LEVEL-OF-SERVICE CONCEPT APPLIED TO PUBLIC TRANSPORTATION

Sponsored by
State Department Of Highways and Public Transportation
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Technical Report 1067-1F
Study 2-10-81-1067

Texas Transportation Institute

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by

Diane Bullard
Assistant Research Planner

and

Dennis L. Christiansen
Associate Research Engineer

Edited by

A. V. Fitzgerald
Assistant Research Specialist

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ABSTRACT

This report presents a preliminary level-of-service (LOS) concept applicable to fixed-route, fixed-schedule transit systems in Texas. This concept was based on the results of a review of existing LOS models and interviews with transit professionals across the state concerning how their systems currently evaluate the level-of-service being provided. In this concept, 8 level-of-service indicators were identified and defined, quantitative values were assigned to each indicator and a weighting technique was developed to reflect the relative importance of each indicator. A draft LOS concept, which utilizes 5 major attributes, was also suggested for use in the evaluation of demand-responsive transportation systems. In addition, data collection procedures for LOS evaluation and a sample application of these procedures are also presented.

The purpose of the LOS concepts is to provide more precise methods of measuring various quality aspects of public transportation and to determine where service improvements are necessary.

Key Words: Level-of-Service (LOS), Level-of-Service Indicators, Public Transportation, Service Evaluation, Transit

SUMMARY

The ability of public transit to provide fast, dependable and comfortable transportation service depends on the ability to effectively evaluate that service and determine where improvements should be made. In recent years, considerable attention has been focused on developing standards by which the cost, amount and impacts of public transit can be measured. Yet comparatively little research has concentrated on establishing a methodology for evaluating an equally important aspect of transit operations, the quality of transit service. It has been suggested that the quality aspects of public transit can be placed in two categories: transportation hygiene factors and level-of-service (LOS) indicators. Examples of transportation hygiene factors include interior and exterior vehicle cleanliness while LOS indicators refer to such factors as travel time, schedule adherence, and passenger density. While there exists the need to develop a methodology for evaluating hygiene factors, this report primarily addresses the level-of-service concept.

Based on a review of existing LOS models and interviews with transit officials across the state, a draft level-of-service concept appropriate for the fixed-route, fixed-schedule transit systems of Texas was developed. In this concept:

- Eight LOS indicators were identified and defined, including accessibility, travel time, directness of service, delay, frequency of service, reliability, passenger density, and passenger comfort (acceleration, temperature and noise);

- Quantitative values corresponding to levels-of-service A through F were assigned to each indicator (Table S-1); and

- Based on user preferences, a weighting technique was developed to determine the relative importance of each indicator. Passenger density, reliability and frequency of service were ranked the highest (15 points each), followed by travel time, accessibility, directness of service and temperature (10 points each). Delay, acceleration and noise were rated lowest (5 points each).

Table S-1: Summary of LOS Indicators and Their Values

Indicator	LOS A	LOS B	LOS C	LOS D	LOS E	LOS F
Accessibility						
Time, min.	2 or less	3 to 4	5 to 7	8 to 12	13 to 20	20+
Walking Distance, ft.	375 or less	376 to 660	661 to 1320	1321 to 2000	2001 to 3300	3300+
Park-and-Ride, mi.	.5 or less	.6 to 1	1.1 to 2	2.1 to 3	3.1 to 5	5+
Travel Time						
Travel time ratio	1.00 or less	1.01 - 1.10	1.11 - 1.34	1.35 - 1.50	1.51 - 2.00	2.00+
Directness of Service						
Transfers	0	1	1	1 or 2	2	3+
Wait time, min.	0	5	5 to 10	10 or 5	5+	
Delay, min.	0	0 to 1	1 to 2	2 to 4	4 to 8	8+
Frequency of Service						
Large Systems						
Peak, min.	10 or less	11 to 15	16 to 25	26 to 40	41 to 60	60+
Off-peak, min.	15 or less	16 to 30	31 to 45	46 to 60	61 to 90	90+
Small Systems						
Peak, min.	15 or less	16 to 30	31 to 45	46 to 60	61 to 90	90+
Off-peak, min.	30 or less	31 to 40	41 to 50	51 to 60	61 to 90	90+
Reliability						
5 min. headways or less % runs 0 min. early to 1 min. late	85 to 100	75 to 84	66 to 74	55 to 65	50 to 54	<50
6 to 10 min. headway % runs 0 min. early to 1 min. late	90 to 100	80 to 89	70 to 79	60 to 69	50 to 59	<50
11 to 15 min. headway % runs 0 min. early to 3 min. late	95 to 100	90 to 94	80 to 89	65 to 79	50 to 64	<50
15+ min. headways % runs 0 min. early to 5 min. late	98 to 100	95 to 97	90 to 94	75 to 89	50 to 74	<50
Passenger Density	1 seat/pass; individual seperated seats	1 seat/pass; parallel rows of upholstered seats	1 seat/pass; parallel rows of molded seats	Perimeter seating w/ 100 to 110% of seated load	111 to 125% of seated load	More than 125% of seated load
Passenger Comfort						
A) Acceleration Horizontal, ft./sec.^{2}	<1.0	1.0 to 2.0	2.0 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0+
B) Temperature						
Low, degrees F	72	68	64	58	50	<50
High, degrees F	76	78	80	84	90	90+
C) Noise, db	<60	61 to 75	76 to 85	86 to 90	91 to 95	95+

In addition, a LOS concept which utilizes five basic indicators was suggested for possible use in the evaluation of demand-responsive transportation systems.

THE LOS concepts proposed enable the evaluation of an entire transit system, a single route (or run), or a segment of a specific route (or run). These concepts should facilitate both daily transit management and the provision of quality public transportation services throughout the State of Texas.

IMPLEMENTATION STATEMENT

In order to provide the best transportation service possible, transit planners must continuously monitor and evaluate transit system operations. However, an established methodology for evaluating one important aspect of transit operations, level-of-service, has not been developed.

The level-of-service concepts presented in this report enable transit professionals, elected officials, and other decision-makers to effectively evaluate current transit level-of-service and determine where service improvements and/or reductions should be made. The LOS standards proposed should facilitate both daily transit management and the overall improvement of public transportation services.

DISCLAIMER

This report was prepared by the Texas Transportation Institute for the Texas State Department of Highways and Public Transportation in cooperation with the U.S. Department of Transportation, Urban Mass Transportation Administration.

The contents of this report reflect the views of the authors who are responsible for the opinions, findings and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the sponsors. This report does not constitute a standard, specificiation or regulation.

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INTRODUCTION

To achieve the objective of providing fast, dependable and economical public transportation service, the transit systems throughout the State of Texas have strived to provide convenient and comfortable transit service to persons in all sectors of their cities. Particular concern has been expressed toward the provision of transit service to those who depend on it because of income, age or physical limitations (captive ridership).

In addition, the continuing growth of many urbanized areas and the intensifying concern for mobility and energy conservation have increased the awareness of public transit at all levels. The need for mobility in the urban areas, especially during peak travel hours, has grown along with populations to the point that freeways and streets in many of the larger cities in Texas are severely congested. The ability of public transit to aid in alleviating this congestion and improving mobility depends on its ability to effectively evaluate the transit service it is currently providing and determine where service improvements or reductions should be made.

In the past, when the majority of urban mass transportation systems were privately owned, service evaluation was relatively unimportant and the provision, expansion or reduction of service was based on economic considerations. That is, if a service change would result in a net profit (or a lower deficit) it was instituted; if the continued provision of certain services could not be made at a profit, the services were generally discontinued.

This situation has changed considerably in recent years, however. Today nearly all urban transit systems are publicly owned and operated. While there are many reasons for this change, studies indicate that one key factor appears to be the rapidly increasing costs of operation (1, 2, 3)*. It is true that inflation has had an adverse effect on all labor-intensive industries, but the transit industry seems to have been hit particularly hard and has required ever-increasing governmental subsidies to continue operation. After years in which survival rather than progress was their main objective, most transit operators have now become agencies whose purpose is to serve the transportation needs and interests of the public at a reasonable cost. This shift of the transit industry from a private, profit-oriented business enterprise to a public service function operated largely from tax dollars has resulted in the need for new methods of evaluating the efficiency, the effectiveness and the quality of public transportation service. Profitability alone is no longer suitable as a single method of evaluation; additional measures are now needed.

Considerable research has been conducted in response to this need for improved evaluative techniques. Studies have indicated that there are four major elements of service to be evaluated: cost, amount, impacts and quality. Approaches for measuring the first three factors have been developed. The fourth, however, is much more difficult to describe meaningfully since there are no generally accepted standards or evaluative criteria by which quality can be measured. Thus, there exists the problem of assigning a quantitative value to a qualitative judgement.

It has been suggested that quality of urban transit service can be placed into two categories, transportation hygiene factors and level-of-service (LOS) indicators (1). Examples of transportation hygiene factors include interior and exterior vehicle cleanliness, while LOS indicators refer to factors such as travel time, frequency of service and passenger density. While there exists

* Numbers in parentheses refer to references listed at the end of this report.

the need to investigate and develop a methodology for evaluating hygiene factors, this research project primarily addresses the level-of-service concept.

The term "level-of-service" as used in highway planning is a well-defined measure which has had widespread application in highway design and analysis for more than thirty years. The Highway Capacity Manual defines level-of-service by the effects of several highway operational factors, such as operating speed, travel time, traffic interruptions, freedom to maneuver, safety, comfort, convenience and cost (4). Six specific levels-of-service, A through F, are used to represent the entire range of operating conditions for the highway facility, from best (level-of-service A) to worst (level-of-service F).

