Methodology for Determining Level of Service Categories Using Attitudinal Data

SAMER M. MADANAT, MICHAEL J. CASSIDY, AND WAN-HASHIM WAN IBRAHIM

Level of service (LOS) is standard terminology used for characterizing the operational quality of a transportation facility as perceived by the user of that facility. Given that transport systems are commonly designed and operated to maintain a specified LOS, it is a matter of some concern that the measures of effectiveness currently adopted for assessing LOS, as well as the threshold values for partitioning LOS designations, have been established subjectively. A methodology for partitioning LOS designations by using an ordered probit model calibrated with attitudinal data collected by transportation "users" is described. The application of this methodology is demonstrated by using survey data of bus riders. The basic approach, however, can be applied to all types of transportation facilities.

The 1985 *Highway Capacity Manual* (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" (*1*). Thus, a designation of A through F is intended to characterize the operating quality of a subject transportation facility or system as perceived by the user. Although the HCM does state that its published analysis techniques are not intended to serve as legal standards for designing transportation systems, LOS has become a deeply embedded concept in the transportation psyche. Both the professional and the layman use it to depict existing or projected conditions. And, most important, LOS designations are used to influence decisions of tremendous economic consequence.

In a typical jurisdiction, for example, transportation systems may be designed and operated to maintain a stipulated LOS. Where changing environmental conditions (e.g., increased vehicle demand) cause LOS to erode below a stipulated designation, mitigating measures may be obligated at great cost to taxpayers, developers, and users.

Given the consequences of decisions made in response to measured or predicted LOS, it is imperative that LOS designations truly reflect that which they are intended. That is, the parameters thought to best characterize operating conditions for a particular type of transportation system (called measure of effectiveness, or MOE) must actually reflect user perceptions of operational quality. Likewise, the parameter values that separate LOS A from B, B from C, and so on must reflect boundaries that are consistent with the perceptions of the user population.

It is therefore a matter of some concern that the measures of effectiveness currently used to characterize LOS, as well as the threshold values used to separate LOS designations, reflect nothing more than the consensus of those involved in developing the HCM techniques. In short, LOS parameters and threshold values represent the judgment of a TRB committee. There appears to be no body of work conclusively relating LOS parameters to the perceptions or attitudes of the user population.

The work described in this paper has focused primarily on the identification of appropriate threshold values for partitioning one LOS designation from the next. The paper describes a technique to establish threshold values by making use of an ordered probit model (*2*) calibrated with survey data of user attitudes. Because the threshold values identified in this work actually reflect user perceptions, the proposed methodology is a considerable improvement over the somewhat arbitrary manner in which LOS designations are now partitioned.

The paper demonstrates the proposed methodology by applying it in conjunction with survey data reflecting LOS conditions perceived by bus riders. Although bus transit is only one type of transportation system, the methodology presented in this paper can be applied to any type of transportation facility currently addressed in the HCM. The decision to use attitudinal data collected from bus passengers was motivated solely by the relative ease with which such data could be collected.

RESEARCH APPROACH

Threshold values for partitioning LOS designations were identified by using an ordered probit model. Ordered probit modeling is one of several commonly used econometric techniques for the analysis of rating data. Specifically, where respondents are asked to evaluate a product or service on an ordinal scale (e.g., from 1 to 10 or from A to F), the correct methodology is to use a class of models with ordered dependent variables such as ordered probit or ordered logit. These techniques allow the analyst to correlate user responses to a host of explanatory variables (i.e., potential measures of effectiveness). Simultaneously, these techniques facilitate the identification of the thresholds between successive ratings.

Calibrating the ordered probit model required a data base relating the LOS designation perceived by users to the actual parameter values of the MOE. For example, the adopted MOE for signalized intersection LOS is delay. One could measure the intersection delay imparted to a specific motorist and then, in theory, ask the motorist to rate his or her perceived LOS at the conclusion of the delay period. Repeating this experiment for numerous motorists would provide the necessary data base for calibrating the ordered probit model.

The obvious procedural problem is that of usurping from motorists their perceptions of service quality. Conducting controlled experiments using a selected study group represents one feasible approach to collecting such motorist data. However, such an

S. M. Madanat and W.-H. W. Ibrahim, School of Civil Engineering, Purdue University, West Lafayette, Ind. 47907. M. J. Cassidy, Institute of Transportation Studies, University of California at Berkeley, 109 McLaughlin Hall, Berkeley, Calif. 94720.

endeavor was considered to be well beyond the scope of the research presented in this paper. Attitudinal data could, however, readily be collected from bus riders.

