LEVEL-OF-SERVICE CONCEPT FOR EVALUATING PUBLIC TRANSPORT

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A system of evaluating service variables common to all public transport modes is proposed so that an existing system may be managed or improved and a new system may be built on the basis of its ability to fulfill a desired level of service. The variables discussed are those directly perceived by the user regardless of mode: overall trip speed and en route delay and comfort factors associated with the vehicle including density, acceleration, jerk, temperature, air flow, and noise. Improving one or more of these measurable variables bears an associated cost and design requirement. Since better service is desirable in certain situations while average service is sufficient in others, levels of service A through F are adopted for each variable. In the proposed system, level of service is determined by the use of a weighted average of rankings assigned to individual factors. Within tolerable limits, 40 percent of the overall ranking should be based on speed and delay and 60 percent on comfort factors. When an individual comfort variable becomes intolerable, the entire ride is at service level F. Application of the procedure results in reasonable comparisons of both systems and individual trips within a system.

•SINCE the late 1950s, Americans have sought improved public transport. The technology of the automobile has continued to advance, and efforts are being made now for public transport technology to catch up. A host of new, innovative transport concepts are being tested, and the Bay Area Rapid Transit System in San Francisco has just started operations. What is needed is a precise way to measure public transport service so that transit systems can become more competitive with the private automobile. A service measurement system could be used for daily rating and managing of existing modes as well as for specifying the desired level of service for planned improvements.

Each mode of public transport has a different assortment of physical characteristics; but all modes have common service characteristics such as speed and density, and the most important characteristics, particularly as they affect patronage, are those that the user perceives directly. Speed, density, and other individual characteristics such as acceleration, temperature, and noise are easy to measure individually. This paper proposed that the individual measurements be combined to determine an overall level of service for each mode of public transport.

SERVICE CHARACTERISTICS

Other system features such as design standards, operating costs, access, fares, and safety requirements are directly related to basic service characteristics. For example, higher speed, a service characteristic, involves better design standards, more costly construction, and higher operating costs for energy and track maintenence. This section discusses the selection of those characteristics common to all modes of transport that most reflect the quality of service.

One of the basic level-of-service characteristics in highway design is speed (1, p. 7). The speed advantage that users associate with automobiles occurs in part because automobile trips are made directly from origin to destination without intervening transfers, another important service characteristic. However, there is even more to the popularity of the automobile than speed or direct routing. For example, the driver frequently has the ability to vary speed and route. The transit patron can neither select the exact leaving time nor detour if the route is congested. Thus schedule frequency and delays to patrons also must be considered in establishing the level of service for public transport.

Another basic characteristic of level of service is density. The density of automobiles on the highway is related to speed of service; poor service occurs at low speeds. The density of the motorist's personal space is self-determined because he or she selects the vehicle and the passengers. A sedan encloses 25 ft^2 (2, p. 35). Typically, automobiles carry 1 or 2 passengers so that each has 25 to 12.5 ft^2. The space inside the automobile cannot be reduced even in the most severe traffic snarl. In a subway car or local bus, personal density is routinely reduced to as little as 2 ft^2/passenger. This crowding coupled with the absence of personal control of the vehicle can lead to a feeling of panic for transit users and has probably resulted in the diversion of large numbers of persons to the privacy afforded by automobiles.

The absence of control on a public transport vehicle denies the transit patron other service advantages enjoyed by the motorist. The motorist not only can detour around delays but also has a better opportunity to avoid bumps and potholes and can accelerate and decelerate gently so that passengers are not thrown against the seat. The rider of public transport must accept whatever ride is offered whether it be on cobblestone streets or unaligned track. The motorist can cool, heat, or circulate air in the automobile for his or her comfort. The public transport patron must increasingly accept whatever conditions the vehicle can provide.

THE CONCEPT

This paper discusses levels of transport service (LOTS) to apply to all line-haul systems of public transport. The values are based on the patron's environment and travel speed. Comparisons can then be made of the relative service offered by different modes and of variations within the same mode such as those that may occur for different trips on the same route. All transport systems can be compared, but the process described in this paper is intended primarily for commuter trips in the 2- to 40-mile range.