Only recently has the level-of-service concept been suggested for use in describing the quality of service offered by public transportation. Although this concept has been applied to several case studies in the United States, no generally accepted set of standards or evaluative criteria have been developed which can be applied to the transit systems of Texas.

In response to this problem, Texas Transportation Institute undertook a research project for the Texas State Department of Highways and Public Transportation and the Urban Mass Transportation Administration geared toward the development of a level-of-service concept applicable to the transit systems of Texas. The study began with a literature review of existing LOS models and visits to each of the 19 public transit systems in Texas to discuss various techniques currently in use to assess quality measures of transit service. Based on the results of the literature review and interviews with transit officials, a draft LOS concept was developed in which:

- Various LOS indicators were identified and defined;
- Quantitative values were assigned to each indicator; and

- A weighting technique was developed to determine the relative importance of each indicator.

The results of this research are documented in the following sections of this report. In addition, data collection procedures for LOS evaluation and a sample application of these procedures are presented. Guidelines pertaining to how often LOS evaluations should be conducted are also discussed.

BACKGROUND

Several level-of-service concepts for public transportation, each varying in context, have been used over the last thirty years. However, quality of service evaluation has rarely been the sole topic of study; it has usually comprised only a small part of a larger issue.

Review of Existing Level-of-Service Models

To date, transit level-of-services has been variously defined by one or more of the following attributes: speed, transit travel time, headway, operating ratio, and passenger capacity. There have been few attempts to study or implement systems of service evaluation since the National Committee on Urban Transportation (NCUT) of the Public Administration Service published two manuals on measuring transit service in 1958 (5, 6). In its Procedural Manual 4A, the committee proposed generalized standards for routing, loading, frequency of service (headway), stop frequency, speed, and regularity of service. In addition, warrants for extending service into new areas and curtailing or abandoning existing service were also suggested. Procedural Manual 8A described how to collect data and determine whether or not service was meeting the proposed standards. These two manuals have been the standard references in transit evaluation since their publication.

Another major source of information on service evaluation is the Pennsylvania Department of Transportation (PennDOT) report, Operating Guidelines and Standards for the Mass Transportation Assistance Program. The PennDOT report specifies technical guidelines and standards for transit service in the areas of accessibility, capacity, headways, speed, reliability, passenger comfort and convenience, and directness of service. A supplementary paper by

Vuchic, Tennyson and Underwood (3) discusses the possible application of these guidelines for improving transit service and operating efficiency.

Other studies have included some (or all) of the indicators mentioned above, and a few individual transit operations have developed their own guidelines for transit service (8, 9, 10 and 11). These studies were all attempts to define the minimum characteristics of quality transportation systems for a given set of service variables; however, they do not present a sufficient gradation to permit the evaluation of minor system improvements.

Botzow (12) 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 employs 6 distinct levels-of-service, A through F.

Botzow's overall weighted level-of-service is based 40 percent on the value of time-related attributes (adjusted speed and delay) and 60 percent on the value of the comfort-related attributes (passenger density, acceleration, 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.

Botzow establishes standards for each attribute at each level-of-service. For example, in measuring delay, 0 minutes of delay during a trip is rated level A; 0 to 1 minute of delay for level B, 1 to 2 minutes for level C, 2 to 4 minutes for level D; 4 to 8 minutes for level E and more than 8 minutes for level F. Using this methodology, a transit operator can easily evaluate each variable and, using the assigned weights for that variable, determine the overall level-of-service provided. The author further suggests that if any one comfort factor is assigned a level-of-service F, then the entire trip should receive an overall level-of-service F. The 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 becomes intolerable the entire trip becomes intolerable.

Alter (1) proposes a LOS concept similar in some respects to that of Botzow. Alter uses a composite of basic accessibility, travel time, reliability, directness of service, frequency of service, and passenger density to define transit LOS. Like Botzow, Alter establishes specific standards for each indicator at each level-of-service. Alter, however, goes further and suggests that to use these indicators properly an aggregation of factors is required. He proposes an arbitrary five-point grading scale, in which each of the indicators is also weighted. To determine the overall LOS, the number of points for each LOS indicator is multiplied by the weighting credits; the total number of points accumulated is divided by the total number of weighting credits which then equals the aggregate LOS.

Level-of-Service Evaluation in Texas

Working with various SDHPT District officials, visits to each of 19 transit properties throughout Texas were scheduled in order to determine how transit operators currently undertake self-evaluation of the level-of-service they provide (refer to "Acknowledgements" Section for a list of individuals involved in this project). During the interviews, transit managers and planners were asked to describe their service evaluation procedures by listing and defining the criteria or standards (if any) used to assess the level-of-service, as well as those indicators used to rank or choose selected service improvements or reductions. Basic transit system descriptive data were also requested so that similar size and type of operations could be grouped. Table

1 summarizes the general characteristics of the transit operations by size and basic operating characteristics.

Generally speaking, many of the responses from the transit officials contained information about how they evaluate their internal management performance (through the use of "efficiency" measures) and the evaluation of actual service delivery performance (using "effectiveness" measures) as well as how they evaluate the quality of service (using "level-of-service" measures). An example of an efficiency measure is "revenue vehicle-miles per employee." A typical effectiveness measure would be "passengers per vehicle-mile," while a typical quality measure would be "service reliability or schedule adherence." Since this study concerns the monitoring and evaluation of transit level-of-service, discussion of the data and information obtained from the interviews relate only to the use of quality measures in the evaluation of transit service.

Quality of Service Evaluation in Small Properties

After analyzing the responses from the 13 small transit properties across the state (those which operate up to 50 buses on regular routes and serve populations of less than 250,000), it is apparent that the use of a wide range of explicit, quality-of-service evaluation techniques is not common practice. While the smaller number of buses and routes operated by these properties is conducive to frequent collection and analysis of data related to quality of service measures, comprehensive level-of-service evaluation is nevertheless uncommon. There are several reasons for this lack of extensive level-of-service evaluation:

- Managers of smaller transit properties generally do not feel that they have sufficient financial resources and/or sufficient management, planning or administrative staffs with the capability and/or time to evaluate quality of transit service in a comprehensive manner;

Table 1: Characteristics of Transit Properties in Texas for 1980

Transit Systems	1980 Population Served	Total Servicable Buses	Buses Req'd on Regular Routes	Number of Routes	Total Annual Ridership	Annual Vehicle Miles	Annual Vehicle Hours	Number Employees[1]
Small Properties[2]								
Abilene	98,315	12	6	10	315,918	309,902	18,102	16
Amarillo	149,230	30	14	10	746,664	809,541	97,948	43
Beaumont	118,102	25	16	5	1,500,391	615,422	58,834	41
Brownsville	84,997	22	12	10	1,971,609	572,111	60,386	74
Corpus Christi	231,999	54	28	18	2,081,517	1,377,939	99,471	91
Galveston	61,902	15	11	6	1,149,671	452,058	49,673	32
Laredo	91,449	23	18	12	3,457,180	822,093	92,112	66
Lubbock	173,979	34	27	13	2,748,488	1,021,693	73,741	64
Midland	70,525	7	4	5	96,868	256,865	17,749	18
Port Arthur	61,195	5	4	8	280,901	195,481	14,336	18
San Angelo	73,240	9	5	5	338,111	258,383	23,785	13
Waco	101,261	21	13	14	670,600	476,287	38,805	35
Wichita Falls	94,201	10	8	4	328,549	291,095	20,957	17
Large Properties[3]								
Austin	345,496	80	63	25	6,202,946	2,968,808	242,474	201
Dallas	904,078	504	396	69	35,168,915	13,637,473	984,915	917
El Paso	425,259	95	71	25	9,161,146	4,231,380	302,240	247
Fort Worth	385,141	113	93	34	6,339,043	3,169,175	252,153	222
Houston	1,594,086	586	355	60	46,893,496	18,484,796	1,439,021	1,696
San Antonio	785,410	441	404	72	37,900,409	14,653,420	1,062,029	921

1 Figures do not necessarily reflect the total personnel involved in the daily operation of a transit system. For example, administrative or maintenance personnel who devote only a percentage of their time to transit system operations may be listed as city employees rather than transit system employees.
2 Those which operate up to 50 buses on regular routes and serve populations of less than 250,000.
3 Those which operate 50 buses or more on regular routes and serve populations of 250,000 or more.

Source: References 13 and 15.

- Some of the smaller transit properties are operating with older equipment and/or outdated maintenance facilities and are more concerned with routine delivery tasks than with service evaluation;

- Other systems have only been in operation a very short length of time (or have recently come under new management) and have not had the opportunity to develop comprehensive evaluation procedures which could include LOS.

Of those smaller systems which do evaluate level-of-service in some manner, the most commonly listed criteria are directness of service (transfers), frequency of service (headway) and reliability (schedule adherence). For directness of service, concern was expressed toward minimizing the number of transfers required by tying routes together when possible and minimizing waiting time at transfer points through efficient scheduling. In terms of frequency of service (the maximum amount of time between consecutive buses), the standard for the properties ranged from 30 to 70 minutes. Reliability of service was also a concern as several properties required operators to radio in time points as a check on schedule adherence.

