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Planning and Design of Rapid Transit Facilities

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Contents

ENERGY EFFICIENT RAIL TRANSIT OPERATION

Ronald W. Eash, Chicago Area Transportation Study

The paper investigates the energy consumption characteristics of modern rail rapid transit. The paper shows the variation in energy consumption caused by different operating policies and design characteristics of the rail transit mode, and points out the energy economies of improved design and operation. Five variables are analyzed using a rail transit performance computer model that simulates the performance of a rail transit train whose operating characteristics are specified by the program user. The simulated train runs over a track segment established by the user and a performance log of train speed and acceleration along the track segment plus the rate of energy consumption and cumulative energy used are output by the train performance program. The analysis indicates that of the variables studied, the most promising ways of reducing rail transit energy consumption are to include a coasting phase with reduced maximum speeds in the train's performance cycle and to adjust the track vertical profile.

A number of recent studies have attempted to compare the energy consumption of modes and evaluate their relative energy efficiency. For the most part, this work depends on gross average estimates of the energy consumed for a given output such as passenger, ton, or vehicle kilometers (vehicle miles). This acceptance of gross estimates of modal energy consumption has hidden the variation in energy usage due to design and operation of a mode, and the potential energy economies of improved design and operation.

This paper looks at the energy consumption characteristics of modern rail rapid transit. There are at least two reasons to seek energy efficient designs for rail rapid transit systems. First, rail systems are long lived so that even minor inefficiencies in vehicle and track design cause the accumulation of much wasted energy over these long periods of time. A second reason is that a number of new rail rapid transit systems are planned and they should be designed with energy efficiency in mind. In this paper the energy consumption of a rail rapid transit state of the art vehicle is investigated subject to changes in five design and operational variables: length of train, distance between stations, maximum speed permitted between stations, track profile, and train braking policy of the operating agency.

The analysis makes use of a rail transit performance model developed at the University of Pennsylvania by the author. This rail transit train performance program will accept the track profile, vehicle operating characteristics, and braking policies as program inputs and produce a time-distance computation. The program also calculates the rate of vehicle energy consumption in kilowatt-minutes. Since distances between stopping points and train lengths for rapid transit are not large, the program is economical to use and a number of different track profiles and input parameters can be quickly compared.

Characteristics of the Simulated Rail Transit Train

Physical Characteristics

The vehicle used in the simulation program is basically the Bay Area Rapid Transit vehicle (1). Each car has seats for 72 passengers. A normal passenger load for a car is 120 persons, and 216 persons is the crush load. In the simulation an empty car weight of 27.2 metric tons (30.0 tons) was used. The average car weight for a loaded car was taken as 38.1 metric tons (42.0 tons). Maximum acceleration and deceleration rates were held to 5.0 KPHPS (3.1 MPHPS), and the change in acceleration or braking (jerk) was kept to 3.2 KPHPSPS (2.0 MPHPSPS). Both parameters are determined by passenger comfort and safety rather than actual train performance limits (2). Maximum train speed was restricted to 129 KPH (80 MPH). The simulated train is powered by a 1000 volt D. C. source.

Motive Power and Braking

The maximum tractive effort delivered by the train's motors as a function of speed was computed in the simulation from general motor characteristics supplied to the program. With the vehicle weights noted earlier, a maximum tractive effort of 57,000 newtons (13,000 pounds) per car is allowed at low speeds without exceeding the acceleration limit. This tractive effort is less than the maximum tractive effort permitted by the adhesion between wheel and rail in reasonable condition.

Electric traction motors can produce output far in excess of their hourly rated power, the power that can be produced by the motor continuously for one hour without overheating. Since traction motors in transit operations are not run continuously, they can dissipate heat while they are idling during coasting, braking, and station stops. Thus, the motors can be run at overheating levels during acceleration of the train when the highest power output is required. Comparison of computed tractive effort curves with actual tractive effort plots for the BART system indicated that traction motors are commonly run at 140% to 160% of the hourly power rating.

Four traction motors per car, each rated at 104 kilowatts were used in the simulated train. Total kilowatts generated per car at maximum power is then:

$$KW_{max/car} = 1.50KW_{motor}(\text{Motors/Car}). \quad (1)$$

Maximum tractive effort in newtons per car as a function of speed can be computed by:

$$TE_{max/car} = \frac{3600KW_{max/car}EFF_{gear}}{v}. \quad (2)$$

Where v is the speed and EFF_{gear} is the efficiency of the gears between the motors and the wheels which varies between 80% and 95%, with the lower values at higher speeds. Figure 1 compares the reported maximum tractive effort curve for the BART car (1,3) against the computed maximum tractive effort curve used for the simulated car.

Braking effort versus speed for a rail rapid transit car is much simpler to compute than tractive effort. The train is braked by two braking systems, dynamic braking and train friction brakes. Dynamic braking is accomplished by turning the traction motors into electric generators to produce a current which is dissipated as heat through a bank of resistors, or returned to the line source in regenerative braking. With adequate resistance, a dynamic braking effort greater than the amount permitted by the maximum braking rate is possible except at low speeds. When dynamic braking fades, train friction brakes are blended with the dynamic brakes to maintain the braking rate. The BART car's dynamic braking curve (1,3) as it was incorporated into the program is shown in Figure 2.

Figure 1. Simulated and BART Tractive Effort

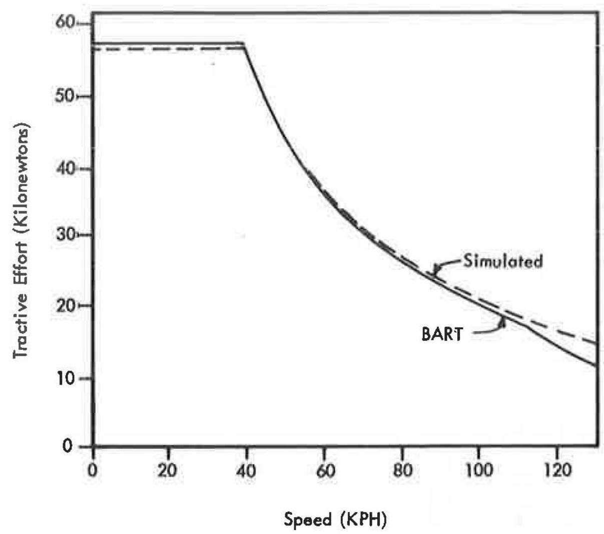
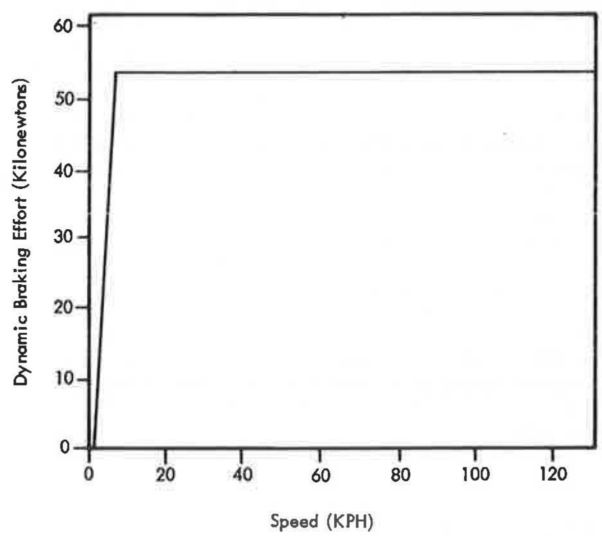


Figure 2. BART Dynamic Braking Effort



Note: 1 Kilonewton = 225 Lbs. 1 KPH = 0.62 MPH.

Train Resistance

In the train performance simulation, resistance to motion comes from two sources: grades and the train's inherent resistance. Resistance on grades is calculated by multiplying train weight times the tangent of the grade. The second component of train resistance, inherent train resistance, is calculated from the Davis Equation, used to compute the inherent resistance to motion of conventional rail transit vehicles (2,4,5,6,7).

To determine inherent train resistance in newtons, the Davis Equation equals:

$$F = 0.65 + \frac{129}{w} + k_1 v + \frac{k_2 A v^2}{W}. \quad (3)$$

where F = newtons of resistance per kilonewton of car weight.
w = car weight per axle in kilonewtons.
W = total car weight in kilonewtons.
v = speed in kilometers per hour.
A = area of a car's cross section in square meters.

In this version of the Davis Equation, an average value for k_1 is 0.009, while for k_2 an average value for a leading car equals 0.030. For trailing cars, an average value of k_2 is 0.0063. However, both k_1 and k_2 depend on car characteristics.

Traction Motor Current Consumption

With the forces of resistance and tractive effort or braking effort acting on the train computed, the acceleration-braking and speed profiles can be simulated. To determine the energy consumed by the train following this performance profile, the current consumption of the traction motors must be estimated. In a D. C. series motor, the following proportionality exists between tractive effort and motor current (8).

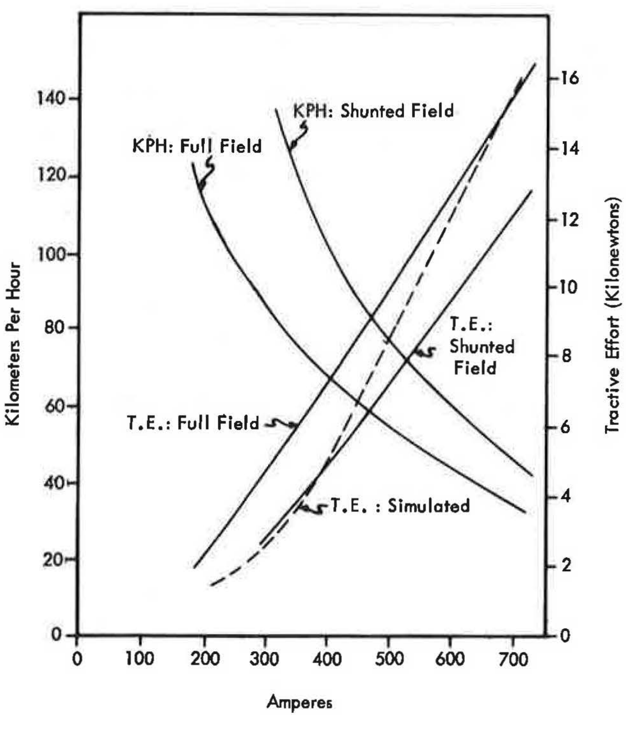
$$I_{motor} = k\sqrt{TE_{car}} \tag{4}$$

To obtain a point with known current and tractive effort to solve for k, it is first assumed that the maximum voltage across a motor is known, and that this maximum voltage equals the motor voltage at the car's maximum speed. The tractive effort at the maximum speed and power output at maximum speed are also known. Substituting this power and motor voltage into the equation relating power, motor current, and voltage determines the minimum current through the motor at the minimum tractive effort. Therefore:

$$I_{motor} = I_{motor}^{min}\sqrt{\frac{TE_{car}}{TE_{car}^{min}}}. \tag{5}$$

In operating the simulated train, it is assumed that all car motors are in series over the range of speed when maximum tractive effort is available. This is in the speed range of 0 to 30-40 KPH (20-25 MPH). Past this speed the simulation assumes that the motors are circuited in parallel. A comparison of the simulated motor operation with actual motor operation is shown in Figure 3, which plots the tractive effort versus motor current curve for a Westinghouse 1463-B traction motor (1), the motor used in the BART car, against the tractive effort versus current curve in the simulation.

