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LEVEL-OF-SERVICE CONCEPTS in URBAN PUBLIC TRANSPORTATION

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16. Abstract

The term "level of service" as used in highway planning is a well defined measure which has had wide spread application in highway design and analysis for over thirty years.

In contrast, urban public transportation has little in the way of standardized measures for evaluating service.

The study examines the level-of-service concept as it might be applied to public transportation services. It describes proposed definitions of public transportation level of service based on both system and rider attributes. The variation in public transportation quality as viewed by various user market segments is examined, and the sensitivity or demand elasticity to the various factors constituting "level of service" is then made. Finally, a proposed study methodology to evaluate the increased level of service provided to user groups in line with their perceived measures of service quality is outlined.

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1. INTRODUCTION

In April, 1978 MTRP recommended to MDSH&T that a "level of service" methodology be developed in order to evaluate proposed demonstration projects. Also during the year, certain study projects were requested by MDSH&T which raised transit efficiency questions that a level of service methodology could be very helpful in answering. As a result, this study was commissioned by MTRP to provide preliminary insights into the form of such a methodology and the ways in which it could be developed.

The term "level of service" as used in highway planning is a well-defined measure which has had wide-spread application in highway design and analysis for over thirty years. The Highway Capacity Manual (HCM) defines level of service by the effect of several highway operational factors, including operating speed, travel time, traffic interruptions, freedom to maneuver, safety, comfort, convenience, and cost. [(1 p.7)*] Limiting values of certain of these factors, specifically operating speed and the volume-to-capacity ratio (v/c), are used to define six specific levels of service, A through F. These six levels represent the entire range of operating conditions for the facility, from best (level of service A) to worst (level of service F). Similarly, at signalized intersections, level of service is discretely defined by limiting values of the "load factor" or the number of signal cycles which are fully "loaded" or utilized by approaching vehicles.[(1 p.131)]

In contrast to the relatively well-defined limits on levels of service in highway planning, urban public transportation has little in the way of standardized measures for evaluating service. In the past, when the majority of public transportation operations in urban areas were privately owned, service evaluation was relatively unimportant and the provision, expansion, or discontinuance of service was based solely on economic considerations. That is, if a service change resulted in a net profit it was instituted; if the continued provision of certain services could not be made at a profit the services were discontinued.

*Numbers in parentheses refer to the list of references.

This situation has changed considerably in recent years, however. Today nearly all urban transit systems are publicly owned and operated. Along with this trend in public ownership has come the increasing use of public funds to subsidize the operation of these facilities. The emphasis in public transportation has thus changed from a private, profit-oriented operation to a public service function operated with tax dollars. Profitability alone is no longer a suitable measure for evaluating public transit. There should be additional measures to evaluate the service provided by the expenditure of public dollars.

The purpose of this report is to examine the level of service concept as it might be applied to public transportation services. The report is structured to first describe proposed definitions of public transportation level of service based on both system and rider attributes. The variation in public transportation quality as viewed by various user market segments is examined and the sensitivity or demand elasticity to the various factors constituting "level of service" is then made. Finally, a proposed study methodology to evaluate the increased level of service provided to user groups in line with their perceived measures of service quality is outlined.

2. SYSTEM ATTRIBUTES DEFINING LEVEL OF SERVICE

Early work in relating public transportation system and service area attributes to a level-of-service concept was performed by the Nàtional Committee on Urban Transportation (NCUT)[2] in its recommendations for standards and warrants for public transportation systems. The committee proposed generalized standards for routing (as direct as possible with a minimum of turns and transfers), loading, frequency of service or headway, stop frequency, speed and regularity of service. In addition, the NCUT suggested warrants for extending service into new areas and curtailing or abandoning existing services.

In addition to the NCUT, a few individual transit operations have developed their own guidelines for transit service institution or discontinuance. The San Antonio Transit System, for example, uses residential density and patronage criteria as the basis for instituting or extending service. The San Antonio criteria include the following:[3]

1. Residential areas requesting bus service must contain an average of three dwelling units per acre within one-quarter mile of the proposed route.
2. Additional route buses require a minimum of 500 dwelling units in the service area.
3. At the end of a 60 day trial period an average of three adult revenue-paying passengers per bus mile is required for continued operation.