While the criteria above primarily represents goals, minimum standards of service or concerns rather than detailed systems of evaluation, they nevertheless indicate a genuine interest in providing quality transit service.

Quality of Service Evaluation in Large Properties

The larger transit properties of Texas (those which operate 50 buses or more and service populations of 250,000 or more) appear to have more comprehensive service evaluation procedures than do the smaller systems. This is probably because the larger systems tend to have greater financial and staff resources available to conduct evaluations and produce written reports documenting the results of their evaluations. The *quality* of service evaluation is nevertheless an area which has not been touched on extensively, except by the Dallas Transit System (DTS).

The Dallas Transit System currently utilizes 5 major quality of service attributes:

- Route spacing and service convenience;
- Directness of routing and transfers;
- Frequency of service;
- Loading standards; and
- Schedule adherence.

These standards are quantified in a written document and are intended to complement the performance and productivity standards established by DTS.

The VIA Metropolitan Transit Authority in San Antonio also utilizes various quality of service attributes but stresses on-time performance (schedule adherence) above all others.

In general, transit officials across the state recognize the need to continuously monitor and evaluate transit system operations in order that they might provide the best transportation service possible. However, an established methodology for evaluating one important aspect of transit operations, level-of-service, has not been developed. Although many systems have made commitments to move toward the establishment of a systematic evaluative effort in this area, very few have achieved this goal at the present time. It is for this reason that a sample level-of-service concept appropriate for transit properties in Texas was developed and documented in this report.

LEVEL-OF-SERVICE CONCEPT

The level-of-service concept and attributes discussed in this report primarily address fixed-route, fixed-schedule public transit operations. Originally, it was proposed that a LOS concept be developed which would be applicable to both fixed-route and demand-responsive forms of public transport. However, investigations into this possibility and discussions with transit officials throughout the state revealed that the operations of these two types of systems vary too widely to evaluate both by a single set of criteria. Therefore, based on the input from the transit operators, it was decided to concentrate research efforts on developing a LOS concept for fixed-route, fixed-schedule transit operations.

The LOS concept presented in this report was developed based on the findings of a review of existing LOS models and discussions with transit managers, planners and other decision-makers concerning how their systems currently monitor and evaluate the level-of-service provided. The intent of this LOS concept is to provide a more precise measure of the quality aspects of transit service.

Attributes Used to Define Levels-of-Service

The following 8 indicators are used to define transit level-of-service: accessibility, travel time, directness of service, delay, frequency of service, reliability, passenger density and passenger comfort. These indicators were chosen because they represent characteristics which are:

- User oriented rather than operator oriented;
- Operations oriented rather than equipment or facility oriented;
- Trip (or link) specific rather than area related;

- Quantifiable by an independent observer;
- Independent of evaluations of efficiency and effectiveness measures, effects of impacts or costs; and
- Exclusive of any transportation hygiene factors.

Indicator 1 - Accessibility

Accessibility refers to the ability of persons to reach important community destinations such as work, shopping or recreational opportunities from their place of residence with reasonable expenditures of time or effort (6). Persons without available automobile transportation must rely on public modes to reach destinations beyond walking distance. For them, the availability of transit service within a reasonable walking distance from their residence is a crucial determinant of their ability to reach important points.

First, however, it is necessary to determine "basic accessibility." Can the trip be made by transit? Assuming the answer to this question of basic accessibility is positive, then the question of accessibility can be further probed to determine transit access time. Transit access time shall be defined as the time necessary to get to transit from a trip origin, then from transit to the trip destination. It should be noted that basic to this indicator is the requirement that a trip be pedestrian-accessible at least at one end of the trip. While this indicator is defined in terms of time, it may also be defined in terms of distance, but this requires several subdivisions into modes of access (Table 2). Level-of-service C represents the commonly accepted distance for pedestrians to travel to transit. Under this standard, time remains constant and distance changes in relation to mode.

Nearness to a transit stop alone does not necessarily guarantee a resident's accessibility as defined above. The transit routes may not go near important destinations, may require a large amount of travel time or may include several transfers to reach final destinations.

Table 2: Transit Access for One Trip End

LOS	Time	Distance	
		Walking	Park-and-Ride
A	2 min. or less	0 to 375 ft.	.5 mi. or less
B	3 to 4 min.	376 to 600 ft.	.6 to 1 mi.
C	5 to 7 min.	661 to 1320 ft.	1.1 to 2 mi.
D	8 to 12 min.	1321 to 2000 ft.	2.1 to 3 mi.
E	13 to 20 min.	2001 to 3300 ft.	3.1 to 5 mi.
F	20+ min.	3300+ ft.	5+ mi.

Note: Each trip end is evaluated separately with the weighting evenly divided between each.

Source: Reference 1.

Indicator 2 - Travel Time

The length of time required to travel between two points is certainly one of the most important factors considered by an individual when selecting a transportation mode. A trip by transit requiring a large amount of time, perhaps an hour or more, may be deferred or foregone, or may be made using another mode (if available) simply because of the excessive amount of time required to travel by transit. The extra time required to make a trip by transit, rather than by the dominant mode (the private auto) can be caused by a number of different factors including circuitous routing or the number of transit stops along the route. On the other hand, traveling by transit can be faster than by private auto when express service and/or priority treatment for buses are available (16). The ability of public transportation to compete with the private auto in terms of travel time can be measured by the travel time ratio. The ratio is the travel time by transit divided by the travel time by auto. (Note: The time required to gain access to transit is not included in the travel time calculation. Transit access time is measured by Indicator 1 - Accessibility). Table 3 relates the travel time ratio to various levels-of-service.

Table 3: Travel Time Ratio

LOS	Travel Time Ratio	Travel Time Description
A	Less than 1.00	Best service is where transit is faster than auto.
B	1.01 to 1.10	Transit is up to 10% slower than auto.
C	1.11 to 1.34	Transit is up to 1/3 slower than auto.
D	1.35 to 1.50	Transit is up to 50% slower than auto.
E	1.51 to 2.00	Transit is no more than twice as slow as auto.
F	2.00 or more	Transit is more than twice as slow as auto; service is basically for transit dependent.

Source: Reference 1.

Indicator 3 - Directness of Service (Transfers)

It is generally acknowledged that people do not like to transfer to complete a trip. Transfers represent an inconvenience. It is also evident that the riders consider the time necessary to transfer as important as the actual need to make a transfer.

Transportation planning models have dealt with the problem of transfers in a number of ways. One method is to add penalty time (frequently called transit excess time) to the total travel time to emphasize the undesirability of transfers. Others also add the walking and waiting time associated with the transfer. Table 4 proposes to consider transfers independently of travel time and assigns LOS values based on a combination of the number of transfers and the total waiting time associated with them.

Table 4: Directness of Service

LOS	Number of Transfers and Waiting Time
A	0 transfers
B	1 transfer with less than a 5-minute wait
C	1 transfer with a 5 to 10-minute wait
D	1 transfer with more than a 10-minute wait <u>or</u> 2 transfers with less than a 5-minute total wait
E	2 transfers with more than a 5-minute wait
F	3 or more transfers

Source: Reference 1.

<u>Indicator 4 - Delay</u>

Delays represent a reduction in the level-of-service and are defined as unexpected increases in normal running time. This measure is presented in order that occurences of delay may be identified particularly when a level-of-service measurement is needed on a daily basis. Rather than including these individual delays in Indicator 2 - Travel Time, they are considered separately because they represent a more immediately correctable situation. For example, delays due to traffic congestion on a freeway at 5:00 p.m. are an unavoidable everyday occurence which is not easily correctable. Therefore, the extra time required to travel the route should be calculated into the normal schedule running times. On the other hand, traffic queued up 3 blocks on a downtown street due to commercial vehicles double and triple parked at loading zones can be corrected through restriction of commercial vehicle loading or enforcement of parking regulations.

In calculating delay time, the duration of each delay that occurs during a single trip is measured and then added together to obtain a total delay time for that trip. (Note: Delays which result from having to transfer from one route to another are considered separately in Indicator 3 - Directness of Service). The level-of-service values for this measure are presented in Table 5.

Table 5: Delay

LOS	Total Delay Time
A	0 minutes
B	0 to 1 minute
C	1 to 2 minutes
D	2 to 4 minutes
E	4 to 8 minutes
F	8+ minutes

Source: Reference 12.

<u>Indicator 5 - Frequency of Service</u>

Frequency of transit service (often referred to as policy headway) is a measure of the maximum time between consecutive buses. Frequency of service should most appropriately be a function of demand. In many cases it is also based on the relative population densities at each trip end, the time of day, the service type and maximum loadings (<u>1</u>, <u>11</u>). It has also been suggested that frequency of service is a "chicken and the egg" type of situation. To attract riders, there must be initial frequency, or policy frequency. Yet people (particularly those who have a choice) may be discouraged from using public transportation if the time between departures is excessive. The problem, then, is to decide the most appropriate policy headway. Generalized frequency of service standards for large and small transit systems are proposed in Tables 6 and 7 respectively. (Note: Tables 6 and 7 are only meant to suggest the policy or minimum frequencies. Whether or not this minimum amount of service is sufficient to handle the demand is measured by Indicator 7 - Passenger Density.)

Table 6: Generalized Frequency of Service Standards for Large Transit Systems

LOS	Frequency of Service	
	Peak	Off-Peak
A	10 min. or less	15 min. or less
B	11 to 15 min.	16 to 30 min.
C	16 to 25 min.	31 to 45 min.
D	26 to 40 min.	46 to 60 min.
E	41 to 60 min.	60 to 90 min.
F	60+ min.	90+ min.

