User Perception of Level of Service at Signalized Intersections: Methodological Issues

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ABSTRACT

This paper addresses methodological issues faced in the development of a study to assess two issues related to user perception of level of service (LOS) at signalized intersections: (1) the appropriateness of the current *Highway Capacity Manual* levels of service for signalized intersections in terms of users' time-estimating capabilities and LOS perceptions; and (2) the factors affecting users' LOS perceptions at signalized intersections. The paper presents a conceptual model of perceived LOS and describes how this model was used to identify data needs and to develop the experimental design and procedure. The purpose of this paper is not to present and discuss results of the research, but to lay the groundwork for the results to come. By doing this, the authors hope to instill confidence in the research methods so that the subsequent results and recommendations will be credible. Further, the authors make methodological recommendations for future driver-perception studies of level of service at signalized intersections.

1. INTRODUCTION

With increasing congestion and delays on our nation's streets and highways, finding effective ways to maintain acceptable levels of service is critical to satisfying users as well as protecting the environment. To help meet these needs, traffic engineers use the *Highway Capacity Manual* (HCM 1997) to monitor traffic conditions and make transportation improvement decisions. The HCM defines level of service (LOS) as "a qualitative measure describing operational conditions within a traffic stream and their perception by motorists and/or passengers."

This paper addresses methodological issues faced in the development of a study to assess users' perceptions of LOS at signalized intersections. First, the research issues, problem statement, and study objectives are briefly presented. Then, the paper reports on the state-of-the art used to develop a conceptual model of perceived LOS, discusses the data needs to meet the study objectives, and summarizes the development of the experimental design and procedure. Finally, this paper concludes with the lessons learned and recommendations for further research.

1.1 Research Issues and Problem Statement

This research effort addresses two issues related to user perception of LOS at signalized intersections: (1) the appropriateness of the current HCM levels of service for signalized intersections in terms of drivers' time-estimating capabilities and LOS perceptions; and (2) the factors affecting users' LOS perceptions at signalized intersections. The problem statements associated with these issues are as follows:

1. Although the concept of LOS is meant in part to reflect the operational conditions as perceived by motorists, the HCM levels of service for signalized intersections were not based on studies of driver perceptions.

2. Although the HCM specifies control delay as the measure of effectiveness for signalized-intersection level of service analysis, it is unlikely that delay is the only factor that influences user perception of service quality.

1.2 Study Objectives

The objectives of the research effort are as follows:

- Examine individual vehicle delay distributions at several signalized intersections (i.e., What is the probability of experiencing different delays or no delay at all?).
- Examine the accuracy with which users estimate delay at signalized intersections (i.e., Do drivers underestimate or overestimate delay?).
- Determine if the current LOS delay intervals are appropriate in terms of users' perceptions (i.e., How many different levels are perceived, and what are the LOS thresholds?).
- Determine if there are other factors that affect delay estimation and perception of service quality at signalized intersections.

The point of this paper is not to present and discuss specific research results, but to lay the groundwork for the results to come. By doing this, the authors hope to instill confidence in the research results so that the subsequent results and recommendations will be credible. Further, the authors make methodological recommendations for future driver-perception studies of level of service.

2. BACKGROUND

2.1 LOS Criteria for Signalized Intersections

The *Highway Capacity Manual* (HCM 1997) defines LOS as "a qualitative measure describing operational conditions within a traffic stream and their perception by motorists and/or passengers." LOS for signalized intersections is defined in terms of average control delay (Table 1). The HCM states that delay is a measure of driver discomfort, frustration, fuel consumption, and lost travel time, and that "the levels of service were established on the basis of the acceptability of various amounts of delay to drivers" (HCM 1997). However, the criteria shown in Table 1 were not based on studies of users' perceptions of

TABLE 1 HCM Delay LOS Criteria for Signalized Intersections

LOS	Average Control Delay (sec/veh)
A	10
B	> 10 and 20
C	> 20 and 35
D	> 35 and 55
E	> 55 and 80
F	> 80

acceptable delay. The LOS criteria were primarily based on field-observed delays from 336 intersection approaches [NCHRP Project 3-28(2)]. A large majority of the observed delays were in the LOS C to LOS D range, while only about 10 percent were in the LOS E range, and only 5 percent were in the LOS F range. Considering the threshold separating "acceptable" from "unacceptable" conditions, a value of 60 seconds per vehicle was chosen, as it was the maximum value "tolerated" in a survey of traffic engineers.