Figure 3. Simulated and Actual Motor Operation



Note: 1 KPH = 0.62 MPH. 1 Kilonewton = 225 Lbs.

Simulated and Measured Train Performance

Speed and Acceleration

It was highly desirable that the output from a simulation be compared against measured performance of a rail transit vehicle. This proved difficult to do because accurate performance data is rarely published. Finally, the simulation was compared against train performance data developed and published during the preliminary testing and evaluation of the BART propulsion system (3).

However, this could not be a straightforward comparison. The most important difference between the test data and simulation output is that the test propulsion system does not exactly match the propulsion system in the final BART vehicle. The test traction motor features lower current consumption at every level of tractive effort than the BART Westinghouse 1463-B motor. The geometry of the test track and its vertical alignment is also different from the simulated track segment. A third problem is that the test car was not completely equal in weight or configuration to the final BART design.

Figure 4 compares the simulated train acceleration and speed against test data. Simulated and reported performance are quite close over the first 150 meters (500 feet) of operation. After this distance, the higher simulated acceleration takes effect and the simulated and test speeds diverge rapidly.

Energy Consumption

Figure 5 shows the instantaneous energy in kilowatts consumed by the test car accelerating over the first 1220 meters (4000 feet) of a run at the rate shown in Figure 4. Simulated energy consumption per car, also shown in this figure, is clearly higher than the BART test vehicle consumption on the test track. Part of this increased consumption is due to the higher current consuming motors of the simulation vehicle and part of the difference is attributable to the higher acceleration rate of the simulated train.

A major difference in energy consumption between the simulated and test vehicle can be seen in Figure 5 during the first 30 meters (100 feet) or so of acceleration. Traction motors in the BART test vehicle were permanently wired with two motors in series on each truck, but all four of the simulated vehicle motors are switched into a series circuit over the first 43 meters (140 feet) of the run. This use of series operation decreases the current consumed per car and explains the discontinuity in the simulation curve and most of the difference in energy consumption between the test car and the simulated vehicle at low speeds.

Simulation Results

Energy Consumption Versus Train Length and Distance Between Stops

The first relationship between energy consumption and rapid transit operation to be investigated using the train performance simulation program was the impact of longer trains and greater distances between stations. A total of nine simulations were run using three different train lengths and three varying distances between stops. Trains two, four, and eight cars long were simulated over distances between stations of 305, 1524, and 3048 meters (1000, 5000, and 10,000 feet). In all these

Figure 4. Simulated and Test Train Performance

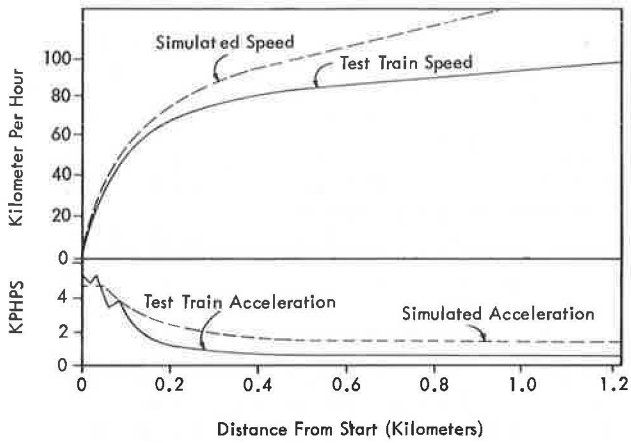
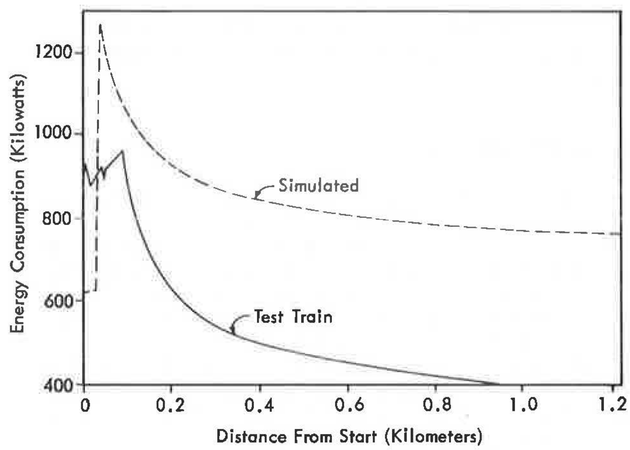


Figure 5. Simulated and Test Train Energy Consumption

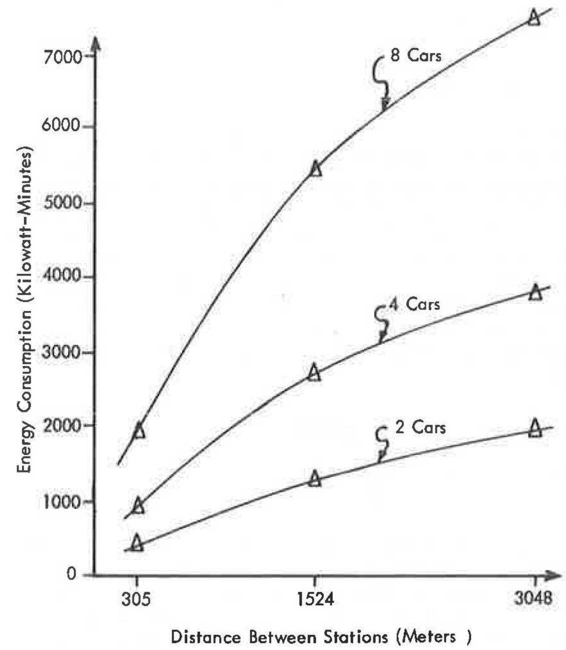


Note: 1 Kilometer = 0.62 Miles.

calculations maximum performance of the train was assumed. Maximum tractive and braking efforts, subject to maximum permissible acceleration and braking rates, were applied and the train was not permitted to coast.

Results of these simulations are plotted in Figure 6. It should be noted that the simulated energy consumption is only for propulsion of the train and does not include energy used for auxiliary equipment such as air conditioning. This figure shows the energy consumed by the train in kilowatt-minutes as a function of train length and distance between stops. Energy consumption rises almost proportionally with the number of cars in the train because all cars are powered and contribute about equally to the tractive effort moving the train. But more importantly, the energy consumption is increasing at a decreasing rate with the distance travelled between stations. At shorter station spacings, the high energy consumption during the initial accelerating portion of the run is a larger portion of the energy consumed for the whole run than it is at longer distances between stations.

Figure 6. Train Energy Consumption, Train Length, and Station Spacing



Note: 1 Meter = 3.28 Feet.

Table 1 further emphasizes this latter point by contrasting average energy consumption rates. In this table, the average energy per car kilometer (car mile) is compared for the simulations of Figure 6. This comparison reveals that the 1524 meter (5000 feet) station spacing is almost 75% more efficient than spacing stations only 305 meters (1000 feet) apart. Extending the distance between stations to 3048 meters (10,000 feet) continues this trend, and this spacing is about 45% more efficient than the 1524 meter (5000 feet) station spacing. Average energy consumed per car kilometer (car mile) at 305 meters (1000 feet) travel distances is almost 2.5 times the consumption rate when stations are 3048 meters (10,000 feet) apart.

There are only slight economies in longer trains. Because the lead car encounters more resistance than a trailing car, the resistance of each car added to a train is slightly less than the average resistance per car in the train. But this factor is negligible at very short station spacings when the train does not attain a high speed. Energy savings per car kilometer (car mile) on the

Table 1. Average Energy Consumption in Kilowatt-Hours per Car Kilometer

Station Spacing	Train Length in Cars		
(meters)	2	4	8
305	11.26	11.22	11.20
1524	6.50	6.47	6.41
3048	4.72	4.51	4.44

Note: 1 Kilometer = 0.62 Miles.
1 Meter = 3.28 Feet.

order of 1% to 2% for each added car are achieved at the 3048 meter (10,000 feet) station spacing distance.

Energy Consumption and Speed Attained Between Stops

The transit performance simulation program was applied to determine the impact of different maximum speeds on energy consumption. A four car train was simulated over different lengths of track at four different maximum speeds. The train was first limited to a maximum speed of 32.2 KPH (20 MPH), then its maximum speed was increased in 32.2 KPH (20 MPH) increments to the maximum permitted speed of 128.7 KPH (80 MPH).

In Table 2, average energy consumption rates per car kilometer (car mile) are again shown. For a trip between two stations 3048 meters (10,000 feet) apart, it requires 3.6 times as much energy to achieve a top speed of 128.7 KPH (80 MPH) than to run at a maximum speed of 32.2 KPH (20 MPH). Over this same length of track, an increase in speed from 32.2 KPH (20 MPH) to 64.4 KPH (40 MPH) requires slightly more than twice as much energy per car kilometer (car mile).

Train Energy Consumption and Track Profile

The simulation program was used to see how much influence the track profile might have upon energy consumption. Simulations were again run for the three station spacings used earlier, but the track profile was depressed between stations. In these runs, the track profile was symetrical on either side of a point midway between the two stations. This meant that the track profile faced by a train was the same regardless of direction of travel. The logic behind this assumption is that most transit designs are for two adjacent tracks, one in each direction, and that the adjacent track profiles could not widely differ without considerable added construction expense for tunneling and elevated structures.

The simulation track profile consisted of a downgrade starting at the station, a level section of track, and then an upgrade into the station. Grades were set so that all train braking would occur on the upgrade. It did not seem desirable to have the train accelerating or holding speed while on an upgrade. Grades of 2% and 4% were used for the track profile, and parabolic curves connected the tangent sections of the vertical profile.

Table 3 shows the results from these simulations of a train running over a depressed track profile. Over a run of 1524 meters (5000 feet) an energy saving of around 16% is possible with a profile incorporating 4% grades. This saving of energy is reduced slightly when the train makes a longer run between stations. The 3048 meter (10,000 feet) simulation shows an energy consumption reduction of less than 14% when 4% grades are used in the track profile. The table also indicates that the energy consumption is nearly proportional to the amount of grade used in the profile even though the length of track on grade changes only slightly due to the increased lengths of vertical curves.

Energy Consumption and Braking Policy

The final aspect of rail transit characteristics to be investigated is the operating agency's braking policy. Allowing a train to coast for some distance before applying the brakes will affect the energy

Table 2. Average Energy Consumption for a Four Car Train versus Maximum Speed in Kilowatt-Hours per Car Kilometer

Station Spacing	Maximum Speed (KPH)			
(meters)	32.2	64.4	96.6	128.7
305	2.91	8.86		
1524	1.62	3.65	5.31	
3048	1.46	3.01	3.87	5.19

Note: 1 Kilometer = 0.62 Miles.
1 Meter = 3.28 Feet.