Table 7: Generalized Frequency of Service Standards for Small Transit Systems

LOS	Frequency of Service	
	Peak	Off-Peak
A	15 min. or less	30 min. or less
B	16 to 30 min.	31 to 40 min.
C	31 to 45 min.	41 to 50 min.
D	46 to 60 min.	51 to 60 min.
E	61 to 90 min.	61 to 90 min.
F	90+ min.	90+ min.

Note: For many small systems, off-peak frequency of service standards will apply throughout the day as these systems serve cities in which the brief duration of peak travel periods does not warrant more frequent transit service.

Indicator 6 - Reliability

The reliability of transit service is directly related to how well the service adheres to its published schedule. Service which fails to run according to schedule adversely affects the travel time of its patrons and their ability to make timely transfer connections. Unreliable service can also discourage the occasional user. Maintenance of proper headways and passenger loading standards are also affected by the degree to which schedules are maintained (11).

Within the transit industry, some officials argue that adherence to strict on-time performance standards is unrealistic since factors such as traffic congestion, accidents or inclement weather can severely hamper transit operations. Admittedly, adverse weather conditions are a factor which cannot be calculated into trip tables except in areas where the weather is always a problem during certain times of the year. Accidents can also sabotage schedule adherence, but the reasoning is the same as for inclement weather: either accidents rarely hurt a schedule, or accidents are so common as to always prevent schedule adherence. In the latter case, Alter suggests that the schedules should be so adjusted. Delays due to traffic congestion can also prevent schedule adherence. However, since traffic congestion is an everyday occurrance in many areas (particularly during peak periods), the extra time needed for travel should be included in the assigned schedule times. Finally, there is the argument that reliability is of less importance than maintaining a "tight schedule" that attempts to encourage operators to provide the fastest service possible (even if it means arriving at and departing from a transit stop early.) From the user's perspective, however, transit should never be early because of the greater inconvenience experienced as a result of missing an early bus, as opposed to waiting for a late bus. Furthermore, properly developed trip tables can accomplish a tight operating schedule while at the same time provide accurate information to the public (1).

In developing a standard for schedule adherence, the National Committee recommends that reliability be expressed as a percentage of operations which run "on time." The Committee also suggests that a higher percentage of runs should be "on time" during those hours of operation when service tends to be less frequent. The premise being: the more frequent the service, the lower the importance of early or late service, and the less frequent the service, the more important reliability. Table 8 establishes standards for schedule adherence based on these recommendations.

Table 8: Indicators of Reliability

5 Minute Headway or Less		6 to 10 Minute Headway	
LOS	% of Runs 0 Minutes Early to 1 Minute Late	LOS	% of Runs 0 Minutes Early to 2 Minutes Late
A	85% to 100%	A	90% to 100%
B	75% to 84%	B	80% to 89%
C	66% to 74%	C	70% to 79%
D	55% to 65%	D	60% to 69%
E	50% to 54%	E	50% to 59%
F	Less than 50%	F	Less than 50%
11 to 15 Minute Headway		**15 Minute Headway or Greater**	
LOS	% of Runs 0 Minutes Early to 3 Minutes Late	LOS	% of Runs 0 Minutes Early to 5 Minutes Late
A	95% to 100%	A	98% to 100%
B	90% to 94%	B	95% to 97%
C	80% to 89%	C	90% to 94%
D	65% to 79%	D	75% to 89%
E	50% to 64%	E	50% to 74%
F	Less than 50%	F	Less than 50%

Source: References 1, 5, 11.

Indicator 7 - Passenger Density

From the transit user's point of view, any density greater than one person per seat is undesirable, particularly when standing is required for considerable periods of time. Many in the transit industry, however, view a standing load as evidence of good planning and optimum utilization of manpower and equipment (1, 5, 11, 17). Nevertheless, standing is strongly disliked by passengers for both comfort and safety reasons, especially if they must travel at high speeds or for long periods of time. Passengers simply prefer to be seated. Furthermore, research has shown that individual seating is favored over the traditional parallel rows of transverse seating (1). Fiberglass, molded seats and perimeter seating are also less desirable from the standpoint of both physical comfort and psychological well-being. This preference in seating arrangements is reflected in Table 9 which suggests level-of-service standards for Indicator 7 - Passenger Density, as the particular type of seat offered is clearly a measure of the quality of ride available.

Table 9: Passenger Density

LOS	Passenger Density at Maximum Load Point
A	Each passenger has an individual, separated seat; or each passenger has a minimum of suburban-type (high-back) seat.
B	One seat per passenger; parallel rows of upholstered seats, with a minimum of 5 sq. ft. per person.
C	One seat per passenger, parallel rows of molded seats, with a minimum of 5 sq. ft. per person.
D	Perimeter seating; or from 3 to 5 sq. ft. per person, or from 100% to 110% of seated load.
E	From 111% to 125% of seated load; or 2 to 3 sq. ft. per person.
F	More than 125% of seated load; or less than 2 sq. ft. per person.

Source: Reference 1.

While Table 9 establishes standards by which each run can be measured, Table 10 recommends acceptable LOS loading standards by type of service and time of day.

Table 10: Recommended Loading Standards by Time of Day and Type of Service

	Acceptable Levels-of-Service	
Time Period	Express and Park-and-Ride Service	Local and Crosstown Service
Peak Hour	LOS D (110% of seated load) or better	LOS E (125% of seated load) or better
Peak Period	LOS C (100% of seated load) or better	LOS D (110% of seated load) or better
Midday and Night	LOS C (100% of seated load) or better	LOS C (100% of seated load) or better

Note: Peak-hour and peak-period standards are applicable to peak direction trips only while midday and night standards apply to both directions.

Source: References 1, 11.

Should the situation arise where the level-of-service along a specific route falls below the standards proposed in Table 10, immediate corrective action should be taken to elevate the level-of-service to a more acceptable level.

Indicator 8 - Passenger Comfort

Levels of comfort on public transit systems are affected by a number of different factors. The effect of crowding on passenger comfort has already been noted in the discussion of Indicator 7 - Passenger Density. Levels of comfort are also affected by acceleration, temperature, and noise. Botzow (12) suggests that each of these effects can be divided into 3 tolerance levels:

- An upper physiological limit beyond which the condition is physically intolerable;
- A limit beyond which the body survives but is uncomfortable; and
- A psychological condition in which the body is comfortable but the situation is not pleasant.

Indicator 8A - Acceleration - Rapid acceleration (or deceleration) results in an increase in overall average system speed, but does so at the expense of passenger comfort. Rapid acceleration is more easily tolerated by a seated passenger than by a standee. Therefore, the levels-of-service proposed in Table 11 were selected with the comfort of the standing passengers in mind. As with other comfort values, the maximum desirable comfort value for acceleration is considerably less than the physical time of 1 g or 32.2 ft./sec.^{2} Furthermore, the maximum value need only be reached once during a trip in order to have the system rated at the associated lower level-of-service (12).

Table 11: Acceleration/Deceleration

LOS	Horizontal (ft./sec.^{2})
A	Less than 1.0
B	1.0 to 2.0
C	2.0 to 3.0
D	3.0 to 3.5
E	3.5 to 4.0
F	More than 4.0

Note: Values below LOS D should occur rarely, and LOS F should occur only at the time of an accident.

Source: Reference 12

Indicator 8B - Temperature - It is generally agreed that 72°F is a desirable temperature for heating transport vehicles and 76°F is a suitable temperature for cooling vehicles (12). Actual thermostat settings should be lower, however, to compensate for heat loads generated by passengers, lights, motors, and outside air that is circulated for ventilation and reduction of offensive odors. Table 12 presents level of service values for temperature.

Table 12: Temperature

LOS	Low (degrees F.)	High (degrees F.)
A	72	76
B	68	78
C	64	80
D	58	84
E	50	90
F	<50	90+

Source: Reference 12.

Indicator 8C - Noise - Noise is defined as loud, discordant, or disagreeable sounds experienced by passengers while inside the transit vehicle. Loud noise is often cited as an undesirable feature of a transit system. The selected unit of measure for noise is decibels (db) or noise level sound pressure ratio. LOS values for noise are presented in Table 13.

Other Conceptual Indicators

A number of measures have been deliberately excluded from the LOS indicators proposed in this report including ridership, public cost, marketing and public information services, and vehicle cleanliness as they do not directly measure a level-of-service provided by a transit system. Ridership, for

Table 13: Noise

LOS	Noise (db)
A	Less than 60
B	61 to 75
C	76 to 85
D	86 to 90
E	91 to 95
F	More than 95

Note: A system is rated LOS F if noise within vehicle exceeds 95 db; for 2 hours per day of sound of 100 db or more can cause permanent hearing loss.

Source: Reference 12.

example, is a response to a specific level-of-service offered by a system. As such, it is an important performance indicator, but in no way does it directly measure level-of-service.

Public cost (subsidy required) is partially created by the LOS offered. The individual cost, or fare, depends on the willingness of the rider to pay for the LOS offered. That willingness, however, may be constrained by the ability to pay or by the availability of alternative means of travel. There is ample evidence that people are willing to pay (if they are able) higher prices for higher quality service (1, 15).

Marketing and public information services are both vital components in the provision of transit services and are therefore considered part of the transit organization. However, they do not affect the operating service at a given time; rather, they represent a means to generate changes in travel behavior. Furthermore, if riders who have a choice are displeased with the level of service provided, any change in travel behavior created by marketing and public information is only temporary.