Level of service is frequently associated with the peak hour. However, an off-peak level of service also may be computed. For complete analysis, LOTS value must be computed for each pair of stops on a given route. In practice, computations may only be made for selected station pairs to establish a range of service values achieved on a particular system. If a single value is to be applied to a route, a weighted average should be used. The average is computed by multiplying the percentage of total traffic between each pair of stations by the level-of-service values for that pair.

CHARACTERISTICS USED TO ESTABLISH LEVELS OF SERVICE

The following paragraphs discuss each of the major characteristics used to establish the levels of service for public transport systems.

Travel Time

In selecting a transit mode, most commuters regard travel time as the most important factor. Travel time depends on average speed on the system. Some systems now operate equipment that can travel 80 mph, while local buses traveling through a heavily congested district may average less than 6 mph. Speeds this low or lower are comparable to walking on high-volume people-moving mechanisms such as moving belts and moving stairs.

More than 90 percent of all automobile commutation trips are 20 miles or less (2). A transit system could accommodate these trips with a maximum travel time of 35 min if the system achieves an average speed of 35 mph. This means that if 25 min is allowed to reach the public transport mode and to go from that mode to the ultimate destination the total commuting would be 1 hour or less. Therefore a speed of 35 mph is selected as a desirable goal. For exurban areas served by commuter railroads, an even higher average speed might be a more appropriate design goal.

In central business districts, commuting trips often are no longer than 5 miles. An average speed of 6 to 15 mph would keep total trip time under 1 hour in these locations. A design goal of 15 mph is the minimum that is recommended, although in existing situations a speed of 6 mph may be tolerated. Higher rates of acceleration and deceleration can save time, but excessive rates of starting and braking are uncomfortable.

Headway

The automobile commuter experiences no delays due to scheduling. Thus, people may be discouraged from using public transport if the time between departures is excessive. Transit headways also interact with density since the latter can be reduced by scheduling more trips on all but the busiest transport routes. Headways are reflected in the calculation of average speed by adding half the headway to the basic travel time on heavily traveled routes. But this would unduly penalize low-density routes with infrequent headways. Therefore, the maximum headway allowance can be limited to 5 min.

Transfers

The public transport user may make one trip from his home to the public transport station and a second trip from the station to his or her destination. A method of accounting for the first trip, the access trip, is given later in the discussion of multimode trips. The computation is omitted from the initial procedure because computing a typical access time is extremely difficult if various patrons use different access modes. Any additional transfers within the transit system represent inconvenience, and a transfer penalty of 5 minutes per en route transfer is added to the basic travel times for the approaching and the departing route. Also added are the walking time associated with the transfer and half of the headway on the departing route.

Fare Collection

Automated fare collection is definitely a patron convenience. The major causes of patron inconvenience probably are waiting to purchase fares and waiting to enter the system. Fare collection should be included in computing trip speed when the delay to the patron exceeds 30 sec.

Speed Adjustment and Values

The following computations show average adjusted peak- and off-peak travel times for the 8.9-mile ride on the Port Authority Trans-Hudson system between Newark and the World Trade Center in downtown Manhattan. The computations yield adjusted average speeds of 26 and 22 mph respectively. Normal running times are used to compute speeds and are defined as the time that the commuter generally encounters rather than the published running times. Fare collection in the example usually takes less than 1 minute, and no en route transfer is needed.

Item	Peak (min)	Off-Peak (min)
Fare collection	0	0
Headway	$(0.5 \times 3) =$ 1.5	$(0.5 \times 10) =$ 5
Running time	19	19
Transfer	0	0
Total	20.5	24

The selected LOTS values for scheduled line-haul speed plus fare collection, headway, and transfer adjustments are as follows:

Adjusted Speed (mph)	LOTS Value
>60	A
35 to 60	B
25 to 35	C
15 to 25	D
6 to 15	E
0 to 6	F

Delay

Delays represent a reduction in the level of service and are defined in this paper as unexpected increases in normal running time. They are introduced so that unique occurrences may be reflected when a level of service is needed on a daily basis. Boarding delays are not a characteristic of travel by private car. Therefore, the absence of boarding delays is particularly important in attracting motorists to public transport. In this analysis delay is expressed as minutes per trip. The times for individual delays that occur during a selected trip are added to obtain a total delay time for that trip. If a trip involves 2 or more transit services, the delays on each service are added to determine total peak-hour delay. The level-of-service values are as follows:

Delay (min)	LOTS Value
0	A
0 to 1	B
1 to 2	C
2 to 4	D
4 to 8	E
>8	F

Individual delays could be included in the previous computation of overall speed. They are considered separately because they represent a more immediately correctable situation. Delays are frustrating because users are aware that the basic capability of the system is not being used but they are powerless to take corrective action.