Table 3. Energy Consumption for a Four Car Train versus Track Profile in Kilowatt-Minutes

Station Spacing	Percent Grade in Profile		
(meters)	0%	2%	4%
305	945	901	
1524	2724	2527	2290
3048	3799	3531	3283

Note: 1 Meter = 3.28 Feet.

consumption of the train. Two simulations of a four car train running 3048 meters (10,000 feet) between stations were completed to test the energy conserving value of coasting before braking. In the first simulation, the train reached top speed then coasted to 112.7 KPH (70 MPH) before applying brakes to come to a stop. The second simulation was similar except that the train coasted to 96.6 KPH (60 MPH) before applying brakes.

Table 4 summarizes the results of these two simulations incorporating coasting and compares them against the maximum performance simulation over the same distance. The results are quite interesting since considerable energy savings occur when the train coasts, with only a small increase in travel time between the two stations. Especially interesting is how long a train can coast on level track without losing too much speed. In the simulation with the longest length of coast, energy consumption is 40% less than in the maximum performance run.

However, these figures somewhat overstate the energy conserving value of the coasting phase. Even with 3048 meters (10,000 feet) between stations, the train was unable to reach its maximum speed before entering the coasting phase of its performance cycle. Thus, a certain fraction of the energy savings cited in Table 4 is attributable to the limited maximum speed reached in the simulations. A glance at Table 2 indicates that approximately 0.6 kilowatt-hours of the 2.10 kilowatt-hours per car kilometer (1 kilowatt-hour of the 3.39 kilowatt-hours per car mile) saved by coasting to 96.6 KPH (60 MPH) is due to the lower maximum speed reached in the simulation.

Conclusions

The most important concept brought out by the train performance simulations is the strong dependence of energy consumption upon the operation of the rail transit vehicle and the design of the

Table 4. The Impact of Different Coasting Policies

Item	Coasting Policy		
	No Coast	1500 Meter Coast	2000 Meter Coast
1. Speed Range of Coast		127 KPH-113 KPH	114 KPH-97 KPH
2. Total Energy Used	3799 KW-Minutes	2755 KW-Minutes	2259 KW-Minutes
3. Energy Used per Car Kilometer	5.19 KW-Hour	3.77 KW-Hour	3.09 KW-Hour
4. Travel Time	117 Seconds	120 Seconds	128 Seconds

Note: 1 Meter = 3.28 Feet. 1 KPH = 0.62 MPH.

track profile. An energy efficient rail transit design and operation would use only about one-half the energy of less efficient designs and operations. Considering the limitations imposed on train size and station spacing by capacity and service requirements, the last two factors discussed in the paper appear to have the most potential for improving energy consumption in rail transit. These two factors are: incorporating a coasting phase in the performance cycle between stations, and adjusting the track profile.

Of these two factors, incorporating a coasting cycle is clearly of greater importance than changing the track profile for energy conservation. A policy of coasting can be easily implemented without capital investment, and coasting between stations generally causes a slight reduction in the maximum speed attained between stations, which also promotes energy efficiency.

The trend toward high performance rail transit vehicles has caused an increase in the energy consumption of the mode. A reported average figure of 3.3 kilowatt-hours per car kilometer (5.3 kilowatt-hours per car mile) used in recent U.M.T.A. analyses (9) is too low for new high performance equipment. This figure is probably too low even when a conscious effort is made to promote energy conservation in this new equipment's operation.

The importance of energy conservation in justifying new transportation system management type improvements should not be overlooked. When electricity costs are rising to $0.04 to $0.05 per kilowatt-hour for rapid transit operations, it is clear that savings in energy costs can rapidly accumulate. Thé advantages of automatic train control for insuring an energy efficient coasting phase in the train performance cycle are obvious, and a portion of the cost of this equipment should be justified through the resulting energy cost savings.

Improvement of poor track alignment is another case where some of the cost of the improvement is covered by the improved energy efficiency of the rail transit operation. In these two situations, and in similar problems in the evaluation and planning of rail transit improvements, the analyst must be aware of how alternative designs and operations impact energy consumption.

Acknowledgements

The simulation program, initial computer runs, and a first draft of this paper were prepared while the author was at the University of Pennsylvania. The support and advise of Professor Vukan R. Vuchic of the University of Pennsylvania in the preparation of this paper is gratefully acknowledged. In addition, the author wishes to note that his time at the University was supported by the Transportation Research and Education Fellowship Program of the Federal Highway Administration.

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Discussion

David R. Phelps, General Electric Company

Optimizing the energy consumption of a rail transit system consistent with operational, physical, and civil constraints is an important issue in the design of new systems and operation of existing systems. Mr. Eash's paper addresses the alternative strategies and design features in a useful manner, and his results are instructive.

It is unfortunate that the validity of Mr. Eash's comparative results is clouded by the serious errors in certain portions of his analysis. Mr. Eash has correctly highlighted several strategies and design considerations capable of significantly reducing the energy consumption of a rail transit system. However, his results are useful only in a qualitative sense; the quantitative, numerical results are derived from a simulation which, regretable, is inconsistent with the true physics of transit railcar propulsion systems.

At the outset, Mr. Eash leaves unexplained the discrepancy between his simulation and the BART data. Investigation of his analysis shows several probable sources of the discrepancy. Taking his analysis in the order of presentation, his train resistance equations were examined. Converting the usual form in English units to metric yielded two coefficients with values different from Mr. Eash: k_1 - 0.014 (rather than 0.009) and k_2 = 0.044 (leading car, rather than 0.030). Unfortunately, Mr. Eash does not give the simulated train length for his Figures 4 and 5. The test data cited is for a single car.

Further review of Mr. Eash's analysis showed a significant shortcoming in the presentation of design parameters of D.C. traction motors. Contrary to his statement, in such motors magnetic flux is not a "linear function of the current through the motor." Because of saturation effects, it is decidedly non-linear. Reference to his Figure 3 shows that his simulation thus becomes greatly in error in that it understates the current required to produce the required tractive effort. In addition, Mr. Eash, although unclear on this point, appears to have ignored field weakening and to have used, in effect, a (erroneous) "Shunted Field" curve throughout.

Mr. Eash is fortunate that the BART car characteristics uniquely comply with his assumptions regarding motor voltage, tractive effort, and power output versus speed. It is unclear that he appreciates that his assumptions, other than for motor voltage, would have been invalid for many other D.C. transit cars.

In addition to the problems with his motor simulation, Mr. Eash then proceeds to miss the point that his curve (Figure 3) is a 2S2P curve, rendering false his assumption that "all car motors are in series" during the constant tractive effort phase. Finally, Mr. Eash seems not to have simulated a current-speed curve (c.f. Figure 3, his report), which might further have highlighted the problem.

All of the above shortcomings are unfortunate because of the ease with which they could have been avoided. With reference once more to the solid line portions of his Figure 3, one may enter the diagram at the desired tractive effort (14.25 KN) to find the intersection with the Full Field T.E. curve (about 670 amperes). This current (and T.E.) can be maintained up to the speed (the "corner point") where the amperes intersect the Full Field "KPH" curve (about 40 KPH). In a switched resistor system using a 4S start, the line current would equal the motor current up to about half the corner point speed. After transition to 2S2P, line current would be double the motor current. (Sometimes a 4S characteristic is also supplied by the motor manufacturer.)

In a chopper situation such as BART, line current is ideally zero at standstill, ramping to twice motor current at the corner point. Chopper losses modify the ideal shape, but the shape of the bottom of Figure 4 looks in error in the early stages for the Test Train.

Referring once more to Figure 3, the propulsion system may undergo field shunting/weakening at constant armature current, or the accelerating rate may be held up by going to higher armature current. In either case, the tractive effort - Shunted Field T. E. intersection determines the current - KPH: Shunted Field intersection. Beyond this point the car is running on the Shunted Field motor characteristic for Amperes - T.E. and Amperes - KPH. Usually the volts per motor have been constant since crossing the current - KPH: Full Field curve; in the case of BART, volts per motor do rise to a maximum at top speed.

The above level of detail is given to indicate that Mr. Eash made his task more difficult than need be. His qualitative results are valid in the relative numbers he computes, but his numerical results rest on an incorrect analysis.

Closure

Mr. Phelps comments are quite informative on the operation of traction motors and it is gratifying to see that this paper has sparked comment from a manufacturer. The dissemination of reliable vehicle design data through this type of discussion can only improve the research of academic and government analysts in the rail transit field.

In light of his discussion comments, two general points about the work described in the paper should be emphasized. First, no attempt was made to totally reproduce the BART vehicle in the simulation computer program. Secondly, simulated motor characteristics are derived from the theoretical performance of D.C. motors in transit operation as opposed to the option of having a unique motor design built into the program. The resulting rail transit performance described in the paper should then be viewed as representative of modern rail transit performance, and not a strict recreation of BART's performance.

The simulation requires some vehicle attributes which could not be obtained from published data on the BART vehicle, and average and estimated vehicle parameters had to be used. Parameters in this category include: actual motor power as a function of hourly rating, the efficiency of gears in the trucks, and axle loadings. Average values were also used for the Davis Equation constants. The constants used were carefully checked against their English unit equivalents, but these constants are vehicle dependent and can differ by the amount noted by Mr. Phelps depending on the source cited.

With regard to the development of the traction motor performance relationships used in the paper, they are derived and discussed in the closure reference (10). The saturation effect which tends to hold magnetic flux constant is ignored in an elementary analysis of D.C. motor performance. Also, the relationships used in the paper are for a series wound D.C. motor, traditionally the most widely used type of motor in transportation vehicle applications. Based on the comparison with the BART motor, these relationships apparently provide results representative of actual transit motor performance.

Finally, some questions are raised in the discussion about the motor circuitry used in the simulation. It is true that BART's traction motors are permanently wired in a two-series-two parallel configuration, but operating a four series motor configuration in the eraly stage of the performance cycle then switching to two-series-two parallel operation is a common design practice. In any case, there is little impact on performance cycle energy consumption since the four motors in series configuration is in effect during only a small portion of the performance cycle.

Reference

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PASSENGER UTILIZATION OF LOCAL VS EXPRESS TRAINS FOR A NEW YORK CITY SUBWAY LINE: A CASE STUDY

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A survey of over 5000 passengers on the IRT #1 line was conducted in New York City in order to examine passenger attitudes, perceptions and, most importantly, travel mode preferences (local vs express). Passengers were asked whether they prefer faster or more comfortable trains. It was found that they were evenly divided in their preference between faster trains and more comfortable ones, regardless of the distance travelled. However, it was found that significant numbers of passengers opted to transfer to crowded express trains, with little or no savings in travel time, while parallel local trains ran much less crowded. Passengers were asked to estimate their travel time and the results were compared to measured travel times. Passengers consistently overestimated their travel time and correlated their use of express trains with faster service. A major conclusion of this study is that the overall quality of service on the #1 line may be improved by inducing passengers to stay on local trains when travelling even moderate distances. This will promote a better passenger load distribution between the local and express and provide all passengers with a more comfortable level of service with no significant increase in travel time.