Studies and surveys have indicated that interior and exterior vehicle cleanliness are very important to many transit riders. While it may be possible to identify degrees of cleanliness, this characteristic is nevertheless a transportation hygiene factor and is outside the concept of level-of-service evaluation.

LOS Indicators in Quality of Service Evaluation

To summarize, 8 level-of-service indicators are proposed for use in measuring the quality of transit service:

- Accessibility,
- Travel time,
- Directness of service,
- Delay,
- Frequency of service,
- Reliability,
- Passenger density, and
- Passenger comfort (a composit of acceleration, temperature and noise).

These indicators and the proposed values for each are summarized in Table 14. Possible methods of collecting data necessary for the evaluation of each indicator are presented in the following section.

Use of LOS Indicators

The LOS indicators proposed in this report have a variety of practical applications in the evaluation of the quality of transit service. For example, a comprehensive LOS evaluation could include all 8 indicators in an overall

Table 14: Summary of LOS Indicators and Their Values

Indicator	LOS A	LOS B	LOS C	LOS D	LOS E	LOS F
Accessibility						
Time, min.	2 or less	3 to 4	5 to 7	8 to 12	13 to 20	20+
Walking Distance, ft.	375 or less	376 to 660	661 to 1320	1321 to 2000	2001 to 3300	3300+
Park-and-Ride, mi.	.5 or less	.6 to 1	1.1 to 2	2.1 to 3	3.1 to 5	5+
Travel Time						
Travel time ratio	1.00 or less	1.01 - 1.10	1.11 - 1.34	1.35 - 1.50	1.51 - 2.00	2.00+
Directness of Service						
Transfers	0	1	1	1 or 2	2	3+
Wait time, min.	0	5	5 to 10	10 or 5	5+	
Delay, min.	0	0 to 1	1 to 2	2 to 4	4 to 8	8+
Frequency of Service						
Large Systems						
Peak, min.	10 or less	11 to 15	16 to 25	26 to 40	41 to 60	60+
Off-peak, min.	15 or less	16 to 30	31 to 45	46 to 60	61 to 90	90+
Small Systems						
Peak, min.	15 or less	16 to 30	31 to 45	46 to 60	61 to 90	90+
Off-peak, min.	30 or less	31 to 40	41 to 50	51 to 60	61 to 90	90+
Reliability						
5 min. headways or less: % runs 0 min. early to 1 min. late	85 to 100	75 to 84	66 to 74	55 to 65	50 to 54	<50
6 to 10 min. headway: % runs 0 min. early to 1 min. late	90 to 100	80 to 89	70 to 79	60 to 69	50 to 59	<50
11 to 15 min. headway: % runs 0 min. early to 3 min. late	95 to 100	90 to 94	80 to 89	65 to 79	50 to 64	<50
15+ min. headways: % runs 0 min. early to 5 min. late	98 to 100	95 to 97	90 to 94	75 to 89	50 to 74	<50
Passenger Density	1 seat/pass; individual seperated seats	1 seat/pass; parallel rows of upholstered seats	1 seat/pass; parallel rows of molded seats	Perimeter seating w/ 100 to 110% of seated load	111 to 125% of seated load	More than 125% of seated load
Passenger Comfort						
A) Acceleration Horizontal, ft./sec.^{2}	<1.0	1.0 to 2.0	2.0 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0+
B) Temperature						
Low, degrees F	72	68	64	58	50	<50
High, degrees F	76	78	80	84	90	90+
C) Noise, db	<60	61 to 75	76 to 85	86 to 90	91 to 95	95+

evaluation of transit system service. On the other hand, the LOS evaluation could be limited to a single route, or to a pair of stops along a route. In addition, it is also possible to single out one or two LOS indicators and apply them to an entire system, a single route, or a pair of stops. When using only one LOS indicator to evaluate a specific characteristic, the LOS values A through F proposed for each are sufficient for the evaluation. However, to use all of these indicators efficiently in an evaluation, an aggregation of factors is necessary. First, a 5-point scale is proposed in which:

LOS A = 5 points
LOS B = 4 points
LOS C = 3 points
LOS D = 2 points
LOS E = 1 point
LOS F = 0 point

Next, because not all service attributes are equally important, it is necessary to determine the relative importance of those indicators for which values are proposed. Studies and surveys (<u>12</u>, <u>15</u>, <u>16</u>, <u>17</u>) have shown that transit riders place the highest importance on the following five characteristics of service:

- Frequent bus service (especially during morning and evening peak periods),
- Reliable bus service,
- Always having a seat on the bus,
- Comfortable temperatures inside the bus (in both summer and winter), and
- Faster bus service.

The ranking system proposed in Table 15 was developed based on these user preferences. Frequency of service, reliability, and passenger density are ranked the highest (15 points each), followed by travel time, temperature, accessibility and directness of service (10 points each). Delay, acceleration and noise are ranked lowest (5 points each), as these three considerations are perceived by users as being areas where problems are less likely to occur. (Note: Each community could develop its own ranking for the indicators based on local rider attitudes.)

Table 15: Weighting System for Level-of-Service Indicators

LOS Indicators	Weight
1 - Accessibility	10
2 - Travel Time	10
3 - Directness of Service	10
4 - Delay	5
5 - Frequency of Service	15
6 - Reliability	15
7 - Passenger Density	15
8 - Passenger Comfort	
A) Acceleration	5
B) Temperature	10
C) Noise	5

Note: Total number of weighting credits equals 100.

To determine the overall level-of-service rating for a transit route, the number of points for each indicator is first multiplied by the weighting credits for each. Next, the resulting products are added together and that sum is then divided by 100 (the total number of weighting credits.) The final answer will be a number from 1 to 5 which will correspond to a level-of-service A through F. This procedure for determining an overall LOS rating is illustrated in Table 16.

Table 16: Procedure for Determining a LOS Rating for a Single Transit Route

Indicator	LOS Rating	LOS Rating Points	x	Weight of Indicator	=	Total Points
Accessibility	B	4	x	10	=	40
Travel Time	C	3	x	10	=	30
Directness of Service	B	4	x	10	=	40
Delay	A	5	x	5	=	25
Frequency of Service	B	4	x	15	=	60
Reliability	C	3	x	15	=	45
Passenger Density	A	5	x	15	=	75
Acceleration	A	5	x	5	=	25
Temperature	B	4	x	10	=	40
Noise	A	5	x	5	=	25
						405

FINAL ANSWER: 405 ÷ 100 = 4.05 or LOS B

Note: Under this procedure, a transit route may offer an overall level-of-service that is higher or lower than the level-of-service exhibited by an individual indicator.

To determine an overall LOS rating for an entire transit system, the procedure is basically the same as that for a single route. The only difference is that a LOS value A through F is assigned to each indicator based on how the entire system (rather than one route) measures up in each category.

Frequency of Evaluation

The frequency and detail of the LOS evaluation should to a large extent depend on the individual transit system's need and the staff and financial resources available. Generally speaking, a rather detailed LOS evaluation focusing on each route individually, as well as the system as a whole, should be conducted on an annual basis. However, it may be desirable to evaluate specific routes more often. It may also be advisable to single out one or two indicators, such as reliability or passenger density, to conduct a route-by-route or system-wide evaluation on a monthly, weekly or even daily basis (staff and financial resources permitting).

Demand-Responsive Transportation Systems

The LOS model presented in this report primarily addresses fixed-route, fixed-schedule transit operations. A similar model could also be developed for demand-responsive (D-R) transportation systems. However, because of the differences in operating characteristics of the two, not all of the indicators selected for the fixed-route model would be applicable to a demand-responsive transportation LOS model.

For example, since demand-responsive systems are characterized by the door-to-door pickup and delivery of passengers, accessibility and directness of service (transfers) as defined in the fixed-route LOS model would not be applicable in a D-R model. Passenger density also would not be an appropriate indicator as vehicles operated by D-R systems (typically station wagons, vans or small buses) are generally not scheduled to pick up and deliver more passengers than they have seating for in the vehicles. In addition, frequency of service (maximum headways between scheduled buses) would not be a consideration since D-R systems do not operate on a fixed-route, fixed-schedule basis. In place of frequency of service, Alter suggests using wait time to measure how long it takes a D-R vehicle to respond to a request for service.

Other indicators which would be applicable to a D-R LOS model include travel time, delay, reliability and passenger comfort (acceleration, temperature and noise). Travel time, for example, is an important characteristic to be evaluated because although D-R service is door-to-door (like the private auto), it is not necessarily as fast as traveling by auto. This is due to the additional time often required to pick up and/or deliver other passengers along the way. Delay (the unexpected increase in normal travel time) and passenger comfort (acceleration, temperature and noise) are also factors which influence the quality of service offered by D-R systems and, therefore, should be evaluated.

Generally speaking, the same values for travel time, delay and passenger comfort suggested for use in the fixed-route LOS model could also apply to a D-R model. Reliability, however, should probably be defined in a somewhat different manner. As discussed previously, scheduled runs along a fixed route should never arrive at stops early due to the greater inconvenience experienced as a result of missing an early bus as opposed to waiting for a late bus. In demand-responsive system operations, however, early arrival at a client's origin does not cause quite the same inconvenience as drivers are usually instructed to wait 5 to 10 minutes for the client before going on to the next stop. Therefore, different values for reliability are proposed.