There are several problems associated with the development of the HCM delay-LOS thresholds. First, the criteria were created from observed field delays. Thus, each LOS represents different delay conditions, but not necessarily the delay that motorists perceived. In addition, the 60-second threshold between acceptable and unacceptable was chosen as a result of a survey of traffic engineers, not motorists or passengers. Additionally, if levels of service were based on field-observed delay, it would be necessary to continuously adjust the delay thresholds to reflect the increasing delays experienced over the years. However, the HCM uses the same delay thresholds that were established 15 years ago.

Cameron (1996) and Baumgaertner (1996) recently proposed extending the LOS criteria from A to J and A to I, respectively. Cameron stated that it was not uncommon to wait three minutes at a congested urban intersection with average delays often exceeding two minutes. Baumgaertner (1996) pointed out that the continuous growth of urban populations, vehicle ownership, average trip length, and number of trips have resulted in a significant increase in traffic volumes. Thus, travel conditions that would have been viewed as intolerable in the 1960s are considered normal by today's motorists, especially commuters. Although these proposed LOS extensions are appreciated in lieu of the research discussed herein, neither proposed studies of motorists' perceptions for the LOS extensions.

One study in 1977 examined user perception of LOS at signalized intersections. Sutaria and Haynes (1977) developed delay intervals based on drivers' LOS perceptions and a delay study of one intersection. Their results, however, were not referenced in the 1985 HCM, where average delay was first introduced as the measure of effectiveness for LOS at signalized intersections.

2.2 Time Perception and Estimation

Considering the human-factors aspects of defining LOS, psychological studies of time perception and estimation may help explain users' perceptions of and reactions to the delay they experience at signalized intersections.

Although the terms "perception" and "estimation" of duration are used interchangeably in the literature, they refer to two separate processes. The difference relates to the fact that there are no specific sensory receptors in our perceptual system that are devoted to the perception of time (Zakay 1989). Fraisse (1984) probably best distinguishes between the two processes, describing three orders of duration on the physical continuum: (1) less than 100 milliseconds, at which perception is of instantaneity; (2) 100 milliseconds to 5 seconds, perception of duration in the psychological present; and (3) above 5 seconds, estimation of duration involving memory. Beyond the limits of the psychological present, duration can only be estimated by the construct which brings to bear short- and long-term memory. "Estimation of duration takes place when memory is used either to associate a moment in the past with a moment in the present or to link two past events" (Fraisse 1984).

Hornik (1993) describes time estimation as the transformation of stimulus time to judgmental time, "the subject's response is a simple chronometric transformation of perceived duration." Time estimation is commonly measured by presenting subjects with an event or activity and asking them to give a verbal estimate of its duration in clock time.

The literature contains conflicting results on factors that influence the estimation of duration. Factors that have been thought to influence duration estimation include: the estimation paradigm and environmental, personal, and situational characteristics.

2.2.1 Estimation paradigm

Prospective time estimation is when respondents know in advance that they will be requested to estimate time. In this case they tend to assess time through a "time processor." Attention is directed in real time to information that is related to the passage of time (i.e., temporal information). A positive relation is expected between attention given to the passage of time and time estimates (i.e., as temporal information processing increased, time estimates incease). The more attention that is given to time, the more time units are recorded, and the longer the subjective duration (Zakay et al. 1996).

Retrospective time estimation is when respondents are instructed to assess the duration of an event after the event ended. Retrospective time estimates are based on memory-related processes and require the recovery of temporal information (Zakay et al. 1996). In this case, time estimates tend to decrease with increasing temporal information processing. The difference between the prospective time-estimation paradigm and the retrospective time-estimation paradigm is illustrated in Figure 1.