The operational effectiveness of mass transit systems is strongly dependent on the attitudes and preferences of the system users. In our study we examine attitudes, perceptions, and most importantly, travel mode and preferences for a sample of riders on one New York City subway line.

The subway system of New York City consists of a diverse network of interconnecting lines. In many parts of the network, local tracks run parallel with express tracks, providing the passenger with two travel modes. For example, the IRT #1 line, which starts at 242nd Street and Broadway, joins the #2 line and #3 express line at 96th Street. The local and express tracks run parallel down to Chambers Street in lower Manhattan. Figure 1 shows a map depicting the express and local stations involved in our study.

During the morning rush period, the local trains frequently have empty seats at 96th Street, whereas the express trains are most often extremely crowded. Many passengers who board the local trains at the uptown stations transfer to the express at 96th Street. Since this transfer appears to involve a sacrifice of travel comfort, it seems to be motivated by the passenger's desire to decrease the overall travel time (defined as the time from boarding at the station of origin to arriving at the station of destination).

It has been observed that many passengers choose to transfer at 96th Street to the express, henceforth referred to as "local/express" travel mode or simply "express" mode, rather than continue on the local train ("local" mode). There is a visible imbalance in the passenger loads carried by the local trains versus the express trains departing the 96th Street station, downtown. One of our goals was to examine whether passengers indeed correlated the express mode with faster service and, if so, whether the transfer to express trains was justified in terms of the gains in speed, in view of the resulting discomfort.

We have surveyed over 5000 passengers boarding the #1 IRT line at uptown 157th through 103rd Street stations. In addition, we have measured the actual travel times from any of the uptown stations to the downtown stations shown in express stops in Figure 1. Measured travel-times were obtained for both the local and local/express travel modes. Twelve independent timed runs, made during the morning rush period in April 1977, form the basis for the travel-time matrix. By comparing the passenger's travel mode preferences with the data in the measured travel-time matrix, we are able to evaluate how effectively the subway passengers are utilizing the travel mode option that is available to them. Based on this analysis, recommendations are made to affect improvements in the passenger utilization of the system.

The level of service provided by the subway system is dependent on both the speed of transport and the level of comfort provided to passengers. We investigated subway user attitudes concerning their preference for speed versus comfort and in particular correlated this preference with their choice of travel mode. Since the overall level of comfort is not readily quantifiable, we related "comfort" merely to the observed passenger loads and the availability of seats. No attempt was made to measure these variables, but it was observed that passenger loads on local trains were significantly and visibly lower than on express trains.

Our study provides the basis for:

1. An evaluation of the effectiveness of the passenger utilization of the local vs local/express travel modes.
2. An evaluation of subway user perceptions concerning overall travel time.
3. An evaluation of passenger preference for speed vs level of comfort and a correlation of their preference with their choice of travel mode.
4. Recommendations for improving the overall level of service on the studied line by effecting improvements in the passenger's choice of travel mode.

The above evaluations and recommendations are presented below.

Survey Method

Passenger Interviews

The passenger survey was conducted during the morning rush hours (7:00 a.m. - 9:30 a.m.) during five consecutive weekdays in April 1977. Passengers boarding the downtown IRT #1 trains at the survey stations (indicated in Figure 1) were asked five questions:

1. Do you regularly travel from this station?
2. What is your final destination station (any one of the stations in Figure 1 or "other")?
3. Will you transfer to the express train at 96th Street?
4. Do you prefer faster service or more comfortable service?
5. Estimate the travel-time in minutes from the time that you leave here to the time that your train arrives at your destination station.

Passengers were interviewed in turnstile areas of the stations by students of the City College of New York wearing identification badges. The responses of over 6000 interviewed passengers were recorded and carefully screened for errors, ambiguities and inconsistencies. As a result, about 750 (12.5%) of the responses were rejected and not used in the analysis.

Survey Population. We restricted the survey to rush hours since most subway travel takes place in commuting to and from work. Eighty-eight percent of the passengers interviewed were regular commuters. A survey during rush hours may show a bias towards speed preference, but since rush hours are the most critical in designing, scheduling and improving service, it is felt that no significant error would result in our conclusions. In a recent survey of travel modes in New York City (1), it was found that 80% of those who commute to work use public transportation, with a subway to bus ratio of 3:1, i.e., 60% of all commuters travel by subway to work. For travel other than work, the comparable figure is about 16%. These numbers show that the primary use of the subway is indeed in commuting to and from work, and this use far exceeds all other uses combined.

Technical Aspects of the Survey. One objective of our survey was to study the feasibility and the logistics involved in a systemwide origin-destination survey of New York subway riders. Our limited study illuminated some of the difficulties involved, like ambiguities in survey questions, language difficulties in areas with high percentages of Hispanics and even hostility toward pollsters.

Most past surveys of transit users have been based on extensive home questionnaires. On-site interviews have limitations on scope and depth, but provide a fast and cost/effective method of collecting data. Such surveys have been used to obtain simple preference data in the past. See, for example, Zell's study of bus riders in the San Francisco Bay area (2).

Data Analysis. Rigorous statistical analysis of variance was carried out for the measured travel time matrix to find the effects of station of origin, station of destination and travel mode on the travel times. The analysis showed that there is a statistically significant difference between travel time via the local/express mode as compared to the local mode. However, the effect due to the travel mode was found to be much smaller than the effect due to either the station of origin or the station of destination.

The data compiled for the passenger survey included statistics on:

a . Local vs local/express use.
b . Speed vs comfort preference.
c . Correlation of "a" and "b".
d . Speed-comfort preference vs distance travelled.
e . Choice of travel mode vs distance travelled.
f . The number of passengers travelling from origin to destination.
g . The percentage of "f" who use express or local trains.
h . The percentage of "f" who prefer speed vs comfort.
i . The mean estimated travel time from origin to destination.
j . The standard deviation of "i".

Results and Conclusions

Travel Time Analysis

Table 1 shows the mean travel-times measured from every station of origin to every station of destination obtained from twelve independent measurements. Also included in Table 1 are the mean passenger estimates of their travel-times. The standard deviations of the measured travel times are in all cases less than 10% of the tabulated means. The standard deviations of all the passenger travel-time estimates are in all cases less than 25% of the tabulated means.

From Table 1, it is evident that the travel times using the "local" mode are competitive with the travel times using the "express" mode for all stations of origin and stations of destination down to and including 34th Street. At 34th Street, the difference between the mean travel time (averaged over all stations of origin) for the "local" vs "express" modes is two minutes. This 11% difference is not judged significant. Although only express stops are included in the list of destinations, it is obvious that for any

Figure 1. Map of Studied Subway Line

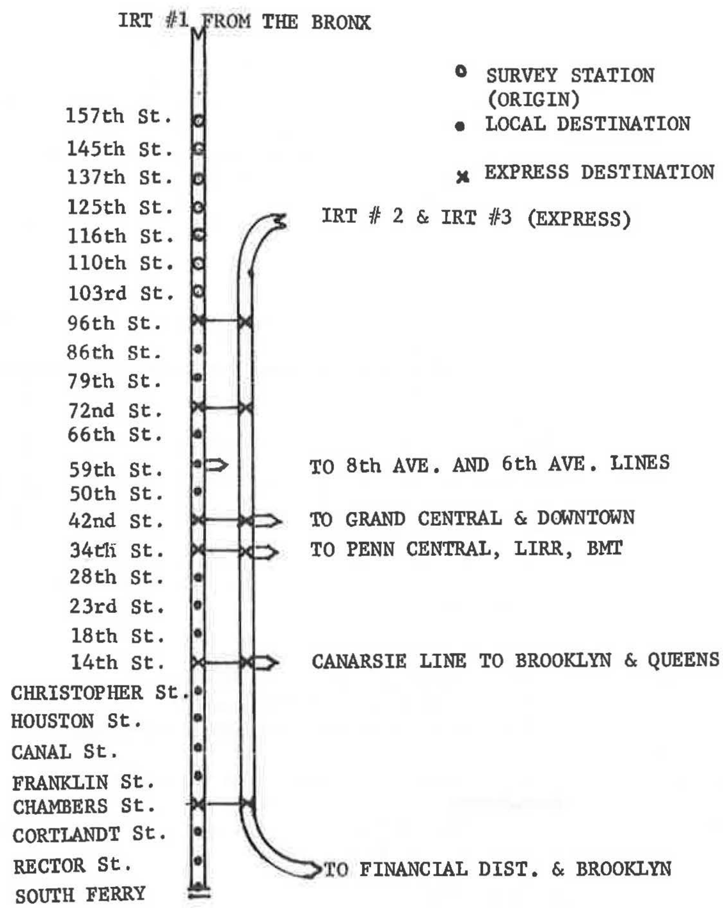

Table 1. Measured and Passenger Estimated Travel-Time (Minutes).

DESTINATION	72 St.			42 St.			34 St.			14 St.			Chambers St.		
ORIGIN	Est.	Loc.	Exp.	Est.	Loc.	Exp.	Est.	Loc.	Exp.	Est.	Loc.	Exp.	Est.	Loc.	Exp.
157 St.	20.3	17.8	18.3	29.2	23.8	22.6	31.0	26.7	24.6	34.8	31.1	27.1	41.6	37.6	31.0
145 St.	18.3	15.8	16.5	24.3	21.8	20.9	27.1	24.7	23.0	31.8	28.9	25.3	38.4	35.6	29.2
137 St.	22.0	13.8	14.1	24.1	19.9	18.5	27.0	22.6	20.4	36.0	27.1	22.9	37.7	33.5	26.8
125 St.	14.5	11.1	11.9	22.3	17.3	16.2	24.2	20.0	18.2	31.5	24.4	20.7	33.4	30.9	24.5
116 St.	15.0	8.4	9.0	19.2	14.5	13.4	20.4	17.1	15.3	27.3	21.7	17.8	27.4	27.9	21.7
110 St.	11.9	7.2	7.2	18.1	13.4	11.5	20.0	15.7	13.5	24.0	20.7	16.0	30.7	27.1	19.9
103 St.	10.8	6.0	6.0	16.3	12.1	10.3	18.3	14.6	12.3	21.4	19.4	14.8	27.3	25.9	18.7
Mean:	16.1	11.5	11.9	21.9	17.8	16.2	24.0	20.2	18.2	29.5	24.8	20.7	33.8	31.2	24.5

Est = Overall Passenger Estimate, Loc = Measured in Local Mode,
Exp = Measured in Local/Express Mode.