Table 17 outlines possible D-R LOS indicators and the range of values proposed for each.

To use these indicators in an overall evaluation, an aggregation of factors is necessary. Again, the 5-point scale in which:

LOS A = 5 points,
LOS B = 4 points,
LOS C = 3 points,
LOS D = 2 points,
LOS E = 1 point, and
LOS F = 0 point

is suggested. To determine the relative importance of each indicator the

Table 17: Possible LOS Indicators and Range of Values

LOS Indicator	LOS A	LOS B	LOS C	LOS D	LOS E	LOS F
Wait Time, min.	9 or less	10 to 14	15 to 25	25 to 60	60+	24 hrs.+
Travel Time						
Ratio of the travel time by auto to the travel time by D-R transit.	$\leq$1.00	1.01 to 1.10	1.11 to 1.34	1.35 to 1.50	1.51 to 2.00	2.00+
Delay, min.	0	0 to 1	1 to 2	2 to 4	4 to 8	8+
Reliability						
% of trips not more than 10 min. early or 10 min. late	90 to 100	80 to 89	70 to 79	60 to 69	50 to 59	<50
Passenger Comfort						
Acceleration Horizontal, $ft./sec.^2$	<1.0	1.0 to 2.0	2.0 to 3.0	3.0 to 3.5	3.5 to 4.0	4.0+
Temperature						
Low, degrees F.	72	68	64	58	50	<50
High, degrees F.	76	78	80	84	90	90+
Noise, db	<60	61 to 75	76 to 85	86 to 90	91 to 95	95+

Source: References 1, 12

ranking system in Table 18 is proposed. Under this system, reliability and wait time are ranked highest (20 points each), followed by travel time and temperature (15 points each). Acceleration, noise and delay are ranked the lowest (10 points each) as these are areas where problems are less likely to occur.

Table 18: Weighting System for D-R Transportation LOS Indicators

LOS Indicator	Weight
1 - Wait Time	20
2 - Travel Time	15
3 - Delay	10
4 - Reliability	20
5 - Passenger Comfort	
A) Acceleration	10
B) Temperature	15
C) Noise	10

Note: Total number of weighting credits equals 100.

The procedure for determining an overall LOS rating for a D-R transportation system is similar to the procedure outlined in the fixed-route model. First, the number of points for each indicator is multiplied by the weighting credits for each. Next, the resulting products are added together and that sum is divided by 100 (the total number of weighting credits). The final answer will be a number from 1 to 5 which will correspond to a level-of-service A through F.

Use of D-R LOS Indicators and Model

Like the LOS model for fixed-routes, a D-R model has practical application in a comprehensive evaluation of an entire system's operations, a single run, or a pair of stops along a run, or, one or two LOS indicators can be singled out and applied to either the entire system, a single run, or a pair of stops along a run.

Frequency of Evaluation

Again, the frequency and detail of LOS evaluation of demand-responsive systems will depend on the individual system's needs and the financial and staff resources available. However, at least once a year, a comprehensive evaluation of the entire system is suggested.

DATA COLLECTION PROCEDURES FOR LEVEL-OF-SERVICE EVALUATION

This report proposes a series of LOS indicators and how they might be used in an evaluation of the level-of-service currently being provided by both fixed-route and demand-responsive public transportation systems. To use these various indicators effectively, however, requires assembling a reliable data base. Procedures which might possibly be used for the collection of data necessary to evaluate each LOS indicator are briefly described in this section. When proposing these methods of data collection, the major concern was suggesting procedures which are practical for transit systems to undertake, requiring as little additional manpower and expenditure of funds as possible. Thus, whenever possible, the suggested procedures utilize data currently available to most transit systems.

Accessibility

The number (or percent) of residents which have LOS A through F access from their homes to fixed-route public transit service can be calculated by plotting transit routes and stops on a base map showing population distribution for each neighborhood. (Most systems have access to census information which is disaggregated by district or block. As census data becomes dated, rough updatings of the population distribution would be needed.)

Pedestrian access to each transit stop can be measured by delineating the area from which each stop can be reached in a specified amount of time (2 minutes or less for LOS A, 2 to 4 minutes for LOS B, etc.). In measuring distance to transit stops any physical barriers which might limit direct access to the transit stop should be considered. This same procedure can be repeated on a separate base map to determine LOS A through F Park-and-Ride transit access.

While transit access can generally be determined from secondary data, it can also be determined from on-board surveys. The advantage of the on-board surveys is that is is possible to ask questions pertaining to transit access time and/or distance for <u>both</u> trip ends, whereas the mapping technique described previously is primarily concerned with determining access time/distance from a trip origin (usually "home") to a transit stop (rather than from a transit stop to a trip destination).

The techniques described above estimate number (or percent) of residents who have reasonable access to fixed-route transit service (LOS A through E). They also provide an estimate of the number (or percent) of persons who are <u>without</u> reasonable access to transit service (LOS F). However, it is likely that many of these residents own or have regular access to an automobile and therefore may not require or desire transit service. It is also desirable, then, to provide an estimate of the number of residents who depend on transit service and do not have reasonable access to it.

Persons most likely to rely on public transit (thereby warranting special consideration in application of this measure) include:

- Members of families without automobiles;
- Adults in families who do not have regular access to an automobile (such as housewives without an automobile during the daytime hours);
- Adults who are unable or unwilling to drive;
- Children or adolescents unable to drive, but able to use public transit independently.

An estimate of the number of persons in each neighborhood in these categories can be based on automobile ownership and family size data from census counts or citizen survey data. In interpreting data for each neighborhood, it is also important to consider subgroups which have special need for transit service, such as the elderly and the handicapped. On each map, rest homes, convalescent hospitals and facilities for the care of handicapped persons could be identified (8).

For those persons who do not have reasonable access to transit (LOS F), the solution might be as simple as adding another stop along an existing route or as complex as adding another route. The ultimate route spacing and number of stops will depend on density, income, terrain, service type, distance from activity centers, headways and financial considerations.

Travel Time

A study of the travel time over the length of a regularly scheduled transit route (or a scheduled run of a demand-responsive transportation system) covers the actual running time, or the time the vehicle is in motion between scheduled "time points." In a fixed-route, fixed-schedule system, time points are established along each route in both directions and usually remain constant until the route is modified. In demand-responsive transportation systems, time points are estimated for each scheduled run of the day and usually change from day to day as new runs are planned to meet the current day's demand. These time points are established as a means of control over operations to assure that service will be available when and where it is needed.

In an effort to provide minimum travel times for their passengers, transit planners take into consideration variations in running time which occur during different hours of the day and different days of the week. Systematic running time checks on a regular basis are essential so that transit planners and schedulers are fully aware of actual travel conditions on the streets - as measured by travel time. In this way measuring and improving service is possible by adjusting schedules.

Travel running time checks should cover an entire day's operation from early morning to late night. There are several ways to conduct running time studies, however. It is possible to obtain travel time data from either "standing" checks made at two or more street locations along a route or from "riding" checks made by personnel riding the transit vehicle. The advantage of the riding check is that personnel can observe operations and conditions which bring about interference and delays.

After transit travel time field data are summarized, it is then possible to compare it to automobile travel time data. The ability of public transit to compete with the automobile in terms of travel time is measured by the travel time ratio. The ratio is the travel time by transit divided by the travel time by auto measured for each daily period. It is desirable for special city-sponsored studies of transit travel time and auto travel time to be made simultaneously - usually on a normal weekday (Tuesday, Wednesday or Thursday). It may be necessary for the city or the transit system, or both, to adopt temporary coinciding time points other than their usual time points so that travel time observations are made over identical lengths of the same control section.

When special transit time studies are conducted simultaneously with the city traffic authority's surveys of auto travel time, the following sampling process is recommended by the National Committee (6) to obtain accurate transit running time data.

- Six runs for each time period would be made for those transit routes on major streets where comparable automobile running time studies are conducted: a.m. peak., in the inbound direction; base period, in both directions; p.m. peak in the outbound direction, a total of 24 runs.

- Two of the six runs should be made on each of three weekdays - Tuesday, Wednesday, and Thursday. The runs should be preselected to be representative of each time period and to avoid duplications.
- The six runs during each time period should be averaged. After obtaining this average, the difference between each reading and the average should be computed. The differences should then be summed. If the sum of the differences is less than the average of the six readings, the average may be considered representative; if not, it is recommended that more runs be checked to obtain greater accuracy.

The six representative runs for each daily period and direction should then be totaled and an average travel time for the direction and period be determined. This average is directly comparable to the auto travel time figure obtained in the simultaneous study for that same period and direction on the same group of survey days. The travel time ratio is then determined from these figures. The resulting values will correspond to LOS A through F for travel time.

Directness of Service (Transfers)

Direct service from a trip origin to a trip destination is desirable throughout a public transit system, as it is generally acknowledged that riders do not like to transfer from one route to another in order to complete a trip. Transfers mean additional time is usually required to reach final destinations. However, it is not economically feasible to provide every transit patron with directly routed service (11).

Levels-of-service A through F for directness of service can easily be determined for each route from a review of transfer tickets collected, operator records and schedule information on transfer times. It is also possible to obtain information pertaining to transfers from on-board surveys. Transfer data from each route should be collected and analyzed to determine the percentage of riders who experience LOS A through F for directness of service. To determine a route's overall LOS rating for directness of service, the number of points for each LOS rating (5 points for LOS A, 4 for LOS B, 3 for LOS C, etc.) is first multiplied by the percentage of patrons who experienced each LOS. Next, the resulting products are added together and that sum is then divided by 100. The final answer will be a number from 1 to 5 which will correspond to an overall LOS A through F for the directness of service indicator. An example of this procedure is presented in Table 19.

