's. Beginning the 1970's, due to changes in technology and concept of traffic flow, transportation engineers and planners embarked on a program to update the 1965 HCM to adopt the new factors and problems confronting today's traffic analyst.

The purpose of this paper is 1) to review newly proposed measures of effectiveness for signalized intersection analysis such as approach delay, stopped delay and percent of vehicles stopping, 2) to provide concept and application of capacity and level of service, which are of importance for the determination of intersection adequacy, and 3) to evaluate the usefulness of intersection delay measures using empricial data obtained from the Seattle metropolitan area in the United States.

II. Relationship of Level of Service and Delay

Level of service is a qualitative measure that incorporates the collective factors of speed, travel time, traffic interruptions, safety, and driving comfort under a particular volume condition. Level of service is described by a letter scale from A to F. "A" represents the highest quality of service a transportation facility can provide and "F" represents the lowest quality of service. Historically, roadways and intersections have been designed to provide level of service C for their projected travel demand. Level of service D has been considered undesirable. In recent years, because of increased pressure to improve the efficiency of the transportation system, the design level of service has been reduced to D and the undesirable level considered to be E.

The 1965 HCM has been specified for intersection performance in terms of the load factor which is defined as the ratio of the number of green phases that are loaded or fully utilized by traffic to the total number of green phases available for that approach during the same period.[2] However, due to a lack of accuracy in the load factor, alternative measures such as delay, percent of vehicles stopping, and the ratio of volume-to-capacity (V/C) were suggested and developed to determine the intersection level of service in the recently proposed capacity manual.

Of major concern in evaluating intersection capacity and level of service is the proper measure to describe the traffic performance at intersections. Criteria used in free-flowing traffic situations such as speed, density, and volume are not directly applicable and thus surrogate measures must be used. One of these measures is the intersection delay. Although some form of intersection delay would probably be the most satisfactory measure, its calculation under field conditions is not easy, and since it is defined in various ways, from time to time it is misinterpreted. A Federal Highway Administration report (FHWA-RD-76)[3] has been directed at this problem and has evaluated the several delay determination methods. This report discussed characteristics of vehicle delay at intersections and suggested three delay measures: stopped delay, approach delay, and percent of vehicles stopping.

Stopped delay is the most practical method for field use. Basically, it involves recording at specific intervals the number of fully stopped vehicles on an approach. The total stopped time, that is, interval between samples times sum of observed point sample values, needs to be adjusted by the factor 0.92 to represent actual stopped delay more accurately.

Approach delay is the best single measure of overall intersection performance. However, it must be derived indirectly from the stopped delay determined by the field survey. Approach delay can be estimated by multiplying the stopped delay by the factor 1.3. In the United Kingdom, this approach delay is known as the average delay on approach, which can be computed by Webster's equation. The basic Webster's equation is as follows:

$$d = \frac{C(1-\lambda)^2}{2(1-\lambda X)} + \frac{X^2}{2q(1-X)} - 0.65\left(\frac{C}{q^2}\right)^{1/3} X^{(2+5\lambda)} \qquad (1)$$

where

d = average delay per vehicle on approach
c = cycle length
λ = proportion of cycle that is effective green time
q = approach flow
s = saturation flow
x = degree of saturation, i.e., q/s

An approximation to equation (1) is usually used in practice as follows:

$$d = \frac{9}{10}\left[\frac{C(1-\lambda)^2}{2(1-\lambda X)} + \frac{X^2}{2q(1-X)}\right] \qquad (2)$$

To use this equation, flow rates for the approah, saturation flow rate, and effective green time must either be obtained from field observations or be estimated.

Percent of vehicles stopping is a third intersection performance measure. This measure is defined as a proportion of vehicles stopping to all vehicles passing through the intersection approach. Like the stopped delay and approach delay, percent of vehicles stopping is a useful measure to evaluate the intersection capacity and level of service. This measure can be used for estimating fuel consumption and pollutant emissions at an intersection.[4]

Table 1 shows general relationships between level of service and a set of interesection performance measures such as delay range, volume-to-capacity ratio, and percent of vehicles stopping. These relationships are based on a 1974 OECD report,[5] a 1976 FHWA research project[6] on delay characteristics at traffic signals and on data collected in the NCHRP 3-28 research project.[7]