Table 2. Passenger Estimated Travel Times for Local Mode Passengers Vs. Local/Express Passengers (In Minutes)

Destination		Origin						
	Mode	157 St.	145 St.	137 St.	125 St.	116 St.	110 St.	103 St.
72 St.	Local	20.5	20.0*	20.0*	13.2*	-	11.3*	-
	Express	20.0*	17.3	30.0*	15.7*	15.0*	12.5*	10.8*
42 St.	Local	27.3	24.6	24.2	22.9	21.2	19.0	15.8
	Express	29.7	23.7	24.2	22.1	18.8	17.8	16.4
34 St.	Local	30.6	27.1	26.6	24.8	19.4	17.7	17.1
	Express	31.2	27.1	27.2	23.9	20.6	21.0	18.8
14 St.	Local	31.2	32.8	32.6*	31.0	26.5	21.0	21.7*
	Express	36.0	31.6	36.8	31.7	27.5	24.4	21.3
Chambers	Local	31.2*	39.3	49.7*	30.0*	-	41.2	26.0*
	Express	42.5	38.2	36.5	33.6	27.4	29.3	27.7

Note: Numbers marked * are based on small samples of less than five responses.

local destinations above 34th Street, the local mode would be preferable to the local/express mode because of the need for a second transfer. At the 14th Street and Chambers Street destinations, the local/express travel mode is faster than the local mode by 4.1 and 6.7 minutes respectively. These are judged to represent a significant reduction in overall travel time (i.e., 16.5% and 21.5% reductions).

A major conclusion from Table 1 is that the transfer to the express train may be justified (from the viewpoint of overall travel time) when the destination is either 14th Street or further. We have excluded stations of destination in Brooklyn, lower Manhattan (below Chambers Street) and Queens from our analysis where it may indeed be sensible to choose the local/express mode.

From Table 1, it also is evident that passengers consistently overestimate their overall travel-time by roughly 10% to 20%. This suggests that they perceive the system as offering a lower level of service than it actually provides, with respect to travel-time. Table 2 compares estimated travel times of passengers in the local mode vs passengers in the local/express mode. The table shows that the estimates obtained by the two groups do not show any significant difference. In particular, express users do not have lower estimates of their travel time although the measured times in express mode are somewhat lower as shown in Table 1. This evidence suggests that those passengers who choose the express mode are more pessimistic in their time estimate than those using local mode. Perhaps their choice of mode is affected by this pessimism.

The results of Tables 1 and 2 are displayed graphically in Figures 2 and 3 for travel originating at one typical station.

Travel Mode and Service Preferences. Table 3 presents contingency tables relating the choice of travel mode (local vs express) to the service preferences of passengers (speed vs comfort). The tables show that regardless of the type of destination (local stop or express stop) the choice of mode is not independent of the service preference, based on X^2 tests at 0.01 level of significance. All three tables show a positive correlation between express mode and speed preference. Further analysis of Tables 3b and 3c shows that the type of destination (local or express) has an effect on service preferences: passengers to local destinations show a higher preference for comfort than do passengers to express destinations. This seems to confirm the fact that passengers who are more likely to use the local train become aware of the greater level of comfort that it affords.

These conclusions also are supported by the numbers in Table 4. Figure 4, on the other hand, shows that the speed or comfort preferences did not change significantly with the distance travelled. Roughly half the passengers surveyed prefer speed and half prefer comfort, independent of the distance travelled. In contrast, the choice of travel mode is strongly affected both by type of destination and by distance. There is a significantly higher use of the express mode to express destinations (Table 4), and the choice of express increases with the distance as shown in Figure 5.

Conclusions. While most of the results above are not surprising, our analysis demonstrates that many passengers erroneously correlate the express mode with higher speed and as a result are misusing the system. A striking example is that 46.4% of the passengers to 72nd Street transfer to the express even though the overall travel time in this mode is slightly longer than with the "local" mode. Seventy-seven percent of the passengers to 42nd Street chose the express to gain an average of 1.5 minutes. We conclude that the severe imbalance in passenger loads between local and express trains leaving 96th Street is not justified and that many passengers who transfer to the express are doing disservice to themselves as well as to others.

Recommendations

Since the major cause for the imbalance in passenger loads arises from misconceptions held by the public about the relative speed of express and local trains, the forthright approach to remedy the situation would be to educate and inform the public. This is usually easier said than done. A step in the right direction has already been taken on some lines by posting and distributing subway timetables showing travel times to all destinations along the line.

Passengers might be induced to stay in the local train if the practice of waiting for the local at 96th Street were stopped. Under this practice, express trains wait in the station for the next local train, so that local passengers can transfer without waiting on the ramp. The net result is further delay of the express and an inducement to transfer from the local into the crowded express train.

Finally, if the above measures fail, rescheduling of express trains might be considered, along with possible changes in routing. For example, it seems that the express stop at 72nd Street could be eliminated without adversely affecting many passengers.

Acknowledgments

This study was sponsored in part by a grant from the Sloan Foundation and was conducted with the cooperation of the New York City Transit Authority.

References

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2. C. E. Zell. San Francisco-Oakland Bay-Bridge Trans-Bay Bus Riders Survey. Highway Research Record No. 114, 1966, pp. 169-182.

Figure 2. Measured and Estimated Travel Times From 145th Street to Destination.

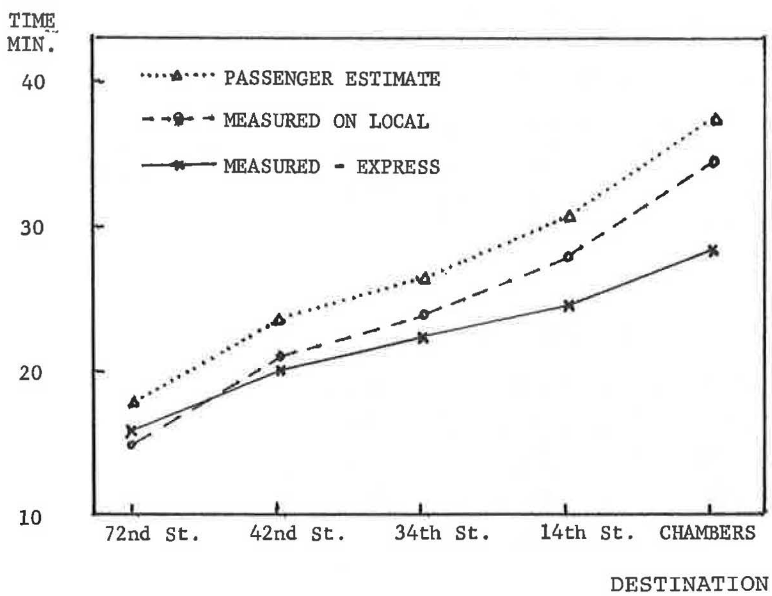


Figure 3. Passenger Estimates of Travel Times From 145th Street to Destination

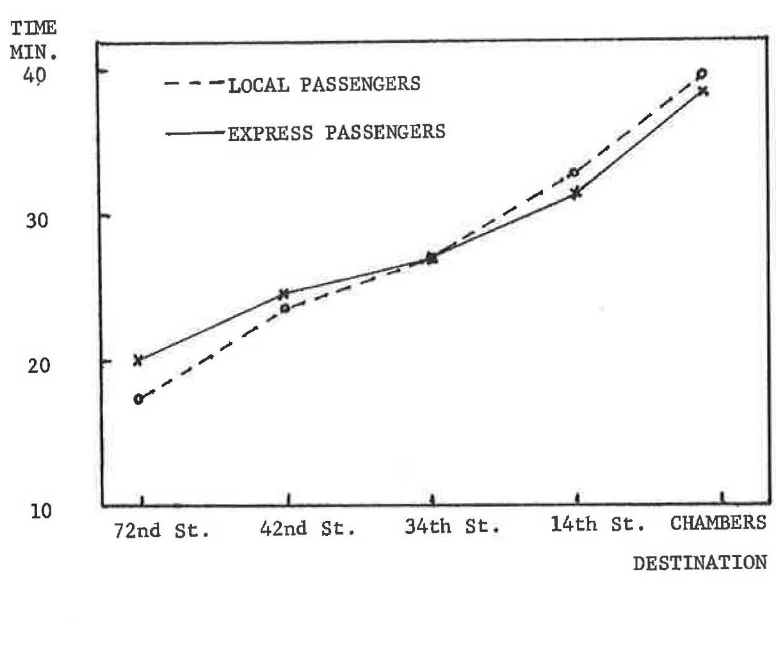


Table 3. Cross Tabulation of Mode of Travel and Passenger Service Preferences

A. Number of Responses for all Passengers:

Mode/Preference	Speed	Comfort	Total	%
Express	1595	1336	2931	55%
Local	970	1433	2403	45%
Total	2565	2769	5334	
%	48%	52%		

$X^2 = 104.4$

B. Number of Responses for Passengers with "Express" Destinations.

Mode/Preference	Speed	Comfort	Total	%
Express	762	648	1410	76%
Local	148	293	441	24%
Total	910	941	1851	
%	49%	51%		

$X^2 = 56.3$

C. Number of Responses for Passengers with "Local" Destinations Below 72nd Street.

Mode/Preference	Speed	Comfort	Total	%
Express	188	148	336	22%
Local	480	681	1161	78%
Total	668	829	1497	
%	45%	55%		

$X^2 = 22.5$

Table 4. Mode of Travel and Service Preferences by Destination

		Mode		Preference	
Destination	Total Number	Local %	Express %	Comfort %	Speed %
All Local Above 72 Street	518	92.1	7.9*	54.4	45.6
Local Between 42 Street and 72 Street	923	93.2	6.8	55.4	44.6
Local Between 14 Street and 42 Street	406	54.9	45.1	55.7	44.3
Local Below 14 Street	168	46.4	53.6	54.8	45.2
72 Street	47	53.2	46.8	63.8	36.2
42 Street	1003	23.0	77.0	51.5	48.5
34 Street	405	30.9	69.1	49.1	50.9
14 Street	215	19.1	80.9	47.0	53.0
Chambers St.	181	10.5	89.5	51.9	48.1
All Others (Below Chambers or on Other Lines)	1468	22.1	77.9	48.8	51.2
Total	5334	45.1%	54.9%	51.9%	48.1%

*Note: These responses were inconsistent, since the local/ express mode is not possible above 72 Street.

Figure 4. Percent of Passengers Preferring Speed Over Comfort as a Function of Distance to Their Destinations.