Bus route operating standards have also been developed by the Southeast Wisconsin Regional Planning Commission (SEWRPC),including the following:[4,5]

1) Demand forecasts of 600 passengers per bus per day are necessary to institute service.

2) Service areas on either side of a route should vary in width, depending on the area's population density.

3) Average bus stop spacing should be 660 feet (1/8 mile).

A composite set of guidelines for fixed-route, fixed-schedule bus services based on the NCUT, San Antonio, and SEWRPC guidelines has been proposed by Heathington and Brogan.[16] These standards define minimum, desirable, and maximum levels for several service area and system characteristics and are shown in Table I.

These studies were all attempts to define the minimum characteristics of quality transportation systems for a given set of service area variables, and are basically binary in nature. They do not present a sufficient gradation to permit the evaluation of minor system improvements.

Botzow,[7] in contrast, has developed a method of measuring level-of-service based on the system's ability to provide reasonable travel times and a comfortable ride. To provide a comparison with the highway level-of-service concept, Botzow likewise employs six distinct levels of service: A through F.

Botzow's overall weighted level of service is based 40 percent on the value of the time-related variables - adjusted speed and delay - and 60 percent on the value of the comfort-related variables - primarily passenger density (square feet per passenger), vehicle acceleration and jerk, temperature, ventilation, and noise. The adjusted speed portion of the time variable is composed of a weighted combination of travel time, vehicle headway, number of transfers, and type of fare collection parameters.

Botzow established standards for each variable at each level of service. For the delay variable, for example, level of service A corresponds to zero minutes of delay for a trip. Other levels of service relating to delay are: 0 to 1 minutes of delay for level B; 1 to 2 minutes for C; 2 to 4 minutes for D; 4 to 8 minutes for E; and more than 8 minutes for F. Similar ranges are developed for each of the characteristics included in the definition of level of service. Thus, a transit operator can easily evaluate each variable and, using assigned weights for that variable, determine the overall level of service provided. The author proposes that if any one variable is assigned a level of service of F, the entire trip is assigned an overall level of service of F.

TABLE I

RECOMMENDED LEVELS OF SERVICE

FOR FIXED-ROUTE, FIXED-SCHEDULE BUS SYSTEM OPERATIONS[(a)]

Characteristic	Level of Service		
	Minimum	Desirable	Maximum
Service Area (lateral distance on either side of bus route in miles)	(b)	¼[(c)]	½[(d)]
Service Area Density (persons per square mile)	3,000	8,000	(e)
System Patronage (revenue-passengers per bus mile)	(f)	3.0	(e)
Vehicle Headways (minutes)	3	15-30	60
Vehicle Loading Factor (numbers of passengers/ number of seats)	1.0	1.0	1.25[(g)]
Lateral Bus Route Spacing (miles)	(h)	½[(c)]	1[(d)]
Bus Stop Spacing (feet)	660	(h)	(h)

Notes:

(a) Source: Ref. ~~X~~(6)

(b) No minimum.
(c) For relatively high density areas (>8,000 persons per square mile
(d) For medium density areas (3,000-8,000 persons per square mile).
(e) No maximum.
(f) This is a policy decision which depends on the public service aspects of the system.
(g) During peak period operation.
(h) Depends on the demand.

This reasoning is based on a rider's perception of a level of service F corresponding to an intolerable situation; if one component of a trip is intolerable the entire trip becomes intolerable.

This concept of level of service could be used for comparing the effect of alternate changes in the system for measuring present and proposed future transportation service. A decision to provide level of service B on a planned public transportation system, for example, would be a major determinant of the system type or technology to be employed. Botzow's concept is simple to comprehend, easily implementable, and has application in both evaluation and planning. Its major deficiency is the lack of rationale for the level-of-service boundary conditions, and the assumption that all users will assign the same weight to each variable.

Aronstein,[8] proposed a standard for all urban transportation systems, including the automobile. In this way, the definition would address the boundary-condition question by placing equivalent limits on the measure used to define highway level of service (vehicle velocity or travel time). By scaling user responses (waiting time, cost, safety, pollution, etc.) relative to travel time savings, a normative transportation system standard based on traveler-perceived performance measures is developed. Aronstein concludes by arguing that the formulation of a standard measure is the first step in system evaluation. The principal limitations of this definition are that it includes only one measure (travel time) and it relies on aggregate user values.