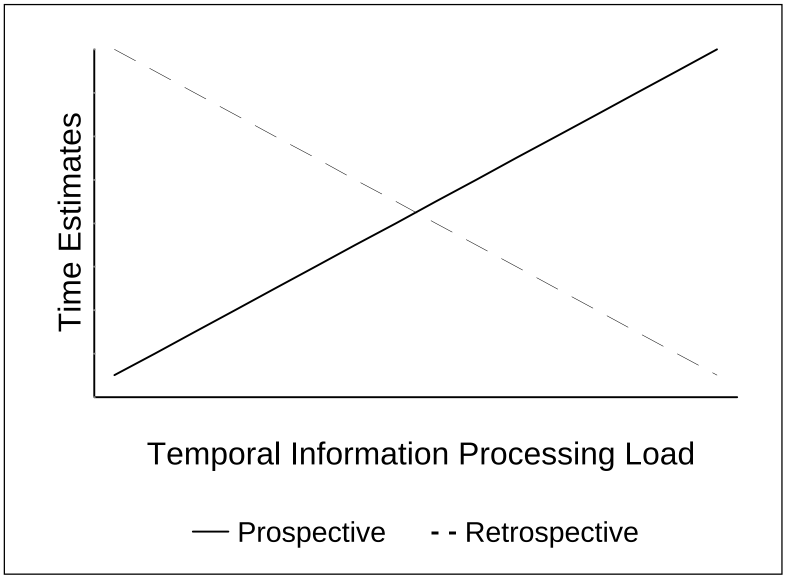

FIGURE 1 Difference between retrospective and prospective estimation paradigms.

Meyer et al. (1996) state that regarding the prospective versus retrospective paradigm of time estimation, it is not clear which one corresponds to real-life situations where people wait for the termination of a process (like waiting at traffic signals). People may take a prospective stance at the beginning of the delay (i.e., How long will it take?), or they may take a retrospective stance at the end of the delay (e.g., How long did that take?). It may be appropriate to consider both the information and memory processors.

2.2.2 Environmental and personal characteristics

The pace of life is the flow or movement of time that people experience and is a matter of tempo. The economics of an area is the number one determinant of tempo. Tempo is also influenced by degree of industrialization, population, climate, and cultural values (Levine 1997). Although tempo of life differs among cultures, there are also vast differences in tempo between individuals within the same culture. Most of the attention to individual differences in tempo has centered on the concept of time urgency, the struggle to achieve as much as possible in the shortest period of time.

Hancock et al. (1992) examined the effects of gender and body temperature on time perception. The results showed clear and impressive differences in duration estimation depending upon subject gender. The findings agreed with a simple chemical clock postulate that the higher body temperature in female subjects would be accompanied by shorter time estimates.

2.2.3 Situational characteristics

Levine (1997) reports that there are at least five major factors that influence the experience of duration. People tend to experience time passing more quickly when they are busy, when they experience variety, when events are pleasant and carry little sense of urgency, and during activities that engage right-hemisphere modes of thinking.

The relationship between time-of-day and duration estimation has yet to be fully resolved, and Thor (1962) was perhaps the first to test the implied relationship. Pöppel and Giedke (1970), however, may have made the most persuasive argument for a time-of-day influence on time perception. Their results revealed a systematic diurnal variation (function) in estimated duration, the shape of which was opposite for subjects who described themselves as "day active" and those who described themselves as "night active."

While the link between mood and time estimation has scarcely been examined, a few studies do suggest a relationship. Hornik and Meir concluded that the perceived duration of an activity seems shorter under positive mood conditions than under negative mood conditions (in Chebat et al. 1995). In another study by Hornik (1993), subjects' moods were manipulated using two techniques. Subjects participated in two activities and were asked to estimate the duration of the activities to the nearest minute. Results showed that the "elated" and "happy" subjects exhibited a clear tendency to underestimate the duration of the two activities, whereas the "depressed" and "sad" subjects tended to slightly overestimate the durations. It was concluded that positive mood is a powerful determinant in time estimation.