Table 19: Procedure for Determining a Route's Overall LOS Rating for Directness of Service

LOS Rating	LOS Rating Points	x	% Patrons Experiencing Each LOS	=	Total Points
A	5	x	86	=	430
B	4	x	12	=	48
C	2	x	2	=	4
					482
FINAL ANSWER:	482 ÷ 100 = 4.82 4.82 when rounded to nearest whole number = 5 or LOS A.				

Delay

The purpose of collecting and evaluating delay is to identify controllable causes of delay to normal transit running time so that they may be addressed as necessary. This should ultimately bring about smoother transit operations in terms of travel time and convenience and should also improve the general flow of traffic.

Evaluation of the cause and duration of delays in normal travel time can be coordinated with the transit running time checks outlined previously. In recording each delay encountered along a specific route (or D-R run), observers equipped with stop watches must note the location of the delay, the stop watch reading at the beginning of the delay, stop watch reading at the end of the delay and the cause of the delay.

In cases where extremely long delays are experienced, the National Committee (6) suggests that investigations be conducted which would explore the possibilities of improving the movement of all vehicles, including transit, through:

- Enforcement of existing traffic and parking regulations;
- Improved traffic control measures and devices;
- Improved traffic signal timing and progression for transit and automobile operations;
- Restriction of curb parking in the prevailing direction of traffic flow during high-volume hours;
- Restriction of commercial vehicle loading;
- Restriction, and eventual elimination, of double parking;
- Pedestrian control, or elimination of such controls where not needed;
- Provision of adequate transit stops and terminal facilities;
- Provision of reserved transit lanes;
- Provision of reserved transit streets; and
- Provision for the operation of transit on expressways.

Frequency of Service

Frequency of service (often referred to as service headway) is a measure of the maximum amount of time between consecutive buses traveling in the same direction along a route. For most transit systems, the frequency of service will vary according to the time of day and day of week. During peak travel hours, service headways are generally based on ridership demand and service tends to be more frequent. On the other hand, during off-peak periods (midday, night and weekend) demand is not as great, and service tends to be less frequent. In fact, off-peak service is often operated at intervals determined by policy or constrained by the running time required to make a complete circuit of the route (11).

Data on frequency of service to be used in LOS evaluation may be obtained by reviewing schedule information for each route. From these schedules it is possible to determine the maximum headways between consecutive buses (in both directions) for any time of the day or day of the week. These figures can then be compared to values for level-of-service A through F for frequency of service.

Reliability

The reliability or dependability of transit service is directly related to how well the service adheres to its schedule. Data on service reliability (or schedule adherence) for use in LOS evaluation can be obtained in a number of different ways. For example, many transit systems (both fixed-route and demand-responsive) have vehicles equipped with 2-way radios and require operators to radio in at various time points along their routes (or D-R runs). It is also possible for operators to phone in time points (as is the practice with VIA in San Antonio) when 2-way radios are not available.

Checks on service reliability can also be conducted simultaneously with riding checks on travel time and delay, as it is also possible to record actual vehicle arrival times at various stops or time points while recording information necessary to evaluate travel time and delay.

In some cases, it may also be desirable to set up checkpoints at various street locations along a specific route to conduct additional studies of service reliability. As the transit vehicle passes a checkpoint, the route name, train (or block) number, vehicle number and time are recorded.

Data on actual transit arrival time (obtained from radio, phone, riding checks or checkpoint stations) are then compared with the scheduled times and the number of minutes ahead or behind schedule is determined. The percentage of trips which ran "on-time" is then calculated and the level-of-service A through F identified.

Passenger Density

Levels-of-service A through F for passenger density can be determined from passenger load data. Transit passenger loads are generally observed and recorded at predetermined points along a route where the heaviest loads are known to occur. The point (or points) of maximum passenger load on a route may be determined by a series of trial-and-error passenger load counts at several likely points, or by an "on and off" passenger riding check on vehicles in the prevailing direction during peak hours of travel (6).

Generally, the entire day's operating schedule of a route should be checked in order to determine the extent of transit travel throughout the peak, off-peak and night periods. However, more frequent checks covering shorter periods of time may also be desirable so that routine schedule adjustments can be made on a more regular basis.

In conducting passenger load checks, the passengers in every transit vehicle are counted as they pass a predetermined point. The first step is to record the train (or block) number, vehicle number, and a code designation for vehicle destination as the vehicle approaches. The second step is to record the arrival (and/or departure) time of the vehicle to the closest half-minute. The checker then counts and records the heavier load (arriving or leaving) and designates which it is. To assure a high degree of accuracy, experience indicates that the checker should be stationed at a point opposite the front end of the transit vehicle when it has come to a stop. This allows the checker to walk alongside the vehicle, if necessary, to facilitate the counting of passengers (6).

Passenger load counts can also be coordinated with travel time, delay, and reliability studies as maximum load counts may be recorded while riding the transit vehicle and collecting data for these other areas of evaluation. Many transit systems feel that simply reviewing the individual checking records as they come in from the field does not provide an adequate picture of the loading characteristics on that line. For this reason, it is recommended that summaries of the load data be prepared so that the results of several days' checks may be studied simultaneously and trends observed. Load data from these summaries may then be totaled for 15- to 30-minute time periods, depending upon the time of day. The average load per vehicle for each such period is computed (total load divided by the number of vehicles carrying it). This average vehicle load is then divided by the seating capacity of the transit vehicle and multiplied by 100 to determine the percentage loading of seating capacity. The result will be a percentage which will correspond to a level-of service A through F.

Passenger Comfort

Levels-of-service A through F for the three indicators of passenger comfort (acceleration, temperature and noise) may be determined for each route on the basis of data collected from riding checks conducted on the transit vehicle. During these riding checks, acceleration, temperature and noise levels should be measured and recorded at those points along the route (or D-R run) where the heaviest passenger loads are known to occur. This procedure is necessary to provide a more accurate picture of passenger comfort as temperature and noise levels are affected by the number of passengers on board. In addition, acceleration becomes a particularly important consideration when there are passengers standing in the aisles or seated in wheelchairs.

Temperature and noise levels may be measured by taking readings from a thermometer and sound level meter at regular intervals (every 30 seconds, for example). The maximum temperature and sound level readings are then compared to levels-of-service A through F for the temperature and the noise indicators.

Acceleration/deceleration may be determined by observing the speedometer on the transit vehicle and recording how many seconds it takes the vehicle to accelerate/decelerate from one speed to another (such as the number of seconds to accelerate from 0 to 10 mph, from 10 to 20 mph, 20 to 30 mph, etc., or the number of seconds to decelerate from 50 to 40 mph, 40 to 30 mph, etc.). Then, the fastest acceleration/deceleration time is used in the computation of the acceleration/deceleration rate. After converting miles per hour (mph) to feet per second (fps), the following formula can be applied to yield the acceleration/deceleration rate.

$$\frac{V_f - V_o}{t} = a$$

where: V_f = final velocity
V_o = initial velocity
t = time
a = acceleration rate (in feet per second^2)

Note: 1 mph = 1.47 fps

The final answer (expressed in feet per second^2) is then compared to levels-of-service A through F for acceleration.

Wait Time

In a demand-responsive system, transit wait time measures the amount of time required from the time a client requests service to the time it is promised. (Whether or not the service actually arrives when promised is measured by the indicator reliability.) Data on wait time to be used in a LOS evaluation can usually be obtained by reviewing the records of the scheduling and dispatching department. When a client phones in a request for service, the time he phones in and the time he is promised service are generally recorded along with his origin, destination and other pertinent information. The wait time for a particular trip is determined by calculating the number of minutes, hours or days which elapse from the time service is requested to the time it is scheduled or promised. This figure is then compared to values corresponding to levels-of-service A through F.

EXAMPLE APPLICATION OF LOS DATA COLLECTION AND EVALUATION PROCEDURES

To further illustrate how a level-of-service evaluation might be conducted, the data collection and evaluation procedures outlined previously were applied to the analysis of an outbound and inbound trip on the Austin Transit System South Congress #13 route. The 8:25 a.m. outbound trip and the 8:55 a.m. inbound return trip were selected for study.

The evaluation was conducted on a Tuesday morning during clear weather conditions. Two surveyors boarded the South Congress bus and collected the information necessary for LOS evaulation. One surveyor was stationed toward the back of the bus and recorded information on travel time, delay, passenger loads, temperature and noise levels using the field inventory form illustrated in Figure 1. The other surveyor, who remained at the front of the bus, was responsible for recording data on acceleration/deceleration and distributing on-board survey questionnaires. An example of the form used for recording acceleration/deceleration data and a sample survey questionnaire are presented in Figures 2 and 3 respectively.

In addition to the outbound and inbound riding checks conducted while on board the transit vehicle, auto travel time checks were also conducted along the same trip link during the midmorning time period. Twelve auto travel time checks (6 in each direction) were run. Auto travel times for each direction were then averaged to compare transit travel time to auto travel time in each direction of travel. Data from the transit riding checks and auto travel time checks were then grouped according to direction of trip (whether outbound or inbound), summarized and compared to levels-of-service A through F for the various indicators. An overall LOS rating for both the outbound and inbound trip was also determined using the weighting technique described previously.