The HCM does include a chapter dedicated exclusively to transit LOS (and capacity). According to the HCM, the LOS imparted to bus passengers directly corresponds to the level of crowding on the bus. More specifically, the selected MOE is available square feet per passenger. The following table reproduces the MOE thresholds adopted by the HCM:

LOS	*Space per Passenger (ft^2)*
A	≥ 13.1
B	13.0 to 8.5
C	8.4 to 6.4
D	6.3 to 5.2
E (maximum scheduled load)	5.1 to 4.3
F (crush load)	< 4.3

The primary task in this work was to compare the MOE thresholds for bus riders arbitrarily adopted by the HCM with the thresholds rationally established using the stated perceptions of bus riders themselves.

DATA COLLECTION

Data reflecting rider perceptions were collected on numerous buses in the Chicago Transit Authority (CTA) system on Monday, March 22, 1993. To conduct the survey, a data collector individually asked riders to specify their perceived LOS. Specifically, the data collector identified himself as a CTA employee, stated that he was conducting a passenger survey, and asked each rider to rate his or her "present level of comfort on the bus on a scale of one to six; where one corresponds to a rating of very comfortable and six to a rating of unacceptable discomfort." Note that a rating of 1 to 6 corresponds to a LOS of A to F.

Coincident to each rider response, the data collector kept a running count of the number of passengers on board the bus. In this way, perceived LOS designations were correlated with the MOE currently used in the HCM: available square feet per passenger.

The data collector strived to randomly sample riders in an effort to avoid systematic bias in the data base. Moreover, the data collector spatially sampled individual passengers within the bus so that respondents would not be influenced by the responses of those around them. In total, 174 responses were collected from passengers riding standard 40-ft-long buses. The following table summarizes the total number of responses for each of the six specified ratings:

Stated Response	*Count*	*Percentage*
1	65	37.4
2	31	17.8
3	35	20.1
4	19	10.9
5	5	2.9
6	19	10.9

The survey instrument used in this work (i.e., the question posed by the data collector) was a fast and simple way to obtain the needed attitudinal data. The responses provided an adequate data base to satisfy the methodological objectives of this research (i.e., to demonstrate the application of ordered probit for partitioning LOS designations). In terms of its ability to obtain unbiased data, the survey instrument is suspect. The conclusions of this paper include a discussion of how the instrument might be improved as part of a comprehensive effort to identify LOS thresholds appropriate for generalized application.

MODEL SPECIFICATION AND ESTIMATION

For each observation (individual) i, the following variables are available:

y_i = stated level of comfort, $y_i \in \{1, 2, 3, 4, 5, 6\}$;
x_i = passenger density on bus at time individual i provided a response (passengers/ft^2); and
$i = 1, 2, \ldots, 174$.

Define as the latent comfort of individual i at the time of his or her response

$$U_i = \alpha + \beta x_i + \epsilon_i$$

where α and β are parameters to be estimated (where α can be thought of as absorbing the mean of ϵ), and ϵ_i is the random error term, accounting for all unobserved attributes contributing to individual i's perceived comfort; because the error term is the sum of a large number of random effects, it can be assumed normally distributed, that is,

$$\epsilon_i \sim N(0, \sigma^2) \tag{1}$$

Thus U_i can be divided into two components: a systematic component, $V_i = \alpha + \beta x_i$, and a random contribution, ϵ_i.

The stated level of comfort for individual i, y_i, is related to his or her latent comfort in the following manner:

$$y_i = 1 \text{ if } U_i \leq k_1 \Rightarrow \alpha + \beta x_i + \epsilon_i \leq k_1 \tag{2a}$$

$$y_i = 2 \text{ if } k_1 < U_i \leq k_2 \Rightarrow k_1 < \alpha + \beta x_i + \epsilon_i \leq k_2 \tag{2b}$$

$$y_i = 3 \text{ if } k_2 < U_i \leq k_3 \Rightarrow k_2 < \alpha + \beta x_i + \epsilon_i \leq k_3 \tag{2c}$$

$$y_i = 4 \text{ if } k_3 < U_i \leq k_4 \Rightarrow k_3 < \alpha + \beta x_i + \epsilon_i \leq k_4 \tag{2d}$$

$$y_i = 5 \text{ if } k_4 < U_i \leq k_5 \Rightarrow k_4 < \alpha + \beta x_i + \epsilon_i \leq k_5 \tag{2e}$$

$$y_i = 6 \text{ if } U_i > k_5 \Rightarrow \alpha + \beta x_i + \epsilon_i > k_5 \tag{2f}$$

where $k_1, \ldots, k_5$ are the unobserved thresholds on the latent scale separating consecutive levels of comfort.