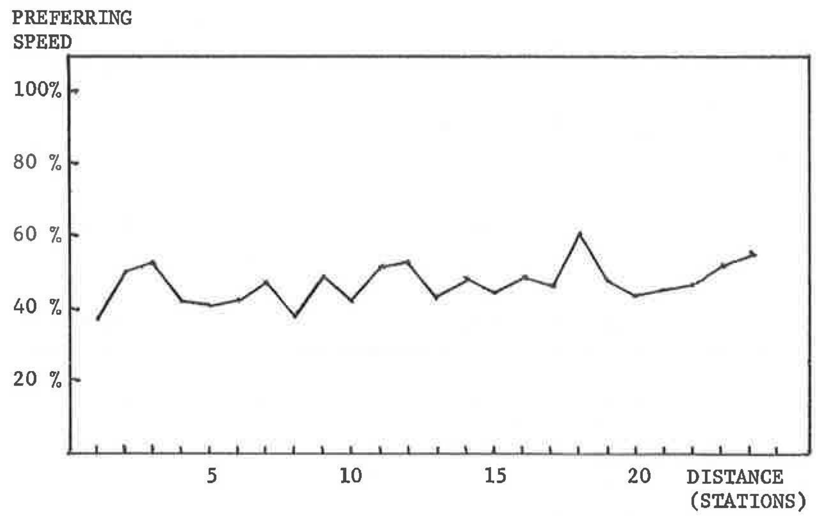
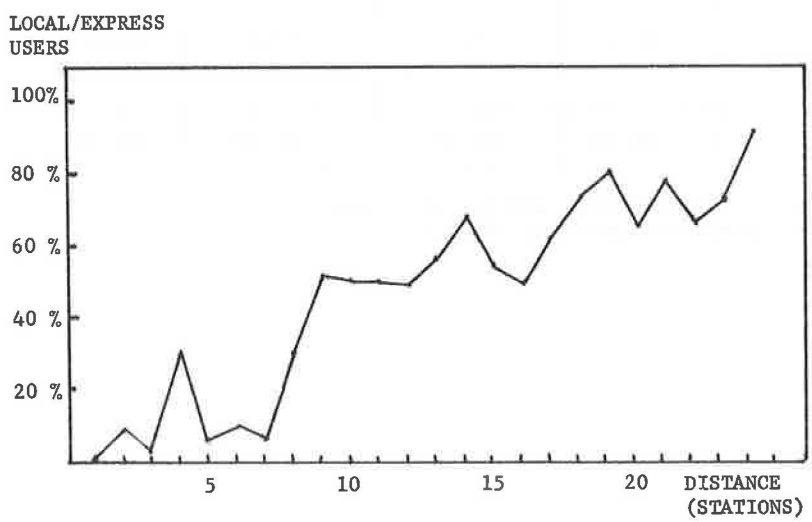


Figure 5. Percent of Passengers Using the Local/Express Mode as a Function of Distance to Their Destinations.



SOME AESTHETIC CONSIDERATIONS IN LIGHT RAIL DESIGN

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Concern over the visual impacts of LRT remains one of the obstacles to a more general acceptance of the mode. Nor is this concern unjustified; for often, in the past, once a project had been approved, scant attention was paid by transit engineers to the appearance of LRT overhead and trackway. Yet all the fixed elements of LRT, trackway, overhead, and stations, are amenable to visual improvement if some of the principles of visual design, widely used in other fields, are applied. This paper outlines and illustrates some of the concepts that lie behind the installation of visually satisfactory and operationally functional LRT facilities, and suggests that closer coordination is needed between technical specialists and urban designers.

During the past few years increasing attention has been paid to the future potential of the light rail mode. Much technical material has been compiled on light rail vehicles, and on the various design elements that make up LRT systems. Despite this, scant attention has been given so far to the visual aspects of surface electric transit, and to techniques for achieving functional engineering requirements in a visually satisfactory manner. None the less, the achievement of a visually satisfactory design has a major impact on how a community perceives its transit system. Failure to address this issue in the past has led to considerable community concern over the appearance of electric transit, particularly the electrical overhead.

For the past thirty years, it has been commonly held that electric surface transit would gradually fade away, replaced by automobiles, some buses, and perhaps a subway or two, and was not therefore worthy of attention by the urban design profession. There was only one solution to overhead wires -- get rid of them.

Because overhead power supply is used by only about half of the electric transportation mileage in the U.S., it is often not realized that over 95 percent of electrified transportation worldwide depends on overhead electrification (1), a trend that is likely to assert itself in the U.S. as the need for all kinds of electric transportation grows. Thus the need to understand and apply the principals of good visual design is likely to become increasingly relevant, not least in the field of LRT.

This paper is intended to focus on some of the visual problems that confront LRT designers, and to outline some of the design concepts that can lead to a more satisfactory approach to these problems.

Overview

It is widely held that the need for urban transit will continue to grow in the years ahead. At the same time, there is growing concern that unless we can become proficient at planning and constructing less costly and disruptive transit facilities, the role of rail transit in this increasing market will be very largely confined to a few major corridors in the larger cities. One part of this design proficiency must address the visual aspects of system elements in conspicuous or sensitive locations. Unfortunately, the sometimes clumsy approach to the visual aspects of LRT design in the past, compounded with the generally decayed state of those facilities in recent years, has resulted in considerable public resentment towards fixed on-street transit facilities, both for LRT and trolley buses.

Nor is the perception of this issue just a contemporary concern. Even in streetcar times, some cities delayed the introduction of electrification because of their concern over the visual effects of overhead electrification. In more recent times, some communities, in considering their future transit needs have suggested that overhead wires are not "acceptable" as part of any future transit mode. Ironically, the same communities sometimes consider that the so-called "light weight guideways" required for elevated, automated transit do not, for some reason, suffer the same lack of acceptability.

The adoption of such a simplistic response to the design of overhead is scarcely consistent with the effort with which other aspects of transportation analyses are conducted. Nor can it be considered an adequate approach to a design problem that is, in fact, susceptible to a variety of design solutions. While the most obvious, and commonly cited problem is overhead wires, other elements, such as trackway and stations, can also benefit from an integrated approach to their visual and functional aspects. Each of these is discussed in turn.

Overhead Design

Design Requirements

Allegations of "overhead clutter" are commonly leveled at electric transit (Figure 1). It is an impact that is readily identified, less easily quantified, and seldom subjected to a design analysis. One possible approach to this problem is to systematically review the functional elements of an overhead system, decide why it is considered unattractive, and what remedial measures are practical.

For the light rail designer, the basic problem is simply how to suspend an insulted power wire within reach of the pantograph over each track. This is the sole requirement. The other components of overhead (poles, span wires, messenger wires, feeder cables and guys) can be constructed in a variety of ways, each with different costs and visual implications. It is here that the application of visual sensitivity can make the difference between a design that is visually offensive, and one that is visually and functionally satisfactory.

Design Treatments

The development of satisfactory overhead design treatments requires a basic understanding of how overhead wires are perceived. Some streets, particularly arterial streets where LRT is likely to be constructed, are already subject to a jumble of utility poles, wires, billboards, and signs that create an unsatisfactory visual environment. Setting is therefore one important element in overhead design, and provides an indicator as to the appropriate level of investment in visual design. In many situations, the combination of LRT overhead in a coordinated approach to other street furniture can result in an overall visual improvement.

The first and basic concept governing visually effective overhead design is that wires are conspicuous only in silhouette. Where wire silhouette is masked by vegetation or by buildings, it becomes at the least inconspicuous, and often even invisible.

Where overhead silhouette cannot be hidden, then its mass must be minimized, and its shape made as regular and geometrically pleasing as possible. This is the second concept.

These two concepts provide a basis for a systematic approach to the visual design of overhead based on:

1) Minimizing hardware in the sky.
2) Management of the wire silhouette.

Hardware Minimization. The techniques to achieve this objective are relatively straightforward. Where possible, a single contact wire should be used rather than a double wire catenary in sensitive or conspicuous areas. Feeder cables should be underground. Usually center poles with bracket arms are less conspicuous than side poles with span wires, particularly if integrated with street lighting. The general use of pantographs on new LRT installations already minimizes the need for secondary hardware such as pulloffs on curves, or overhead switches. Figures 2 and 3 illustrate two approaches to the same problem.

Engineers are usually under pressure to minimize cost, and in the absence of effective community or environmental control, may be tempted to allow wires and poles to proliferate as needed with little thought for appearance. The adoption of a comprehensive systems approach to the installation of street facilities can do much to avoid the installation of separate poles or wires for street lighting, traffic signs, signals and utilities.

Management of Wire Silhouette. The techniques for managing wire silhouette are less obvious and are worthy of discussion in more detail. Three approaches can be used:

- Landscaping.
- Decoration
- Geometry

Landscaping. The landscaping approach is already widely applied. It consists basically of using trees or buildings either to hide or to provide an alternative silhouette to the overhead from common viewpoints. Figure 4 illustrates how both buildings and trees can interrupt the wire silhouette for an observer's normal viewpoint, so that it becomes an inconspicuous element of the street scene. Notice that wire silhouette can be interrupted from in front of or from behind with equal effect (Figure 5).

The observer's viewpoint is critical to silhouette management. Overhead is almost always conspicuous to auto occupants or pedestrians on the trackway, and can be screened from this viewpoint only with landscaping directly overhead (Figure 6). With the increasing tendency to segregate transit from autos, this problem occurs less frequently.

Decoration. The second approach is to apply decoration. This was widely used on the earliest street car installations, particularly in Europe where ornate cast iron poles and bracket arms were often seen. In the first decade of this century, the use of wrought iron scroll work, ornate finials and pole bases became a highly developed art form (Figure 7). Later examples were often somewhat less ornate, and some remain in use as light poles to this day, though the wires they once supported are gone.

The decorative approach need not necessarily be ornate. A common variation has been the use of curved bracket arms, providing both a pleasing and functional design (Figure 8). Similar designs are often used in the U.S. for street lights.

Geometry. With the geometric approach, the designer's objective is not to hide the wires but rather to create a pleasing, or at least inoffensive pattern through the use of clean, simple and functional design. The geometric approach is largely a modern concept and has been applied with considerable success on a number of recent installations. Geometric design is particularly effective with centerpole overhead, since this permits elimination of all wires but the contact wires themselves. Often, but not always the centerpoles are integrated with the street lighting for the adjoining highway, if any. The bracket arms may be cantilevered, hinged, or supported by stays or props. Bracket arm selection depends in part upon the method of wire tensioning used, and whether expansion compensation is to be included. In the last few years, a number of effective geometric designs have been installed, both in Europe, and, in 1977, in San Francisco (Figures 9 and 3). One attraction of the geometric approach is that it need cost little more than a design developed without aesthetic consideration.

The design and installation of electric transit overhead often provides an opportunity for simultaneous removal of utility wires and coordination with street lighting. While it may sound self-defeating to place utilities underground at the same time that electric transit overhead is installed, the visual impact of this treatment can be very effective due to the reduction in the amount of aerial hardware, and the geometric coordination of what remains. The cost of such projects should not be borne solely by the transit operator. Two recent examples include the rewiring of the San Francisco LRT overhead, which includes overhead utility removal, and the extension of the Seattle trolley bus system, which similarly incorporates the removal of all other unnecessary utility and lighting poles by way of visual "compensation."

Alternatives

Numerous attempts have been made over the years to devise an alternative to overhead power supply on city streets. In the past, both the surface contact stud system, and the conduit system have been used to power street cars operating on streets and in mixed traffic (2). The surface contact stud system consisted of a row of studs placed between the rails, energized as the rail vehicles passed over them. Power was collected by means of a ski-like skid placed beneath the car. Historically, this system was conspicuous by its unsuccessful performance, including failure to operate, and conversely the tendency to occasionally electrocute other highway users. The conduit system worked rather better, and was used extensively in Washington, D.C., New York, Paris and London. Overhead could be eliminated, but only by incurring considerably higher installation and maintenance costs, and diminished reliability. The widespread practice, in more recent times, of salting highways in winter would make any new in-pavement electrification even less feasible.