Density

Speed and delay are service characteristics that relate to travel time. Density and the other remaining characteristics deal primarily with user comfort. Passenger densities encountered inside the vehicle reflect, in part, the level of service of a transport system. Actually, the reciprocal of density, area per passenger, is used to avoid fractional values. Table 1 gives examples of space offered on transport vehicles in the New York metropolitan area.

The area per passenger varies markedly from a commuter railroad with spacious seating arrangements and no standees to a jammed subway car with few seats and many standees. Fruin's descriptions of the various levels of service for standing passengers in terminals are given in Table 2 (3).

The areas given bear an interesting relation to those given in Table 1. The cost of producing transportation is reflected in the absence of public transport vehicles with levels of service A and B. (An example of level of service A is railroad parlor cars used for intercity travel.) The Erie-Lackawanna Railroad cars are level of service C. Those cars are equipped with doors at each end and are used for long commuting trips. Rail cars allow for an appropriate degree of circulation, and the subway car, which has 4 doors on each side to reduce the need for interior circulation and a minimum number of seats to permit maximum loadings, is at the low end of the density scale.

The Fruin standards (Table 2) naturally were not intended to account for sitting passengers. In the railroad cars, each seated passenger occupies at least 3.5 ft^2, leaving too little space in the aisle to achieve an average density of 2 ft^2/passenger when the

Table 1. Space on transit vehicles.

Vehicle	Operator	Seats	Normal Peak Passenger Loading	Interior Area[a] (ft^2)	Area per Passenger (ft^2)
Commuter rail car	Erie-Lackawanna	108	108	829	7.7
Suburban bus	Transport of New Jersey	50	50	272	5.4
City bus	Transit Authority	40	80	290	3.6
Subway car	Transit Authority	46	272	535	2.0

[a]Includes area for seats, but excludes areas allocated to operators and conductors.

Table 2. Levels of service for standing passengers in terminals.

Description	Area per Person (ft^2)	Level of Service
Adequate area for standing and free circulation	13	A
Adequate area for standing and restricted circulation	10 to 13	B
Same as B except circulation occurs by disturbing others	7 to 10	C
Can stand without contacting others, but circulation severely restricted	3 to 7	D
Adequate standing room, but contact with others is unavoidable and circulation is impossible	2 to 3	E
Equivalent to body area, close unavoidable contact, physical and psychological discomfort, and potential for panic	1½ to 2	F

Table 3. Level-of-service values.

Characteristic	A	B	C	D	E	F
Adjusted speed, mph	>60	35 to 60	25 to 35	15 to 25	6 to 15	0 to 6
Delay, min	0	0 to 1	1 to 2	2 to 4	4 to 8	>8
Space, ft^2/passenger	>13	10 to 13	7 to 10	3 to 7	2 to 3	<2
Horizontal acceleration, 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
Vertical acceleration, ft/sec^2	<1.5	1.5 to 3.0	3.0 to 4.5	4.5 to 5.2	5.2 to 6.0	>6.0
Jerk, ft/sec^3	<1.0	1.0 to 2.0	2.0 to 3.0	3.0 to 4.5	4.5 to 6.0	>6.0
Temperature, deg F	72 to 76	68 to 78	64 to 80	58 to 84	50 to 90	<50 to >90
Ventilation, ft^3/min/passenger	>35	30 to 35	25 to 30	20 to 25	15 to 20	<15
Noise, dB	<60	60 to 75	75 to 85	85 to 90	80 to 95	>95

Table 4. Points for achieving each level of service.

Characteristic	A	B	C	D	E	F
Adjusted speed	30	24	18	12	6	0
Delay	10	8	6	4	2	0
Space	25	20	15	10	5	0
Acceleration and jerk	10	8	6	4	2	0
Temperature	15	12	9	6	3	0
Ventilation	5	4	3	2	1	0
Noise	5	4	3	2	1	0
Total	100	80	60	40	20	0
Range	100 to 90	90 to 70	70 to 50	50 to 30	30 to 10	10 to 0

Table 5. Hypothetical level of service on BART system.