Equations 1 and 2 fully describe the model specification. Such a specification represents an ordered probit model (2). An ordered probit structure is an extension of a simple binary probit model to a case in which the observed indicator variable is ordinal and takes a value between 1 and $m > 2$.

The objective of the estimation is to provide statistical estimates of the model parameters α, β, and $k_1, \ldots, k_5$. This objective is achieved through the use of maximum likelihood estimation (MLE).

Not all parameters of Model 2, however, are uniquely identifiable by MLE. This can be readily observed if Equation 2 is rewritten as

$$y_i = 1 \text{ if } \beta x_i + \epsilon_i < k_1 - \alpha \tag{3a}$$

$y_i = 2$ if $k_1 - \alpha < \beta x_i + \epsilon_i \leq k_2 - \alpha$ (3b)

$y_i = 3$ if $k_2 - \alpha < \beta x_i + \epsilon_i \leq k_3 - \alpha$ (3c)

$y_i = 4$ if $k_3 - \alpha < \beta x_i + \epsilon_i \leq k_4 - \alpha$ (3d)

$y_i = 5$ if $k_4 - \alpha < \beta x_i + \epsilon_i \leq k_5 - \alpha$ (3e)

$y_i = 6$ if $\beta x_i + \epsilon_i > k_5 - \alpha$ (3f)

It can be seen that α is not distinguishable from the thresholds $k_1, \ldots, k_5$. Only the differences $k_i^* = k_i - \alpha$, $i = 1, \ldots, 5$ are statistically identifiable. Therefore, the MLE procedure will only provide estimates of β, $k_1^*, \ldots, k_5^*$. This is basically equivalent to the normalization $\alpha = 0$.

The standard normalization $\sigma^2 = 1$ is also required. This latter normalization is common to all probit models and determines the scale of the model parameters.

Model 3 can be estimated by using a general-purpose MLE routine available in most statistical software or by using specialized probit estimation programs. This research has used the standard probit procedure available in SST (*3*).

The estimation results are presented in Table 1. Referring to Table 1, all threshold parameters, with the exception of k_1^*, are highly significant (i.e., all t-statistics $>\cdot>$ 2). This reflects a high level of confidence in their values. The density parameter, β, is significantly different from 0 (t-statistic = 3.19), indicating that passenger density does influence perceived LOS. The overall fit of the model, however, is low ($\rho^2 = 0.083$), indicating that passenger density alone does not explain variations in rider responses to the level of comfort question.

To compare threshold values estimated through the ordered probit approach with those documented in the HCM requires that all thresholds be of equal scale. To convert those thresholds generated by the ordered probit model, the values of $\hat{k}_1^*, \ldots, \hat{k}_5^*$, (the estimated k_i^* values) were first divided by $\hat{\beta}$ (the estimated value of β) to obtain $\hat{k}_i' = \hat{k}_i^*/\hat{\beta}$, $i = 1, \ldots, 5$ thresholds on the density scale. These density thresholds $\hat{k}_1', \ldots, \hat{k}_5'$ are then inverted to obtain area thresholds $\hat{t}_1, \ldots, \hat{t}_5$, compatible with the scale used for thresholds in the HCM.

$$\hat{t}_i = 1/\hat{k}_i' \quad i = 1, \ldots, 5$$

where $\hat{t}_i$ equals thresholds on the scale of available area per passenger, in square feet per passenger.

The following table presents the threshold values estimated by the ordered probit procedure:

LOS	Space per Passenger (ft^2)
A	$\leq$ 305.0
B	305.0 to 13.2
C	13.1 to 6.0
D	5.9 to 4.3
E	4.2 to 3.9
F	< 3.9

ANALYSIS OF FINDINGS

If one were to assume that the responses collected from CTA riders in this research at least approach or approximate the perceptions of bus riders in general, the MOE and threshold values adopted by the HCM are highly suspect. To begin, both the currently adopted thresholds presented in Table 1 and the values generated from the ordered probit model in the previous table reflect LOS thresholds relevant to a standard 40-ft bus with an interior area of about 340 ft^2. Significant differences exist between the threshold values presented in these two tables.