In a study based on written scenarios of waiting at traffic signals, Zakay et al. (1996) showed that participants overestimated waiting intervals of drivers who were described as being in a hurry. In most waiting situations, levels of temporal relevance and temporal urgency are high, leading to high awareness of the passage of time and to feelings of impatience. It was hypothesized that by reducing the level of temporal urgency, drivers would reduce the allocation of attention to time, thereby reducing the level of impatience associated with waiting.

They tested their hypothesis in a computer simulation using a new type of traffic signal containing an analogical "Sand Watch" (i.e., hourglass). It was assumed that the temporal cue would reduce participants' preoccupation with time. The results showed that the performance (i.e., pressing the gas *after* the light turned green) was much more accurate with the experimental traffic signals than with the traditional ones. In addition, participants reported feeling less impatient in front of the experimental traffic signals.

2.2.4 Time estimation studies

Although the mathematical theory of waiting lines has been highly researched, the experience of waiting has been relatively neglected (Meyer et al. 1996). Meyer suggests that if managers are concerned with how long their customers or clients wait in line for service, they must pay attention to not only the actual waits, but how they are perceived.

Chebat et al. (1995) conducted a study to assess the impact of mood on perceived waiting time and waiting-time satisfaction. Several mood factors were manipulated. The results showed that mood (pleasure versus non-pleasure) had a significant effect on waiting-time satisfaction, however, it had no significant effect on time estimation.

In a study of waiting times at a bank, Katz et al. (1991) conducted a study to test several hypotheses about the relationship between waiting-time estimates and perceived service quality. The results showed that customers tended to overestimate their wait by an average of about one minute, and as waiting-time estimates increased, customer satisfaction tended to decrease. Increased distractions using an electronic message/news board made the waiting experience more interesting and tended to increase customer satisfaction. Information on the expected time-in-queue increased the accuracy of waiting-time estimates but did not affect on customer satisfaction.

Bennett (1980) applied the idea of time estimation to travel time and trip distribution. He presented a probability density function, derived from empirical data, that statistically described the travel time perception differences between individuals, along with a method of incorporating the density function into the gravity model. The hypothesis was that a model that could account for differences between individuals in perception and tolerance in making travel decisions would be better able to predict actual travel behavior. The results showed that the model based on perceived travel times was closer than the gravity model in seven out of ten cases. The main conclusion drawn was that the hypothetical relationship between user-perceived time and the actual network-computed travel time does indeed exist, and when utilized in a gravity model, it seemed to enhance the model's ability to replicate the O-D trip matrix.

3. CONCEPTUAL MODEL

Figure 2 illustrates the hypothesized perceived LOS model for signalized intersections, the working model for this research. This model was conceptualized based on the state of the art and was used in conjunction with the research objectives to determine the data needs and to develop the experimental design for this research.

The hypothesized perceived LOS model assumes that delay estimates at signalized intersections are influenced by many factors: (1) situational characteristics (e.g., time-of-day, location, trip purpose); (2) personal characteristics (e.g., socio-demographics, personality); (3) value of time and time use (i.e., how individuals use their time, how valuable their time is to them); (4) temporal relevance (i.e., the level of relevance/ importance of the time dimension in a specific state); (5) temporal urgency (i.e., the struggle to achieve as much as possible in the shortest period of time; (6) actual delay; (7) signal/intersection characteristics (e.g., operational/design characteristics); (8) the estimation paradigm (prospective vs. retrospective); and (9) user experience and expectations.

Based on the acceptable delay threshold for each individual in each situation, a delay is perceived to be either acceptable (i.e., estimated delay is less than acceptable delay threshold) or unacceptable (i.e., estimated delay is greater than acceptable delay threshold). A priori, it was expected that the subjects would perceive fewer than six levels, but it was not known on how many levels they would perceive. Thus, the conceptual model simplifies this by assuming two levels (although it is likely that there would be more).