Characteristic	Level of Service	Points
Adjusted speed (34-min travel time and 3-min gap for 28 miles = 48 mph)	B	24
Delay	A	10
Space (no standees, 647 ft^2, 72 seats = 9 ft/passenger)	B	20
Acceleration (3 ft/sec^2)	C	6
Temperature[a]	A	12
Ventilation[a]	B	4
Noise	A	5
Total	B	81

[a]Level assumed by author.

aisle is filled. However, the cars are not intended for use at these densities. The subway car, in which higher densities are intended, has fewer seats, and standees share the leg room allocated to seated passengers. Therefore, the above standards are offered as a satisfactory first approximation for public transport vehicles.

Passenger Comfort

The effect of crowding on passenger density has been noted. Levels of comfort on public transport systems also are affected by temperature, odor, ventilation, noise, vibration, acceleration, deceleration, and position change (or jerk). Each of these effects can be divided into 3 tolerance levels (4):

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

This area of transport service is much talked about, but there are a number of serious deficiencies in the present selection and application of standards of tolerance. A level of service F for even one comfort factor is far more serious to the passenger than a level of service F for characteristics such as speed or delay. In other words, the author's opinion is that the operation of one comfort factor at service level F at any point in a trip causes the patron to judge the transport service as completely unsatisfactory.

In setting minimum comfort levels, one should also keep in mind that the commutation trip is normally made about 500 times a year. A motorist may never encounter a physically intolerable situation (serious accident) during a driving lifetime. A daily intrusion on upper physiological limits would leave transit systems riderless. The more appropriate design limit might be the second in which the body will survive but be uncomfortable. Such was the case in stalled traffic prior to air conditioning. However, even this limit should never be a recurrent feature of a public transport system, for the thought of facing a psychologically uncomfortable ride each day will also divert users to other modes. Therefore, comfort levels should be established within the area of psychological comfort.

Acceleration

Fast acceleration and deceleration (backward acceleration) yield an increase in system speed at the expense of passenger comfort. Rapid acceleration is more easily tolerated by a seated passenger than by a standee, although the latter can make adjustments if the speed changes are consistent. Even long commuter trains will handle occasional standees. Therefore, the levels of service are selected with the comfort of standing passengers in mind. The positive effect of acceleration on speed is reflected indirectly in the previously discussed service standards for overall trip speed.

Accelerations also occur in other axes, with both linear and torsional (rotational) characteristics. The most common on public transport systems include sway and jouncing. Therefore, acceleration standards are adopted for both the horizontal (longitudinal, lateral, and other horizontal) and vertical planes. As with other comfort values, the maximum desirable comfort value for acceleration is considerably less than the physical limit of 1 g or 32.2 ft/sec^2. Furthermore, the maximum value need only be reached once during a ride in order to have the system rated at the associated lower level of service. Values below service level D should occur rarely, and values below service level E should occur only at the time of an accident. The selected acceleration values are as follows (5, Tables I and II and Figs. 1, 2, 5, 6, 7; 6):

Horizontal (ft/sec^2)	Vertical (ft/sec^2)	LOTS Value
<1.0	<1.5	A
1.0 to 2.0	1.5 to 3.0	B
2.0 to 3.0	3.0 to 4.5	C

Horizontal (ft/sec²)	Vertical (ft/sec²)	LOTS Value
3.0 to 3.5	4.5 to 5.2	D
3.5 to 4.0	5.2 to 6.0	E
>4.0	>6.0	F

Jerk

Jerk is defined as the buildup in acceleration and is given in feet per second per second per second. The effect of jerk in the axis of travel is most noticeable to passengers on side seats during the final phase of deceleration. Jerk values also should be applied to changes in lateral or vertical acceleration caused by faulty track or poor roads. Values presented for this condition are considered tentative pending further research (5, pp. 3-4, Figs. 3, 4, Table II). Random testing of actual systems is advocated, for a poor operator can negate many of the ride benefits of an excellent roadbed, vehicle suspension, and throttle control.