Table 1. Level of Service and Intersection delay

Level of Service	Delay Range (sec/vehicle)			Typical V/C Ratio			Percent Stopping
	FHWA	NCHRP	OECD	FHWA	NCHRP	OECD	NCHRP
A	0.0-16.0	0.0-10.0	0.0-30.0	0.0-0.60	0.0-0.45	0.0-0.70	≤50
B	16.1-22.0	10.1-20.0		0.61-0.70	0.46-0.60	0.71-0.80	51-67
C	22.1-28.0	20.1-30.0		0.71-0.80	0.61-0.75	0.81-0.90	68-76
D	28.1-35.0	30.1-40.0	30.1-360.0	0.81-0.90	0.76-0.90	0.91-0.95	77-83
E	35.1-40.0	40.1-60.0		0.91-1.00	0.91-1.00	0.96-1.00	84-93
F	≥40.1	≥60.1	≥360.1	>1.00	>1.00	>1.00	94-100

As shown in the table, the level of service can be determined using the delay value which is measured as stopped delay per vehicle entering the interesection. The levels of service represent different ranges of delay per vehicle. For example, based on the NCHRP delay range, at the lower end of level of service E (60.0 seconds delay per vehicle), the flow into the intersection reaches a maximum or intersection capacity and any additional flow can begin to cause level of service F. In terms of V/C ratio, level of service E ranges from 0.91 to 1.0 which is widely used in the United States, although European countries use narrower ranges of V/C ratios (0.96-1.0).

In fact, the ranges of V/C ratios for a given level of service are difficult to establish because each set of field data may provide a different relationship depending on the signal type and coordination aspects. The measure of percent of vehicles stopping also can show variations depending on the type of intersection to be observed. Although the ranges of delay, V/C ratio, and percent of vehicles stopping are dependent on various factors affecting intersection traffic volume, the relationships indicated in the table can be used as a guideline to determine the intersection level of service in a general manner. In this paper, the ranges used in the NCHRP 3-28 report are used to identify the levels of service of selected intersections in the Seattle metropolitan area through field observations.

III. Data Collection and Analysis

There are three methods for measuring intersection delay:[8] point sample, path trace, and modeling. In this paper, the point sample method was applied due to its simplicity and economy. The point sample method is based on a periodic sample of some factor such as number of stopped vehicles on the intersection approach. In essence, it is a series of instantaneous samples having an interval of time between each sample.

Using the point sample method, a total of 15 intersections in the Seattle metropolitan area were observed. The intersection delay survey was mainly conducted in September 1983. The time period selected in this survey ranges from 3:30 PM to 6:30 PM depending on the location of the intersection. The length of the survey period was selected from a 30-minute to 40-minute period during the peak hour. Since most of intersection signals in the study area belong to semi-or full-actuated signal system, a 15-second interval between samples was used.

Based on the method and procedure mentioned above, levels of service for the 15 intersections were determined in terms of stopped delay and percent of vehicles stopping. These results were compared to the intersection levels of service determined through the use of the CAPCALC computer program which was developed by Roger Creighton Associates Incorporated in 1982. The CAPCALC program performs a level of service analysis for signalized and unsignalized intersections using the same procedures documented in Transportation Research Circular 212[9] to calculate congestion levels at intersections. Traffic volumes for each of the intersections were adjusted to reflect actual conditions observed during field observations.

Table 2 is a summary of each intersection's level of service calculated by three different measures. Since the CAPCALC levels of service were expressed as V/C ratios, the numerical values computed from the stopped delay and percent of vehicles stopping measures were converted to the V/C ratio using a scaling range suggested by NCHRP 3-28. If, for example, an intersection's stopped delay is 30 seconds per vehicle, then the level of service is C and the corresponding V/C ratio is 0.75 (see Table 1). Likewise, percent of vehicles stopping of an intersection was also converted to V/C ratio. The main reason for the conversion is that it facilitates a statistical comparison between the results obtained from CAPCALC, stopped delay, and percent of vehicles stopping.

As can be seen in Table 2, levels of service by stopped delay are highly correlated to those determined by the CAPCALC computer program. That is, among the 15 intersections, eight of them show identical levels of service and five of them differ by only one category. Only two intersections, located in Newcastle and in Federal Way, show quite different levels of service. A detailed examination indicates that this difference is due to each intersection's unique location and poor observation view. The differences in intersection numbers 1 and 2 were partially due to the observation of only one leg rather than two, as was the case with all other intersections. The observation of intersection number 6 was complicated by the length of backup on the major route and the difficulty in counting cars which were actually stopped or those that were out of view. Intersection number 8 involved selection of a poor site. Three signals affected this site and it was impossible to identify a location where an accurate field observation could be made.