While not proposing any solution, Deen[9] and Dajani and Gilbert[10] argue the need for development of transit performance measures covering system operations and equipment. Deen contends that the demand for such performance measures is quite well documented, but the complexities of developing and implementing them will be an enormous task.

Rider Perceptions and Market Segmentation

A major portion of this task is to identify the perception, by both transit users and non-users, of desirable or preferable system attributes.

Those system attributes which the public perceives as being important in transit system performance should form the basis for measuring the quality of service, and if improved, should contribute to the capture of additional market shares by transit.

In addition to the question of the aggregate perception of important system attributes, there is evidence that various market subgroups within the total population have quite different perceptions of attributes considered to be most important for their particular transportation needs.

Attitudes toward urban transportation mode choice, in both the aggregate and by various market subgroups, has been widely researched, primarily by psychological approaches. Such factors as safety, reliability, various time parameters (walking, waiting, riding), cost, convenience, comfort,and aesthetics have long been recognized as affecting the mode-choice decision. In general, according to Golob et al.[11] the total population gives preference, in decreasing order of importance, to the following factors:

1. arriving when planned, having a seat, not having to transfer;
2. total customer trip time, fares, and the provision of shelters at stops;
3. interior design of the vehicle, aesthetics, social aspects;
4. exterior design of the vehicle, provision of amenities on board the vehicle.

Other research has shown that these priorities are not identical for all groups. Golob, Dobson, and Sheth[12] found in their study that in public transportation females are most concerned with man-machine interface and shopping convenience, and males find amenities and options the most important attribute. Residents of the central city find man-machine interface and the duration of service more important than do suburbanites. Younger respondents (age 34 or less) are less interested in level of service, amenities, man-machine interface, and more interested in shopping convenience than other age groups. Middle age people are most interested in level of service. The low-income group (less than $6000) are more concerned than other respondents with level of service, man-machine interface, shopping convenience, and duration of service.

In their previously cited study of demand-responsive systems, Golob et al.[11] used the following market subgroups:

1. low income (less then $5000),
2. elderly, young, non-drivers,
3. housewives (non-employed females),
4. both spouses employed,
5. multi-car households,
6. one-car households.

They found three groups with significantly different preferences from the overall market. These are the elderly, the low income, and the young. The elderly are most concerned with accessibility. They want to have a seat, pay a low fare, and not have to transfer. They place a lower value on their time and are not as concerned with travel time as the general population. The low-income person places a high value on wait time, shelters, dependability, and long hours of service. Finally, the young are not concerned with physical problems of accessibility. They place importance on time savings - having a vehicle available when they want it, longer hours of service, and amenities, such as newspapers and music on board.

In an attempt to describe attitudes toward automobile and transit travel by means of a composite index, Hartgen[13] surveyed 360 households in New York State. The survey was conducted to determine: (1) how important a specific attribute was to the respondent, (2) how satisfied the respondent was with the ability of the automobile to provide this particular attribute, and (3) how satisfied the respondent was with the ability of transit to provide the attribute. Responses were on a scale of one to seven, one being a very negative response and seven being a very positive response.

To evaluate the results, Hartgen proposed the following model:

$$Y_i = I_{ij} \ (1 - ST_{ij}/SA_{ij})$$

where:

Y_i = value of index for respondent i,

I_{ij} = subjective importance i places on attribute j,

ST_{ij} = perceived level of satisfaction by i for attribute j for the transit mode,

SA_{ij} = perceived level of satisfaction by i for attribute j for the automobile mode.

According to the model, if $I_{ij} \ (1-ST_{ij}/SA_{ij})$ is positive, the auto is perceived as the more satisfactory mode. Conversely, if the term is negative, then transit is the more satisfactory mode. The deviation of the sum from zero is a measure of bias toward either auto or transit.

With this form of a model, it might be possible to define that set of attribute values for transit that yield model values of zero for each highway level of service. This has not been done, however, or at least it has not been reported in the literature. At the very least the model provides a possible continuously distributed measure from which definition of level of service could be defined as a function of several system attributes.