Jerk (ft/sec³)	LOTS Value
<1.0	A
1.0 to 2.0	B
2.0 to 3.0	C
3.0 to 4.5	D
4.5 to 6.0	E
>6.0	F

Temperature

There is general agreement that 72 F is a desirable temperature for heating transport vehicles and 76 F is a suitable temperature for air-conditioning equipment. However, the actual temperature will vary with the amount of clothing that people wear in the vehicle. During the winter, thermostat settings on subways and local buses should be lower, say 60 F, so that the passenger is not uncomfortably hot in a topcoat. Heating units should provide the heat needed to raise interior temperatures to comfortable levels when outside design temperatures are reached. In New York City, a design temperature of 0 F can be used, but in colder cities, temperatures as low as -40 F may be appropriate.

Air-conditioning or cooling equipment must be designed to offset heat loads caused by heat transmission through walls and ceilings and heat generated by passengers, lights, motors, and outside air that is circulated for ventilation. The heat load from passengers is often the largest load. However, the effect of door openings at stops also is significant for local bus and subway routes. The design temperature for cooling is usually 95 F in New York City and may be as high as 115 F in southern locations.

The level of service is determined by taking the worst value of temperature that occurs inside the transport vehicle during the line-haul portion of the trip. For systems where the patron is faced with a potential wait of more than 5 minutes, the temperature of the waiting area should be assessed because the patron achieves thermal equilibrium or a steady-state condition of comfort or discomfort after 5 minutes (7). The LOTS values are as follows (4, 8):

Low (deg F)	High (deg F)	LOTS Value
72	76	A
68	78	B
64	80	C
58	84	D
50	90	E
<50	>90	F

A subway car temperature of 60 F in winter could be given a value of A if the patron wears sufficient clothing so that he or she perceives a temperature of 72 F.

Ventilation

Ventilation is closely associated with temperature. Thus, outside air required for heating and air-conditioning systems can be modulated to provide needed ventilation as well as comfort during off seasons. Usually 25 percent outside air represents good design. Ventilation standards are expressed in cubic feet per minute per vehicle (8, pp. 62, 68, 71). It is proposed that the standards be revised to provide cubic feet of air per minute per passenger at maximum contemplated passenger occupancies. A sufficient amount of air is required to maintain a comfortable environment and prevent strong odors from persisting (8, p. 10). As with temperature, the worst en route ventilation controls and the standards apply to stations if waits of more than 5 min occur. The LOTS values are as follows (4, p. 38; 8, pp. 10, 62, 68, 71):

Ventilation (ft^3/min/passenger)	LOTS Value
>35	A
30 to 35	B
25 to 30	C
20 to 25	D
15 to 20	E
<15	F

Associated Characteristics

More sophisticated standards might include requirements for associated characteristics such as air filtering and humidity control. Also important to the passengers are separate safety standards that relate to carbon monoxide and other noxious gases.

Noise

Noise is defined as noise perceived by passengers while inside the transport unit. Loud noise is universally recognized as an undesirable feature of a transit system. The selected unit of measure is decibels or noise level sound pressure ratio. A recent Port Authority design specified a maximum permissible noise level of 68 dB for an airport people-mover that traveled at 30 mph and had auxiliaries and air conditioning in operation (9). A system is rated F if vehicle or station noise exceeds 90 to 100 dB, for 2 hours per day of sound of 100 dB or more can cause permanent hearing loss (10). The selected LOTS values are as follows (6, p. 56; 11):

Noise (dB)	LOTS Value
<60	A
60 to 75	B
75 to 85	C
85 to 90	D
90 to 95	E
>95	F

Vibration

Vibration is defined as repetitive, oscillatory movements in any direction. Severe vibrations described by the Institute for Rapid Transit (11, pp. 43-44) should be eliminated during equipment testing. Occasional vibrations should show up during acceleration and jerk tests. Therefore, a set of values is not recommended for vibration at this time.

LEVEL OF SERVICE

The following is a discussion of the individual levels of transport service that lead to an overall service rating for each pair of stops on a transit system. A summary is given in Table 3. Since a weighted average is used, the desired value for all individual characteristics does not have to be attained to achieve an overall level of service of the same value.

Level of Transport Service A

Average speeds are 60 mph or more after adjustments are made for processing and en route transfers and no peak-hour delays exist. Personal space is at least 13 ft^2/passenger. Horizontal acceleration and deceleration are no more than 1.0 ft/sec^2, and temperature does not vary more than 2 deg from normal. Ventilation is 35 ft^3/min/passenger, and noise levels are below 60 dB. Only intercity rail systems operate at this level today. Design of commuter systems at this level of service is suitable for exurban commutation systems that have light volumes and line-haul distances of more than 40 miles.