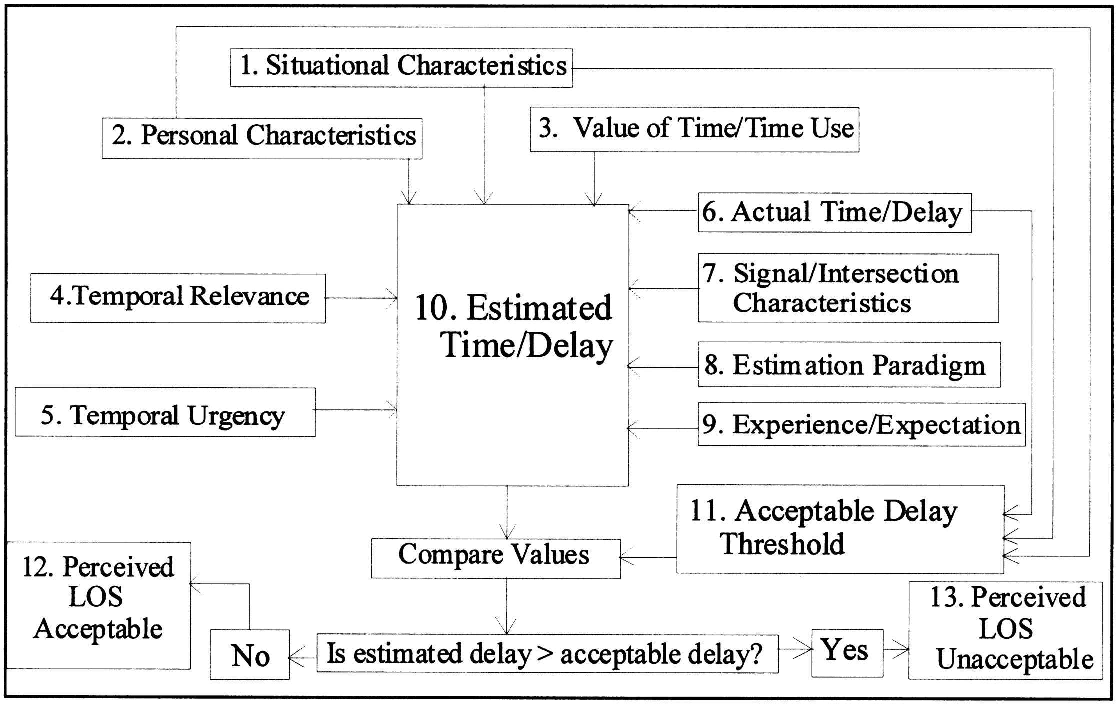

FIGURE 2 Hypothesized perceived LOS model for signalized intersections.

4. DATA ISSUES

Referring to the conceptual diagram illustrated in Figure 2, it can be seen that a considerable amount of data were needed to address the research objectives. Data issues were therefore addressed, for each research objective, by identifying data needs and determining the data-collection methods. After data needs and methods were determined, the experimental design was developed.

4.1 Determine Data Needs and Methods

Table 2 illustrates the data needs and data-collection methods identified for this research. Data needs for meeting the research objectives were identified as: individual vehicle delays, delay estimates, LOS perceptions, and detailed subject and intersection information. Several alternative methods were considered for obtaining subjects' delay estimates and LOS perceptions. These methods included: on-the-road field studies, controlled test-track studies, and controlled laboratory studies.

On-the-road field studies were considered, however two problems were identified. First, having subjects drive around the streets in a vehicle (even on a pre-determined route) would result in a lack of control over the experimental conditions (e.g., actual delay encountered). This would make it difficult to analyze the data, especially if some subjects experienced very little delay overall while others experienced many delays. Second, considering the amount of time and resources available for the study, running each subject individually in the field would result in a small sample size.

Controlled test-track studies were also discussed. The validity of these studies was questioned, however, due to the lack of in-context driving conditions. Even though the subjects would actually be behind the wheel of a vehicle, the test track environment would not afford a real roadway network, an intersection with real traffic signals, or actual cross-street traffic.

Since video studies in laboratory situations have been used in traffic perception studies and human factors experiments for at least 40 years, it was proposed that subjects be shown videos as though they were the driver. This method would allow for multiple subjects to be run simultaneously while allowing the researchers control over the experimental conditions.

With these considerations in mind, it was agreed that video laboratory studies were a good tradeoff between cost, sample size, fidelity, and other issues—the subjects would view an in-context driving situation, all subjects would experience the same conditions, and available time and monetary resources could be used efficiently to gather an adequate sample size.