The possibility still remains that a major research effort might be able to advance one or both of these technologies to a viable state although it is certain that 1) the cost would still be far higher than the overhead system, and that 2) the sole benefit, visual, can already be attained through a lesser investment in landscaping or geometric treatments.

Trackway Design

The appearance of LRT overhead is not the only visual issue. Trackway appearance can also have considerable visual impact, mainly through two design elements, type of surfacing, and fencing.

Where the trackway is part of the street pavement, a variety of paving techniques can be applied. Some properties seek to minimize the difference between the trackway and the rest of the street by completing the track paving in an identical material. Generally asphalt concrete is used, but Portland Cement Concrete is also suitable. Alternatively, the trackway may be paved in a contrasting material, a technique particularly useful when an exclusive transit lane is planned. In locations such as pedestrian mall, ornate paving may be applicable, such as the black and white checkerboard paving used in Zurich, or perhaps rounded cobblestones which can also serve to discourage pedestrians from walking in the trackway except at designated crosswalks, (which would be smoothly paved).

Where the trackway does not need to be paved a variety of treatments are possible. A number of systems have segments of track set in lawn. Such track can be found in many European cities and in New Orleans. To minimize maintenance, a strong, well drained trackbed is required, and wooden ties should not be used. Figures 10 and 5 show lawn covered track under construction, and completed, respectively.

The use of low shrubs along the trackway is another commonly used technique to soften the otherwise arid expanse of street and tracks. Generally no additional space is required for such treatment, since the shrubs can grow within the LRT clearance space (Figure 11).

A common and visually conspicuous design element is the use of fencing on median trackage. Fencing may be located either outside the tracks, or between them. A common design error has been the location of fencing outside the tracks when fencing between the tracks would have provided adequate protection (Figure 12). To evaluate the appropriate design, it is necessary to understand the function of fencing in a light rail median. The primary purpose in an urban situation is not to exclude people from the trackway, but rather to prevent unexpected and random crossing at all locations. This purpose can be achieved by a center fence just as well as by a side fence, while a center fence requires less space and offers considerable potential for visual relief (Figure 13). In either case, the fence need not be more than four feet high, since a fence of this height is sufficient to prevent jaywalking. Moreover, the fence should be raised above the ground to prevent the collection of wind blown debris and other litter. Chain link fencing should be avoided.

As with overhead design, where the median is of minimum width, the geometric concept, of tidy, regular patterns can provide an effective design approach to trackway appearance. Where more space is available, other design options become possible. Where sufficient space exists for landscaping outside the tracks, then a fence can be integrated into the landscaping.

An important consideration in trackway landscaping is to preserve the best possible line of sight at all critical locations. This is achieved primarily by the avoidance of "middle height" landscaping. Thus, landscaping should consist either of ground cover and small shrubs, or of trees, or both (Figure 14), but never bushes which can conceal a potentially hazardous situation.

Station Design Elements

The design of an LRT station in a street environment can also benefit from consideration of its visual elements. For instance if the trackway is paved in the station area, the collection of debris is minimized, and uneven surfaces that may trip pedestrians are largely avoided. A common problem at LRT stations is the tendency of pedestrians to walk behind a stationary LRV into the path of one going in the opposite direction. This problem can be solved by placing a barrier between the tracks. Since all that is needed is to prevent carelessness, an absolute barrier is not needed, and indeed is visually undesirable. Many systems use an ornamental post and chain fence for this purpose (Figure 15).

To protect passenger platforms from both vehicular intrusion, and from traffic wash in wet or snowy weather, barriers may be needed at the back of a platform. Such barriers, and the backs of passenger waiting shelters present a conflict between the design goals of comfort, safety, and appearance. Where additional right of way can be acquired, the space between the platform back and traffic lane can be increased, lessening the need for a splash wall, and additionally, permitting landscaping. Other alternatives might include diverting some traffic to parallel streets, thereby lessening the combined traffic and transit impacts, or the acceptance of the barrier, and its mitigation by the use of textured or decorative treatments.

Summary

Historically, there has been a tendency for engineers, once engaged on a project, to place a low priority on visual quality. This attitude has led to considerable community resentment in the past, and apprehension over future surface electric transit installations. Nevertheless, a number of relatively simple design techniques exist and are being used in a few locations that go a long way toward addressing these concerns. These techniques deserve to be more widely known and more generally applied. While this paper has covered only some aspects of this problem, hopefully it will stimulate both thought and discussion, and lead to a more positive approach to this problem on future installations.

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Figure 1. Overhead Clutter. A mix of overhead feeder cables, utilities, and wires for LRT and Trolley buses.

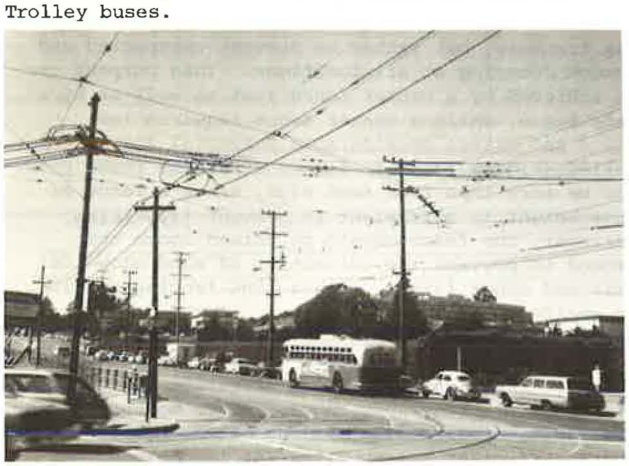

Figure 2. Uncoordinated, side pole design, with independent street lighting--Stuttgart.

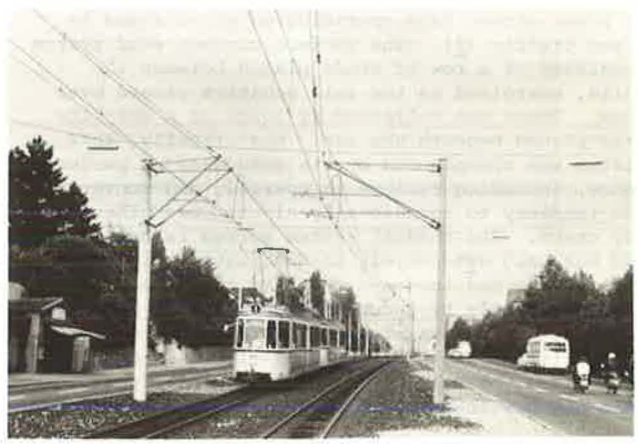

Figure 3. Coordinated, Center pole design--San Francisco.

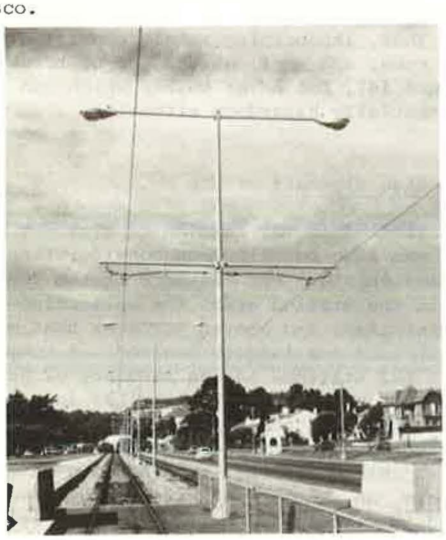

Figure 4. Limits of LRT overhead silhouette due to landscaping and buildings on a transit mall.

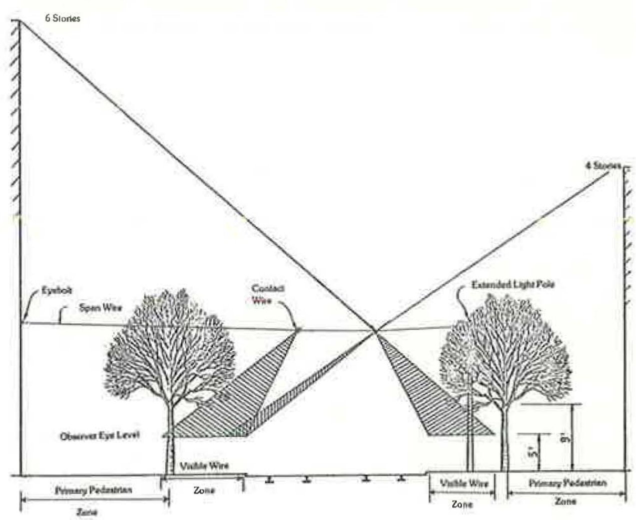

Figure 5. Background Screening. Note that an observer in the street or sidewalk could not see the overhead silhouette--Basle.

Figure 6. Large trees can block LRT overhead silhouette from any viewpoint--Dusseldorf.

Figure 7. Decorative overhead support poles.

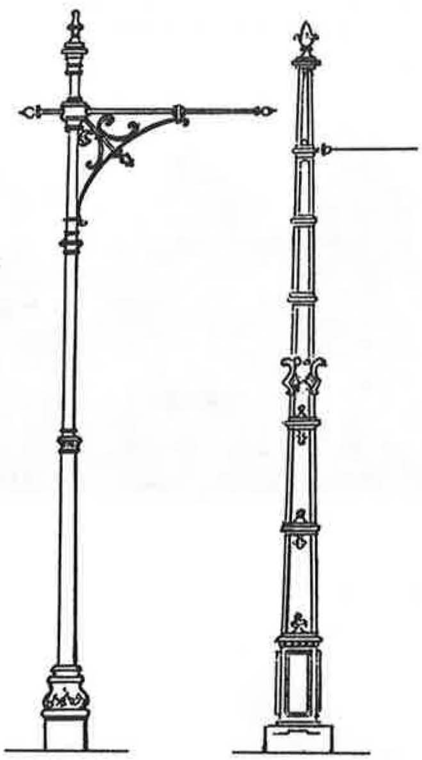

Figure 8. Curved bracket arms--Karlsruhe.

Figure 9. New Overhead. Geometric design--Braunschweig.

Figure 10. Track in lawn under construction--Linz.

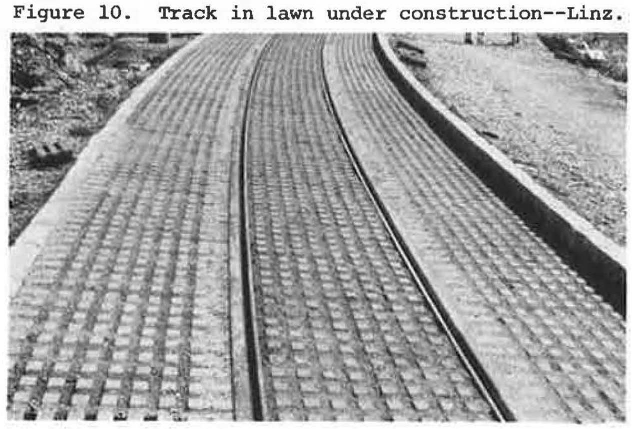

Figure 11. Low shrubs as a track screen--Munich.