Level of Transport Service B

Average adjusted speeds are between 35 and 60 mph, and delays do not exceed 1 min. Personal space is 10 to 13 ft^2/passenger. Standards of temperature, ventilation, and noise are maintained at high levels. The Bay Area Rapid Transit System meets or exceeds most of the criteria for level of service B, which is a standard for modern public transport systems that carry moderate volumes and serve suburban communities.

Level of Transport Service C

Average adjusted speeds are between 25 and 35 mph, and peak delays are no more than 2 min. Personal space is 7 to 10 ft^2/passenger. Acceleration of 3.0 ft/sec^2, a temperature range of 64 to 80 F, and a noise level of 85 dB are permitted. Level C is a suitable standard for an urban transport system that has moderate to heavy use.

Level of Transport Service D

Average adjusted speeds are between 15 and 25 mph, and peak delays are no more than 3 min. Personal space is 3 to 7 ft^2/passenger. Acceleration and deceleration of 3.5 ft/sec^2 are acceptable, the temperature and other environmental features are within tolerable limits. Level D would be suitable but not desirable for a heavily used urban transport system that carries predominately short trips or has construction costs such that heavy use of the system is desirable or has both of these characteristics.

Level of Transport Service E

Average adjusted speeds are as slow as 6 mph, and peak delays are as long as 8 min. Personal space is 2 to 3 ft^2/passenger. Acceleration and environmental features approach the border line of human psychological tolerance. Level E is not used for design, but may occur as maximum capacity is reached on existing systems or for short periods on new systems that are designed for higher levels of service.

Level of Transport Service F

Average adjusted speed is below 6 mph, delays are more than 8 min, and personal space is less than 2 ft^2/passenger. Acceleration, deceleration, temperature, ventilation, or noise exceeds human psychological tolerance levels. That is, horizontal acceleration is more than 4.0 ft/sec^2, high temperatures are above 90 F, low temperatures are below 50 F, ventilation is less than 15 ft^3/min/passenger, and interior noise is more than 95 dB.

Transit systems operating with any one of the above comfort features at level F are not suitable and should be upgraded as soon as possible. When speed, delay, or density reaches level F on an occasional basis, the operating system should be halted until the deficiencies are corrected. Daily or near daily operation at level F should lead to immediate improvements or, if this is not feasible, to either intentional diversion of passengers to other modes or a forced reduction in demand.

WEIGHTING OF SERVICE CHARACTERISTICS

Not all service attributes are equally important. What is most difficult to determine is the relative importance of those attributes for which LOTS values are proposed. One of many available surveys found the following criticisms of public transportation by residents of Washington, D.C., where transit is provided by surface buses (12, Vol. 1, p. 18):

Criticism	Respondents (percent)
Overcrowding	60
Waiting	57
No seat	54
Slower than car	50
Cannot choose own time	38
More walking	25
Not so dependable	25
Hot	21

The same study notes that time savings and comfort are the 2 most desired characteristics of a new system (12, Vol. 2, p. 18). The criticisms deal with many of the previously discussed characteristics such as density (overcrowding, no seat), headways (waiting problem, cannot choose own time), speed (slower than car, not so dependable), and temperature (hot). Empirical weightings are proposed below to reflect the results of this and other studies. The weights are tentative pending further research into their relative importance.

Speed

Speed is of paramount importance in attracting patrons from automobiles to public transport. As the primary service feature, it is assigned the highest value that is used, 30 out of 100 total points.

Delay

Delay is given a weighting of 10, which is selected so that an unexpected increase in travel time has a slightly greater effect than a recurrent speed reduction. A total of 40 points are allocated to speed and delay, leaving 60 points for comfort features.

Density

The most important comfort feature in modern systems is believed to be adequate space for each passenger. Therefore, this feature is assigned 25 points.

Acceleration and Jerk

Rapid or uneven acceleration is one of the most important causes of discomfort. Therefore, these 2 items are given 10 of the remaining 30 points. The points were selected on the basis of the worst condition that occurs for either characteristic.

Temperature

Temperature and humidity are closely related and are important because the transit user cannot personally control these items as he or she can in an automobile. A weighting of 15 is assigned.

Ventilation

A weighting of only 5 is used for ventilation, for its requirements are often satisfied if the temperature requirements are met.