TABLE 2 Data Needs and Data-Collection Methods for Each Research Objective

Research Objective	Data Needs	Data-Collection Method	Details
Examine delay distributions	Individual vehicle delays	Field study	• Range of intersection characteristics
Assess accuracy of delay estimates	Delay estimates	Laboratory/video studies	• Wide range of delays • Various intersections
Determine if current LOSs are appropriate	LOS perceptions for various delays	Laboratory/video studies	• Wide range of delays • Various intersections
Identify factors affecting perceptions	Detailed subject / intersection info	• Questionnaire • Post-lab discussions	

To obtain the information needed to determine other factors that affect the perception of service quality, a questionnaire was designed to gather detailed subject information. The questionnaire was comprised of three parts. The first part was designed to explore the subjects' attitudes about driving in certain situations. For example, people who regularly travel on different types of transportation facilities (e.g., highways versus arterial streets) may have different attitudes about waiting at traffic signals. Similarly, people may have different attitudes when traveling for various purposes (e.g., work, shopping, social). Another "situation" would be the times of the day or locations where congestion is likely to be encountered. Knowing peoples' attitudes about traffic congestion might also help explain their reactions to the delay they encounter at traffic signals.

Other questions in the first part of the questionnaire were included to determine how the subjects use their time (e.g., hours worked each week or traveled each day). One open-ended question was posed to determine the subjects' ideas regarding the maximum tolerable delay at a traffic signal.

The second part of the questionnaire was designed to explore personal characteristics of the subjects including: personalities (e.g., patient, easy-going), habits (e.g., workaholic, list maker, schedule maker), stress level, and temporal awareness and urgency (Levine 1997; Robinson and Godbey 1997). Individuals exhibiting certain personality characteristics may have different perceptions of delay than those who do not. Socio-demographic information was obtained in the third part of the questionnaire.

4.2 Develop Experimental Design

The final step was to develop the experimental design. Since situational and intersection/ signal characteristics could be incorporated into the design, it was important to determine which and how many could be the most easily and effectively used.

After careful consideration of many factors, two factors, signalization (i.e., fixed-time versus actuated control) and approach street (i.e., major versus minor street), were hypothesized to influence users' estimations of delay and perceptions of LOS. More specifically, if the intersection had actuated signalization, users should be more tolerant of delay because actuated signals respond to traffic and therefore operate more efficiently than fixed-time signals. Similarly, users should expect more delay on a minor approach than a major approach, knowing from experience that the major approach generally receives a larger portion of the cycle length in green time.

Although a variety of other factors were considered for use in the experimental design (e.g., time of day, turning movement, size of urbanized area), they were eliminated due to the increased complexity of the design and the desire to keep the experimental conditions to a minimum so that all subjects could experience all conditions. For example, time-of-day was initially considered but was eliminated because it would have been difficult to invoke in the subjects a feeling of difference between time of day while sitting in the laboratory. (Note: situational factors such as being in a hurry and mood were also considered, but eliminated for the same reasons).

Although there was an interest in the difference between the LOS perception of users making through and left-turn movements, only through movements were considered in the study to keep the number of experimental conditions controllable. Similarly, using intersection delays from a large city was also initially considered for this research. However, to simplify the experimental design, only local conditions were considered (to coincide with the participating subjects who were all local residents).

Finally, in an attempt to control for users' experiences and expectations, intersections were chosen in cities outside of, but not far from, the local area in order to reduce the likelihood that subjects would recognize the intersection. Therefore, the ratings would be based on what was seen in the videos alone, not confounded by experiences at the actual sites.

5. EXPERIMENTAL PROCEDURE

Prior to the laboratory experiments, it was not explained to the subjects that the HCM specifies average delay as the measure of effectiveness for LOS analysis at signalized intersections. Subjects were told only that the study was about the perception of traffic signals.