3. SENSITIVITY

The need for a well-defined relationship between various system parameters and a measure of service quality is particularly important from a programming perspective. When considering alternative expenditures, each of which affects a different parameter, optimization can only be accomplished if each of these parameters can be related to some single objective function or measure of quality.

The availability of an accepted and widely used definition of level of service facilitates the evaluation of alternate improvements to the highway. The fact that this definition consists of several components allows the analyst to vary each component and compare the effect on the level of service. Thus, sensitivity analysis can be conducted by determining the increase in the v/c per dollar expended on each element of the highway (for example, increasing the shoulder width versus increasing the pavement width).

Similar analyses in urban transit suffer from two deficiencies. First, there is no generally accepted yardstick for measuring level of service; and second, there are no accepted procedures for testing the effect on system performance of changing individual components. Instead, most of the past studies have tested the impact of changes in one variable (i.e., frequency) on patronage. Using the results of these studies for programming expenditures for alternate improvements requires the assumptions that the component being tested uniquely identifies the level of service, and that ridership alone is an adequate measure of service quality.

In truth, neither of these assumptions is valid. The previous discussion illustrated that both from the riders' perspective and the system perspective, many components are considered important in determining service quality. It would seem logical, then, that patronage would vary with changes in each of these components rather than being related to only one. The assumption that patronage is an adequate measure of service quality can only be valid when applied to the "choice" rider. For captive riders, changes in the service quality may <u>not</u> be reflected in ridership changes.

Another deficiency in utilizing the results of these studies in the evaluation of alternate expenditures is that nearly all of the reported studies aggregate all riders into a single category for determining elasticities.* The optimization of investments in alternative transit system components may depend on disaggregate market analysis if the behavior of each of these segments is not identical.

Domencich and Kraft,[14] Kemp,[15] and Schofer[16] reported on three of the most comprehensive analyses of these elasticities. These studies, while conducted in different cities, all reached the conclusion that the composite fare elasticity was approximately -.33. These results were consistent with many other studies reported in the literature. The consistency with which this result is characteristic of cities of different size and different transit coverage has led to the acceptance of this value as a "rule-of-thumb" for the evaluation of the impact of proposed decreases in fare. Similar studies have shown that this elasticity holds true for fare increases as well as fare decreases.

However, there have been a few cases where fare elasticities have varied significantly from this general rule.[17,18] While there is not sufficient information in these reports to verify this, one possible explanation is that these routes served corridors with an unusual demographic distribution of existing and potential riders. For example, if a route served an area composed of 2/3 captive riders and 1/3 choice riders, and a 100 percent fare increase resulted in the loss of all the choice riders, the elasticity would be -.33. If the same results occurred in another corridor consisting of 1/3 captive riders and 2/3 choice riders, the same behavior would yield an elasticity of -.66. This variation in reported values of fare elasticity illustrates the need for more intensive market segmentation studies of ridership response to changes in system parameters.

The elasticity to service frequency, which is perhaps a better surrogate for quality of service, shows a substantially higher elasticity in

*Elasticity is defined as the percentage changes in ridership divided by the percentage change in the parameter being varied.

those studies where both fare and frequency were analyzed. For example, in the Free Transit Study,[18] elasticities to travel time were as much as 3.5 times as high as fare elasticities. Likewise, Lee and Surti[17] concluded that the elasticity to service frequency was 2 to 3 times greater than that for fare for various trip purposes. Table II presents the results of studies indicating a range of service elasticities from 0 to -3.8. Like the studies of fare elasticities, the results vary sufficiently between the extremes to indicate that the results may be influenced by the study environment.

In addition to these studies of the ridership response to changes in a single variable, there have been a few attempts to relate ridership variations to system measures of the service quality. Using data from seventeen cities, Boyd and Nelson[20] developed a regression model to predict ridership as a function of daily bus miles per capita. Based on this model, the author concluded that the elasticity to service changes is not constant across different cities and different service coverage, but decreases with increasing coverage. Those cities with relatively poor transit service (as measured by route miles per capita) have potentially higher elasticities (as high as 1.0) while those cities with a high quality of service have potential elasticities of only about 0.5. If this is true, it would indicate that the ability to attract additional riders (as a percentage increase) will diminish with system improvements. This study differs from the previous studies in that the elasticities are calculated from models, as opposed to data collected by varying the fare or frequency in a single city or a single corridor.