Noise

This characteristic is assigned a weight of only 5 because the proportion of patrons upset by severe noise is deemed to be small. It must be included, however, since the affected riders will be lost to the system if reasonable levels are exceeded (13, p. 68).

SERVICE MATRIX

The service matrix is given as Table 4. Values for each characteristic of an existing or proposed public transport service are converted to equivalent levels of service established in the text. The points of each characteristic are added to determine an overall level of service. A hypothetical analysis of a trip during the peak hour with all seats filled on the Bay Area Rapid Transit System from Concord in Contra Costa County to downtown San Francisco is given in Table 5.

Effect of Weighting

Under the weighting process, a system may offer an overall level of service that is higher or lower than the level of service indicated by an individual characteristic. This is particularly important for existing systems whose geometrics may preclude any remedial action aimed at increasing speed. On some systems, the same route may exhibit a high level of service between a remote station and a downtown terminal and a low level of service between a close-in station and the CBD terminal. This is entirely appropriate, for lower levels of service can be tolerated for short trips.

Multimode Trip

The level of service can be determined for a multimode trip by the use of a weighted average for each characteristic of each mode based on the time spent riding that mode. The time to transfer between the 2 modes and a 5-min transfer penalty are suggested when overall speed is computed. The multimode technique is useful when the quality of access is studied. An example is a comparison of a commuter bus offering local pickup services to a rail transit line that requires users to drive to the station.

CONCLUSIONS

Many of the individual LOTS standards are based on firm findings. The list of selected characteristics is not necessarily complete and is subject to revision. The weighting process is the least firm because of lack of data. Nevertheless, the overall level of service obtained by the application of the weighted values to various existing modes of transit does produce relative rankings that are consistent with the level-of-service concept. (In some CBDs, the level of service of existing transport is very low. However, the user is forced to ride the system because surface congestion and parking costs make the automobile an even worse alternative.) The rankings provide a more precise measure of service, which is the intent of this paper.

Uniform standards capable of quick and easy measurements can assist in selecting a mode for a new service or pinpointing the places along an existing route where inferior service is rendered. The values can be combined with costs to select an option for upgrading an existing service.

A set of uniform national standards of service such as those advocated in the preceding pages appears desirable to facilitate both the daily management and the uniform improvement of public transport. Federal capital assistance programs might then be based on local conditions and a local plan for attainment of appropriate minimal levels of service. Priorities could include upgrading the routes that exhibit the lowest levels of service. Local and other operating subsidies could be based on the maintenance of a specified level of service if the contributing organization finds that LOTS values provide a more rational basis than those now used for monitoring performance.

REFERENCES

1. Highway Capacity Manual. HRB Spec. Rept. 87, 1965.
2. Automobile Facts and Figures. Motor Vehicle Manufacturers Association of the U.S., Inc., Detroit, 1972.
3. Fruin, J. J. Designing for Pedestrians: A Level of Service Concept. Metropolitan Association of Urban Designers and Environmental Planners, New York, 1971, pp. 85-87.
4. Passenger Psychological Dynamics. ASCE, New York, June 1968, pp. 35-36.
5. Literature Survey of Passenger Comfort Limitations of High-Speed Ground Transports. United Aircraft Corporation, East Hartford, Conn., July 26, 1965.
6. Design and Performance Criteria for Improved Nonrail Urban Mass Transit Vehicles and Related Urban Transportation Systems. National Academy of Engineering, Washington, D.C., May 1968, pp. 56-57.
7. Danziger, N. H. Keeping Cool in the Subway. Railway Gazette International, July 1973.
8. ASHRAE Guide and Data Book: Applications. American Society of Heating, Refrigeration and Air Conditioning Engineers, New York, 1971, pp. 62, 68-69, 71-73.
9. System Criteria for the Newark International Airport Inter-Terminal Transportation System. Kaiser Engineers, Feb. 1973.
10. Siegel, M. H. Elish Warns Subways Impair Hearing. New York Times, Oct. 16, 1973, p. 86.
11. Guidelines and Principles for Design of Rapid Transit Facilities. Institute for Rapid Transit, May 1973, pp. 35, 37-39.
12. A Survey of Commuter Attitudes Toward Rapid Transit Systems. National Analysts, Inc., Vols. 1 and 2, 1963.
13. Beranek, L. L. Noise. Scientific American, Dec. 1966.