At the beginning of each experiment, subjects were given a one-page instruction sheet explaining the task to be performed while watching the video tape. Instructions were carefully worded so as not to persuade subjects toward certain responses. For example, there was no mention of the word "delay" in the delay-estimation task, as "delay" has more negative connotations than the word "time." Further, subjects were not persuaded to estimate stopped delay nor control delay, but were simply told to "estimate the time you are at the traffic signal." With these instructions, subjects were free to estimate whatever delay they felt was imposed by the traffic signal. Similarly, subjects were not persuaded to use delay (or any other specific factors) as criteria for rating LOS, they were simply told to "rate the quality of service provided by the traffic signal."

The questionnaire was administered at the end of the second laboratory session (i.e., after both tasks had been completed). The subjects were debriefed upon completing the questionnaire, and group discussions were initiated to identify factors that influenced their delay estimates and LOS perceptions.

6. LESSONS LEARNED/RECOMMENDATIONS FOR FUTURE RESEARCH

In an earlier paper (Pécheux et al. 2000), the authors presented preliminary results that suggest that subjects' did not perceive LOS on six levels. It appears, rather, that subjects' perceived three or four levels of service, at least for delays of around 100 seconds or less. Subjects were more tolerant of delays that the HCM would suggest, and their LOS ratings tended to be similar for delays associated with LOS A and B and LOS C and D. As a result, future studies should concentrate on users' perceptions of longer delays, and perhaps those associated with oversaturated conditions.

The results also showed that subjects' delay estimates, on average, were fairly accurate, but widely variable, as were their perceptions of LOS. Although variation would be expected in the subjects' responses, there are several procedural factors that may have contributed to this variability.

Although the laboratory instructions were worded somewhat ambiguously so as not to influence the subjects' responses, the ambiguity may have contributed to additional response variance. For the delay estimation task, subjects were told to "estimate the time at the traffic signal." This time may mean different things to different drivers. For example, some drivers may consider only the time they spend stopped as delay, some may feel their delay ends as soon as the light turns green, and still others may feel delayed if they have to slow down at all. It would be important to determine what delay means to drivers.

The instructions "rate the quality of service provided by the traffic signal," rather than "rate the quality of service based on the delay you experience" may have also contributed to response variability. The post-experiment discussions revealed that about 90 percent of the subjects considered delay to some extent; however, very few subjects used delay as the only criterion when rating LOS. Based on the group discussions, it appears that there were at least 15 factors identified by the subjects as influential in their LOS ratings. The subjects' comments were compiled and grouped into the following categories:

- delay
- traffic signal efficiency
- arrows/lanes for turning vehicles
- visibility of traffic signals from queue
- clear/legible signs and road markings
- geometric design of intersection
- leading left-turn phasing scheme
- visual clutter/distractions
- size of intersection
- pavement quality
- queue length
- traffic mix
- location
- scenery/aesthetics
- presence of pedestrians

In one sense, these results are very interesting in that they suggest that users' perceptions of LOS are sensitive to factors other than delay. In another sense, these results are difficult to interpret and analyze due to the confounding factors introduced by the nature of the instructions and the experimental design. As a result, the authors suggest in future experiments that the most important factors influencing users' perceptions first be identified and then controlled in the experimental design.

Since many factors could not be included in this research effort, it is recommended that two specific factors be addressed in future studies. One factor is location. Due to the differences in delays/congestion across locations, as well as the experiences and expectancies of drivers, it is important to determine how these differences are manifested in the perceptions of service quality. This knowledge would be a key factor for improving LOS analysis of signalized intersections. Additionally, only through movements were considered in this research effort. Several post-experiment comments were related to the provision for turning vehicles (e.g., lanes and arrows) and the signal phasing scheme (e.g., as a through vehicle, some do not like protected leading left turns). These comments raise questions as to how geometric and operational details may affect the perception of LOS. It is therefore recommended that turning movement/phasing scheme be considered in future efforts.

Finally, the shape and characteristics of individual vehicle delay distributions from field studies of delay have shown that "average" delay may not adequately characterize the delay experienced by all drivers in a lane group or by individual drivers who make multiple trips through the same intersections. Thus, studies at individual intersections could help determine how users form an overall perception of service quality based on multiple trips through one intersection (versus one trip through several different intersections) while keeping the intersections conditions constant. This could be accomplished using similar experimental techniques or by conducting on-the-road field studies.

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