TRANSIT SYSTEM ______________________ DATE ______________________

ROUTE NAME AND NUMBER ______________________ DAY OF WEEK ______________________

RUN ______________________ WEATHER ______________________

From	Time	To	Time	Passengers	Noise	Temperature	Delay

Figure 1: Form Used for Recording Data on Travel Time, Passenger Loads, Noise Levels, Temperature and Delays

TRANSIT SYSTEM____

ROUTE NAME AND NUMBER________________________ DATE____________________

RUN____ DAY OF WEEK_____________

WEATHER___________________

ACCELERATION (mph)					DECELERATION (mph)				
0-10	10-20	20-30	30-40	40-50	50-40	40-30	30-20	20-10	10-0

Figure 2: Form Used for Recording Acceleration/Deceleration Data

TRANSIT USER SURVEY

Conducted by Texas Transportation Institute in cooperation with the Austin Transit System

1. How did you arrive at the transit stop this morning?

   _____ Walked   _____ Dropped off by someone   _____ Other

2. How long did it take you to walk/ride to the transit stop? _______ Minutes

3. Will it be necessary for you to transfer to another bus in order to reach your final destination? _____ Yes   _____ No

4. After leaving this bus (or the bus you will transfer to later), how long will it take you to walk to your final destination? _____ Minutes

THANK YOU FOR YOUR COOPERATION

Figure 3: On-Board Survey Questionnaire

Level-of-Service Rating by Individual Indicator

The following is a description of the level-of-service rating for the accessibility, travel time, directness of service, delay, frequency of service, reliability, passenger density and passenger comfort indicators. The ratings were based on results of the on-board survey questionnaire, data collected during the transit vehicle riding checks, auto travel time checks, and schedule information obtained from the Austin Transit System.

Accessibility

The results of the on-board survey questions "How long did it take you to walk/ride to the transit stop?" and "After leaving this bus (or the bus you will transfer to later), how long will it take you to walk to your final destination?" were used to determine accessibility. For each survey completed (13 in the outbound direction and 14 in the inbound direction), transit access times listed were added together and divided by 2 to yield an average access time. Next, these averages were grouped according to outbound or inbound direction of the trip, added together and then divided by the total number of responses for each direction. Access time for persons surveyed during the outbound trip averaged 6.5 minutes, or LOS C. Access time for those surveyed during the inbound trip averaged about 7.5 minutes, slightly longer than the outbound trip, but still within the range of LOS C.

Travel Time

The LOS rating for the Travel Time indicator was determined using travel time data collected during the transit riding checks and the average auto travel time computed from the auto travel time check data. The travel time ratio (transit travel time divided by auto travel time) was then applied. The travel time ratio equalled 1.45 for the outbound trip and 1.14 for the inbound trip. Both of these ratios fall within the range of LOS D for the Travel Time indicator.

Directness of Service

The results of the on-board survey question, "Will it be necessary for you to transfer to another bus in order to reach your final destination?" was used to determine directness of service. For the outbound trip, 51% of the riders experienced LOS A and the remaining 49% experienced LOS B in the category of directness of service. In the inbound trip, 22% experienced LOS A and the remaining 78% experienced LOS B. (Note: Transfers were made to and from the M. L. King route which connects with the South Congress route at 6th Street and Congress. Persons transferring from one route to the other remained on the same bus to continue their trip and there was no waiting period where the 2 routes connected.)

The overall LOS rating in the category of directness of service was calculated using the procedure outlined in the previous section. The overall rating was found to be 4.51 for the outbound trip and 4.22 for the inbound trip. After rounding these figures to the nearest whole numbers, the outbound trip was rated a LOS A and the inbound trip to LOS B for directness of service.

Delay

No delays in normal running time were recorded in either the outbound or inbound direction. A LOS A rating for the indicator of Delay was therefore given to both the outbound and inbound trips.

Frequency of Service

The frequency of service (or headway) in both directions was determined from schedule information provided by the Austin Transit System. Service in both directions was operated on 30-minute headways during the time period surveyed (off-peak) and therefore rated a LOS B.

Reliability

The reliability of service was determined by comparing data on actual transit arrival times (at various points along the outbound and inbound trips) to scheduled arrival times. The number of minutes ahead or behind schedule were noted and these figures were then compared to the LOS standards in this category. Actual transit arrival times for the inbound trip were found to coincide perfectly with the scheduled arrival times, thereby rating a LOS A. The outbound trip also received a LOS A rating for reliability as this run was determined to be only 1 minute behind schedule.

Passenger Density

Maximum passenger loads were recorded for both directions of travel. These loads and the type of seating available on the transit vehicle (parallel rows of upholstered seats) were then compared to LOS values for passenger density. The maximum passenger load on the outbound trip numbered 15 while the maximum load on the inbound trip reached 17. Both of these numbers were sufficiently low to enable every passenger to have a seat, thus earning a LOS B rating for passenger density.

Passenger Comfort

Three factors were taken into consideration for passenger comfort: acceleration/deceleration, temperature and noise.

Acceleration/Deceleration - Acceleration/deceleration times were recorded for both the outbound and inbound trips. The most rapid of these accelerations and decelerations were then noted. An acceleration of 0 to 10 mph in 8.2 seconds was the most rapid acceleration/deceleration observed during the outbound trip while a deceleration of 30 to 20 mph in 7.4 seconds was the most rapid observed during the inbound trip. For the outbound trip, the maximum acceleration rate (determined using the formula $\frac{V_f - V_o}{t} = a$ as described previously) was found to be 1.79 feet per second^2, or Los B. In the inbound trip, the maximum deceleration rate was 1.98 feet per second^2, which also corresponds to LOS B.

Temperature - The temperature on board the transit vehicle remained a constant 76° during both the outbound and inbound trip which corresponds to a LOS A rating for this indicator.

Noise - Maximum sound level readings on board the transit vehicle reached 79 db, LOS C, during the outbound trip and 75 db, LOS B, during the inbound trip.

Summary

The level-of-service ratings by category for both the outbound and inbound trips are summarized in Table 20.

To determine the overall level-of-service rating for the 8:25 a.m. outbound trip, the number of points for each indicator was first multiplied by the weighting credits for each. Next, the resulting products were added together and that sum was then divided by 100 (the total number of weighting credits). The final answer was 4.05 which corresponds to a LOS B overall rating for the outbound trip (Table 21). This same procedure was repeated for the 8:55 a.m. inbound trip (Table 22) resulting in a final answer of 4.0 which also corresponds to a LOS B for the inbound trip.

Table 20: LOS Ratings for the 8:25 a.m. Outbound and the 8:55 a.m. Inbound Trips of the South Congress Route

Indicator	LOS Rating	
	8:25 a.m. Outbound Trip	8:55 a.m. Inbound Trip
Accessibility	C	C
Travel Time	D	D
Directness of Service	A	B
Delay	A	A
Frequency of Service	B	B
Reliability	A	A
Passenger Density	B	B
Passenger Comfort		
Acceleration	B	B
Temperature	A	A
Noise	C	B

Table 21: Overall LOS Rating for the 8:25 a.m. Outbound Trip

Indicator	LOS Rating	LOS Rating Points	x	Weight of Indicator	=	Total Points
Accessibility	C	3	x	10	=	30
Travel Time	D	2	x	10	=	20
Directness of Service	A	5	x	10	=	50
Delay	A	5	x	5	=	25
Frequency of Service	B	4	x	15	=	60
Reliability	A	5	x	15	=	75
Passenger Density	B	4	x	15	=	60
Acceleration	B	4	x	5	=	20
Temperature	A	5	x	10	=	50
Noise	C	3	x	5	=	15
						405

FINAL ANSWER: 405 ÷ 100 = 4.05 or LOS B

Table 22: Overall LOS Rating for the 8:55 a.m. Inbound Trip

Indicator	LOS Rating	LOS Rating Points	x	Weight of Indicator	=	Total Points
Accessibility	C	3	x	10	=	30
Travel Time	D	2	x	10	=	20
Directness of Service	B	4	x	10	=	40
Delay	A	5	x	5	=	25
Frequency of Service	B	4	x	15	=	60
Reliability	A	5	x	15	=	75
Passenger Density	B	4	x	15	=	60
Acceleration	B	4	x	5	=	20
Temperature	A	5	x	10	=	50
Noise	B	4	x	5	=	20
						400

FINAL ANSWER: 400 ÷ 100 = 4 or LOS B

CONCLUSIONS

The concepts and evaluation framework presented in this report are intended to provide transit professionals and other decision makers with a more precise methodology for measuring one important aspect of transit service, level-of-service. While the evaluative models discussed in the previous section (particularly the D-R LOS model) contain rather subjective values, they are nevertheless starting points for further discussion and revision. Furthermore, it should be noted that any method of evaluating quality aspects of public transportation service will contain some subjective concepts.

The LOS standards proposed should not only facilitate daily transit management and planning functions, but also aid in the overall improvement of public transportation service in Texas. The LOS standards can be invaluable assets in determining where transit service improvements should be made. LOS values can be combined with costs and design requirements to select options for upgrading existing service to higher levels-of-service. Priorities could include upgrading those operations which exhibit the lowest levels-of-service. Finally, LOS standards could be combined with performance and productivity standards; capital and operating assistance programs could then be based on local conditions and a local plan for attainment of minimal performance, productivity and levels-of-service.

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