The probit-generated thresholds in the previous table suggest that LOS A conditions are difficult to obtain on an urban transit bus as the presence of more than one passenger results in an available area below the LOS A threshold. In contrast, the HCM thresholds indicate that as many as 26 passengers can be aboard before operating conditions erode to LOS B. For Levels B and C, the probit-generated thresholds differ from the currently adopted values by

TABLE 1 Model Estimates

Independent Variable	Estimated Coefficient	Standard Deviation	t-statistic
k1*	0.021	0.141	0.147
k2*	0.478	0.146	3.270
k3*	1.051	0.150	6.985
k4*	1.479	0.150	9.850
k5*	1.631	0.155	10.526
Density	6.313	1.980	3.189

L(0) = - 294.90

L($\hat{\beta}$) = - 270.46

Rho-Squared = 0.083

approximately one step size—that is, the HCM thresholds delineating LOS A from B and LOS B from C are very close to the probit-generated thresholds delineating LOS B from C and LOS C from D, respectively. For the lower LOS conditions, the probit-generated thresholds suggest that riders are more willing to tolerate higher passenger densities than those implied by the HCM thresholds. Given that transit operators may establish service frequencies and bus sizes with reference to maximum allowable (i.e., crush) loads, improving the LOS thresholds by exploiting the proposed methodology with an expanded data base would provide worthwhile information. If indeed LOS F is defined by an area smaller than 4.9 ft^2/passenger (the value recommended by the HCM), a reduced frequency of service might be acceptable. This could lead to substantial cost savings for the transit agency.

Findings from this work, however, are not limited to the identification of large differences between the LOS thresholds currently adopted and those derived through the ordered probit approach. The models calibrated in this research effort indicate that passenger density, while being a significant predictor, does not in itself strongly characterize perceived LOS. The significance of this finding is discussed further in the next section.

CONCLUSIONS

The specific findings resulting from this research are by no means definitive: the probit-generated thresholds presented herein are not values that the authors propose for adoption by the HCM or any transit agency. The objective behind this work has been to demonstrate a more rational methodology for establishing LOS parameters. The small data set collected in this effort provided a simple means to this end. However, the size of the data base and the instrument used for acquiring these data are far from ideal. Obtaining a more reliable and representative data base would require (a) a significantly enhanced survey instrument for measuring latent LOS designations and (b) an expanded number of observations reflecting rider perceptions under a greater variety of operating conditions, bus systems, geographic regions, and so forth.

Regarding the first concern, the instrument used in this research fell short of commonly adopted standards (*4*). For our application, the exclusive use of stated preference data potentially promotes policy-response bias, as respondents may believe that responding negatively to any questions concerning passenger comfort might induce mandated improvements to "their" bus system. The potential for this bias was likely exacerbated by asking respondents a single question reflecting an obvious objective. At the very least, the survey instrument could be enhanced for future surveys by providing riders with a questionnaire incorporating a number of bipolar options characterizing passenger comfort. To further minimize the validity problems commonly associated with stated preference data, a passenger questionnaire could be developed incorporating both stated and revealed preferences (*5*).

The need also exists to identify operating items, in addition to passenger density, that influence LOS perceptions. Such items might include factors such as bus condition and aesthetics, demographic features of the riders and routes, waiting times at the bus stop (i.e., service frequencies), and required number of transfers. Such items (and their associated significance) can be identified only through an extensive data collection effort to measure the values of the potential influences. These values could then be correlated with individual survey responses as part of a comprehensive model-building process. The effort might result in an expression for estimating a performance index characterizing LOS. As noted in this paper, this type of research could also be carried out to assess motorists' perceptions of LOS relevant to other types of transportation facilities.

In the final assessment, the value of the research described in this paper does not lie in the specific parameter values identified. Instead, the contribution of this work has been to demonstrate the manner in which a commonly used modeling technique—namely, ordered probit—can be applied to address an important but overlooked transportation issue: LOS as perceived by the user.

Findings from the specific application described in this paper should prove relevant to transit agencies. Transit operators are certainly concerned with passenger comfort and the service-scheduling and fleet-sizing issues related to comfort. However, the authors hold that the relevance of this work extends well beyond application to bus riders. The proposed methodology applies to virtually all transportation facilities in which LOS is a relevant issue.

If the operating quality of a transportation facility is to be evaluated from the perspective of the user (and it seems logical that it should), adopted LOS designations must truly reflect these perceptions. The lack of existing research in this topic, and the rather subjective manner in which LOS is currently defined, are therefore matters of significant concern. A great deal of money might be spent to improve the operating conditions of a given transportation facility by one or two LOS designations, yet the extent to which these improvements actually influence user perception of LOS is practically unknown. Perhaps more important, the federal government is allocating millions of dollars to fund research projects directed at developing and improving the accuracy of analytical procedures for predicting (arbitrarily selected) MOEs. Still, there is no certainty concerning the significance of these MOEs for characterizing LOS from a user's perspective.

LOS designations must be better understood and applied in transportation engineering and planning. The research described in this paper proposes an approach for addressing this fundamental issue.

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