Other attempts to use regression analyses (with trip rates as the dependent variable) have failed to identify any single parameter which explains a significant amount of the variance in transit patronage. For example, it was found that household income explains 29% of the composite ridership variance, but this is the largest value reported. Average trip length also has been found to explain some but not a significant amount of the variance. A parameter like trip length may also simply be another measure of differences in income, trip purpose, or travel time savings. It has little value in determining the change in service quality that will result from an investment, since the trip length is not likely to change as a result of a modification to the transit system.

TABLE II TRANSIT SERVICE HEADWAY ELASTICITIES

Massachusetts Demonstrations (176*)A/	Headway Elasticity	Months After Impelmentation
Boston-Milford suburban route (new headway approximately hourly)	-0.4	10-12
Uxbridge-Worcester suburban route (new headway hourly)	-0.2	7-9
Adams-Williamstown city route (new headway approximately hourly)	-0.6	1-3
Pittsfield city route (raised from 3 to 8 round trips daily)	-0.7	1-3
Pittsfield city route (raised from 10 to 15 round trips daily)	-0.6	1-3
Newburyport-Amesbury (depressed area) city route (new headway 30 min. peak/60 midday)B/	-0.4	6-8
Fall River (depressed area) city service (overall 20 percent service increase)	nil	4-6
Fitchburg-Leominster city route (new afternoon headway 10 minutes, to match morning) B,C/	-0.3	6-8
Boston downtown distributor, Phase 1 (new midday headway 5 minutes, to match peak)C/	-0.8	5-7
Boston downtown distributor, Phase 2 (new headway 4 minute base, 8 minutes midday)C/	-0.6	8-10
Boston rapid transit feeder route (new midday headway 5 minutes, to match peak)C/	-0.1	4-6
Other Reported Findings (126)		
Study of Milwaukee transit (1955-1970)	-3.8	--
Detroit city route (new headway 2 minute base, 3-1/2 minute midday)D/	-0.2	--
Chesapeake, Virginia, suburban service D/	-0.9	--

A/ Arc elasticity calculated by the Handbook authors on the basis of revenue.

B/ Includes impact of minor route extension.

C/ Approximate elasticity computed for full service day by using an unweighted average of peak and off peak (or morning and afternoon) headway improvements.

D/ Arc elasticity calculated by the Handbook authors on the basis of ridership.

Source: Reference 19.

4. CONCLUSIONS

In conclusion, there is no accepted definition of level of service for urban transit that will facilitate the evaluation of alternative improvements on the basis of cost-effectiveness. It is possible, based on the literature, to estimate increased (or decreased) ridership which would result from changes in fare or service frequency. While these estimates would be reasonably accurate on the average, there would be substantial variation depending on the demographic characteristics of the service area.

Patronage alone is not an adequate measure of the level of service upon which fiscal decisions should be made. This measure fails to recognize additional benefits (or disbenefits) to those who will patronize transit with or without the expenditure. It also fails to recognize the differential benefits across various demographic strata of a unit change in each of several possible system parameters. For example, there is no way to compare the "net benefit" of a frequency change with the "net benefit" of a vehicle design change.

Finally, no references could be found relating the impact of informational signing (changeable message signs indicating the arrival of the next bus) to either ridership or a prescribed level of service.

5. RECOMMENDATIONS

Based on this review of the literature, the following recommendations are presented:

1) The Michigan Department of State Highways and Transportation should conduct (or sponsor) research on the level of service concept in its fiscal year 1979 program. The purpose of the research should be to develop an operational definition of level of service which is both internally consistent across transit modes and externally comparable to the highway level of service definitions.

The models proposed by Hartgen and Botzow should be reviewed and (if applicable) calibrated to a selected Michigan city. In addition, new models should be developed which include additional parameters of interest i.e., informational signs and demand-actuated service.

2) A second project should be included in the research program with the objective of identifying the desirable market segments for programming transit expenditures. This should include the definition of segments with statistically significant differences in their perception of the value of transit attributes, and the development of a weighting system which recognizes the public interest in providing transit service to each segment.

A procedure for determining the optional programming of funds for improvement of public transportation should be developed from this definition of market segments.

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