Table 2. Levels of Service of Selected Intersections

Community Plan Area	Intersection Number	CAPCALC Level of Service	CAPCALC V/C	Stopped Delay Sec/Veh	Stopped Delay Level of Service	Stopped Delay Assumed V/C	Percent Stopping Percent	Percent Stopping Level of Service	Percent Stopping Assumed V/C
Shoreline	1	F	1.13	40	E	0.90	79	D	0.81
	2	C	0.76	11	B	0.47	51	B	0.46
Soos Creek	3	E	0.99	51	E	0.96	78	D	0.78
	4	E	0.99	59	E	0.99	94	E	1.00
Northshore	5	D	0.84	32	D	0.79	67	B	0.60
	6	D	0.87	7	A	0.61	46	A	0.44
Newcastle	7	A	0.54	9	A	0.45	43	A	0.44
	8	D	0.78	7	A	0.44	31	A	0.44
Highline	9	E	0.93	47	E	0.94	73	C	0.70
	10	F	1.06	47	E	0.94	72	C	0.68
Federal Way	11	C	0.76	40	D	0.90	73	C	0.70
	12	E	0.94	20	C	0.60	55	B	0.50
	13	F	1.06	64	F	1.06	73	C	0.71
	14	E	0.93	43	E	0.93	80	D	0.84
Soos Creak	15	E	0.98	54	E	0.97	67	B	0.60

On the other hand, levels of service computed by the percent of vehicles stopping measure show relatively poor correlation with the CAPCALC results. Only three intersections indicate identical levels of service and another three intersections differ by one category. The remainder shows marked difference in terms of level of service. The reason for this is not clear, but one inference is that since vehicles stopping did not include slowdowns or number of speed changes, it may underestimate congestion levels. Interestingly, the relationship between stopped delay and percent of vehicles stopping shows some consistency, although six intersections differ by two or more categories. This result is in general agreement with the relations developed empirically from the FHWA report.[10]

Using the data shown on Table 2, it is possible to test the hypothesis that the CAPCALC levels of service at given intersections are not significantly different from those of the stopped delay measure at the same intersections. In order to the hypothesis, the Wilcoxon test which is one of "distribution-free" or nonparameteric techniques was used. The main reasons for the use of the Wilcoxon test are: 1) the sample size used here is not large enough to use parametric tests, i.e., in this study, only 15 cases were available, 2) the data are not normally distributed, i.e., the distribution in this case is skew to left side, and 3) the test is available to treat data which are inherently in ranks as well as data whose numerical scores have the strength of ranks.

The results of the test can be seen in Table 3. The table shows that there is not a significant difference at $\alpha=0.05$ between the stopped delay measure and the V/C ratio measure computed from the CAPCALC program. That is, the decision would to be accept the hypothesis that the two measures are not significantly different to determine the intersection level of service. Therefore, the stopped delay measure can be used as a surrogate measure for the V/C ratio in order to identify the congestion levels at signalized intersections.

Table 3. The Wilcoxon Test Results

	the number of pairs	the computed Wilcoxon test score	results
Level of service*	7	3	not significant at α=0.05
V/C ratio	10	8.5	not significant at α=0.05

* Each intersection level of service determined by both CAPCALC and stopped delay was ranked as following manner: A=1, B=2, C=3, D=4, E=5, F=6.

IV. Conclusion

This paper attempted to describe the intersection traffic delay measures such as stopped delay, approach delay and percent of vehicles stopping, and to evaluate the usefulness of these measures as a means of indentifying congestion level at signalized intersections. To this end, a total of 15 intersections in the Seattle metropolitan area were observed and analyzed in terms of their stopped delay, percent of vehicles stopping and V/C ratio.

The result indicates that the levels of service measured by stopped delay are highly correlated to those computed by the V/C ratio concept. In order to confirm this result, the hypothesis test using the Wilcoxon test was conducted. The hypothesis was that there would be no significant difference between the stopped delay and the V/C ratio measure. The test accepted the hypothesis that the two measures would not be significantly different to determine the intersection level of service. This means that the stopped delay measure can be used as a surrogate measure for the V/C ratio to identify the intersection congestion level.

In general, the intersection study requires much time and money to calculate intersection capacity and level of service in determination of intersection facilities improvement. The V/C ratio measure based on the Critical Movement Analysis[11)] needs various sophisticated data such as lane geometry, traffic volumes, signal phasing, bus stop operations, parking activity, and turning movement at all intersection approaches. However, the stopped delay measure needs relatively simple data requirements in comparison to the V/C ratio measure. Therefore, the stopped delay measure would be a useful indicator to identify level of service at urban signalized intersection.

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