Figure 12. Side fencing where center fencing could suffice.

Figure 13. Center fencing--Boston.

Figure 14. High and low landscaping at a pedestrian crossing approach--The Hague.

Figure 15. Post and Chain center fence--Mannheim.

Abridgment

A STUDY OF PASSENGER TRANSFER FACILITIES

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Throughout the country, a considerable effort is being made to improve public transit. However, one element of the total transit system which has not been studied at any level of detail and which has not improved to any great extent is the passenger transfer facility. The success of transit is going to depend on improvements made to all segments of the system, including safe, convenient transfer facilities. This study includes an inventory of facilities in some larger communities in New England, and a classification of facilities by size of area served and extent of system. According to an attitude survey, transit operators see a need for improved transfer facilities, minimized transfer times, and provision of shelters. The survey showed that pulsating systems had the highest number of transfers, averaging 27 percent, while transfers on non-pulsating systems generally averaged about 6 percent. The study concludes that transfer facilities must be improved to make transit more efficient and to encourage usage.

During the past few years, a considerable amount of work has been performed to develop plans for more effective urban bus systems. These planning efforts have considered the need for new buses, improved bus routes, improved frequencies, fare structures, transportation for the elderly and handicapped, and management. However, little consideration has been given to the need for improved transfer facilities.

Most systems radiate from the downtown area and stop at a central location, providing an opportunity for patrons to transfer between bus routes. In many areas, these transfer facilities are no more than the curbstone and a sidewalk with possibly a "No Parking Bus Stop" sign. In a few areas, the transfer facility has been developed to include bus shelters, pavement markings, bus schedules, and other amenities to encourage people to utilize the local system. The primary function of the facility is to accommodate transfers between local buses and in some larger areas, between various modes of transportation. The importance of such facilities will be difficult to determine, using objective techniques. Very little data exist concerning the need for transfer facilities.

Functions of Transfer Facilities

Communities with more than one bus probably have locations where passengers transfer between routes. In smaller areas, if transferring exists at all, it is only between a few local buses. In larger communities with large fleets and other modes such as rail and taxi, the need for transferring is greater. In some areas, the magnitude of transferring is considerably higher than in similar areas due to steps that have been taken to encourage transfers.

The attitude in many areas is that service must be as direct as possible, therefore minimizing transfers. However, it is virtually impossible to provide that type of service to all users. The planner and operator must determine the major movements in the area and design routes and schedules to satisfy the movements. After those conditions have been met, steps to increase the number of transferring passengers will increase the productivity of the system. The actions to be taken to maximize transfers vary, depending on the size of the service area and the types of services provided.

Types of Transfer Facilities

In some urban areas, especially the larger ones, there may be five forms of transportation which could utilize a transfer facility; they are local bus, intercity bus, rail, taxi, and demand-responsive service. Each service fulfills a special need for the traveling public and furthermore, each service requires that certain conditions exist in order to operate as efficiently as possible. It would appear that an ideal condition is for all modes to use one facility as which passengers board, alight, and transfer. It is seldom possible for this situation to exist or to be developed in an urban central business district. Some conditions to be satisfied in locating terminals for each mode follow.

Local Bus Service. A large proportion of local bus passengers presently utilize service to the center of the urban area. Recognizing that many passengers must transfer, and that many passengers have destinations in the CBD, the most effective location for a local bus transfer facility is in the center of the downtown area. The facility should be conveniently located to all local bus routes and to the center of commercial and business activities. Scheduling should be developed to minimize transfer times. Buses departing the terminal at the same time encourage transfers. If such scheduling is not utilized or is unreliable, transfers are not made and a terminal is not required.

The cost of transfers is another important issue on which attitudes vary. One thought is that the transfer extends the length of service and adds flexibility; therefore, there should be a charge. Another attitude is that the inefficiency of service develops the need for transferring; therefore, there should be no charge.

Intercity Service. In some areas, over 90 percent of persons using intercity service arrive or leave the present bus station by auto. Intercity buses usually travel long distances, using expressways as much as possible to minimize travel time, so it is critical for these vehicles to spend as little time as possible on city streets. The closer to an expressway interchange the intercity terminal, the more efficient the service. This terminal must provide facilities not necessarily required for other services, such as passenger baggage handling, ticketing, package delivery service, and a passenger waiting room with seats. There also must be adequate bus storage and passenger access to them.

Rail Service. The majority of rail passengers travel to the rail station by auto. To serve these passengers, a waiting room is usually provided in the CBD. In areas with taxi service, cab standing areas should be provided.

Demand-Responsive Service. This service could encourage patrons to gather at the transfer facility for their rides home, providing that they are mobile and that the facility is within walking distance. This will reduce vehicle travel time, increasing service efficiency.

One facility to satisfy all these services must be located adjacent to the rail facility, close to an expressway interchange, and in the CBD. In many areas, such a location cannot be provided.

Size of Area

A direct relationship exists between the size of the urban area and the number of local buses and variety of modes providing service.

Small Urban Areas-To 50,000 Population. Generally, the only effective local bus service that will operate in an area of this size, other than demand-responsive service, is fixed route/fixed schedule service radiating from the CBD. The type of scheduling which encourages the greatest number of transfers is a pulsating system wherein all buses leave the downtown area at the same time and return together to transfer passengers. This type of local bus service requires some kind of facility to accommodate transfers.

Medium Size Urban Areas-50,000-500,000 Population. The medium size area with a large number of buses generally provides local service frequently enough not to require a pulsating system to minimize transfer waiting time. Many of these systems radiate from a central location in the CBD and therefore require a transfer area. If a pulsating schedule is not used, the space required for bus waiting can be reduced.

Large Urban Areas-500,000 and Up Population. In large urban areas, a variety of transfer facilities may be needed. There are facilities located in the downtown area for transferring between local service and other modes. In suburban areas, facilities are needed to accommodate transferring between modes and local service, but usually these are not as large as downtown facilities.

Local and express bus routes may serve rail stations and cross other bus routes, allowing transferring. Bus routes and rail service going to the central area may be located in various segments of the CBD rather than at one central location. This typical type of service requires a variety of transfer points.

Large urban areas with radial rail and bus service require suburban transfer facilities. These facilities often include major commuter parking facilities to allow the transit passenger to utilize fixed rail or the local bus system. In addition, suburban buses traveling to the urban area may meet the fixed rail system at the terminal, allowing for transfers between bus and rail. These types of facilities may also provide taxi service and, on occasion, long-haul intercity bus service.

Bus Scheduling

In many areas, frequencies are often half-hour or greater. Some areas schedule service so that buses come together and depart at the same time, minimizing the transfer waiting time. This type of transfer service requires layover space that some areas find difficult to provide. The Brockton, Massachusetts system operates 20 vehicles on a pulsating system, requiring space on two intersecting streets to accommodate vehicles during the transfer period. On longer frequency systems, transfers are discouraged if a pulsating schedule is not used. Before the Brockton system introduced the pulsating schedule, it had approximately 70 daily transfers. When the pulsating schedule was adopted, the number of daily transfers increased to more than 800, and at the same time, the cost of transferring was eliminated. The transfer facility requirements for a pulsating system therefore, are much greater than for a system which schedules a minimum number of buses in the CBD transfer facility at one time.

In larger areas where bus frequency may be 10 to 15 minutes, it is not necessary to schedule buses in a pulsating fashion, first, because there are too many and second, because the amount of transfer time is not that great. The pulsating system requires each bus to be on time. A bus that is behind schedule may slow down the entire system.

Existing Transfer Facilities

With a new concern for energy conservation, pollution, and the survival of cities, local, state, and federal governments are involved in supporting transit service with capital investments and operating subsidies. Through the use of public monies, many improvements have been made including purchasing new buses and funding operating assistance. However, improvements to transfer facilities have not become very popular, although there is a growing interest in encouraging ridership by increasing transfers.

As part of this study, an inventory of transfer facilities was made in a number of urban areas in New England. Table 1 shows facility amenities, the number of local buses, and the type of schedule.

Table 1. Inventory of Transfer Facilities

Location	Number of Buses	Type of Schedule	Facility Amenities: Shelter	Painted Curbs	Information	Benches	"No Parking" Signs
Bridgeport, Ct.	40	N-Pulse.	x		x	x	
Danbury, Ct.	4	N-Pulse.					x
Hartford, Ct.	185	N-Pulse. Pulse.	x			x	x
New London, Ct.	2	N-Pulse.					
Waterbury, Ct.	19	N-Pulse.			x		
Westport, Ct.	18	Pulse.	x	x		x	x
Brockton, Ma.	20	Pulse.					x
Fall River, Ma.	18	N-Pulse.	x		x		x
Fitchburg, Ma.	7	N-Pulse.				x	x
Haverhill, Ma.	3	Pulse.					x
Lawrence, Ma.	8	N-Pulse.					x
Lowell, Ma.	23	N-Pulse.	x	x		x	x
New Bedford, Ma.	20	N-Pulse.	x		x	x	x
Pittsfield, Ma.	6	N-Pulse.					x
Portland, Me.	50	N-Pulse.					x
Manchester, N.H.	15	N-Pulse.					x
Providence, R.I.	191	N-Pulse.	x	x			x

Pulse = Pulsating Schedule
N-Pulse = Non-Pulsating Schedule

An attitude survey was sent to 21 transit operators in New England to determine their attitudes toward passenger transfers. Following are some major points made by those replying:

1. Seventy percent believed it was important to encourage transfers.
2. All agreed that transfer time should be minimized.
3. Seventy percent believed it was important to locate the transfer facility with other transportation services.
4. All agreed that a downtown facility should be sheltered from the elements.
5. Thirty percent felt that the facility should be off the street.
6. A number of operators did not know how many transfers were being made. The Brockton and Westport systems, both pulsating, each have about 27 percent transfers; the non-pulsating systems generally have below six percent.

Considerations for Future Improvements

Throughout the transfer facility planning process, it is important that the city planner or development agency and transit planner coordinate their efforts to assure that the facility serves the needs of the urban area and the transit system. City planners should understand that a transfer facility serves an important function and should consider that function in the planning process. The transit planner must realize that the logical area for implementation of a facility may have other demands placed upon it, some of which result in increased revenue for the community. Following are objectives to be considered in the planning process. They are neither in priority order nor are they inclusive.

1. Provide convenient, efficient, safe facilities for passenger transfers.
2. Locate the facility in an area providing quick, uncongested access to and from the facility. The facility serving local transit should be located on as many bus routes as possible.
3. Minimize conflicts with auto traffic movements in the area of the facility.
4. Provide an attractive facility which will aid promotion of local ridership, encouraging usage.
5. Costs of operation and maintenance should be reasonable.

If transferring is made as appealing as possible, with minimum transfer times, free transfers, and effective promotion, ridership can be increased. Bus system administrators and local officials must decide if the location of a transit facility is merely a sidewalk/curbside facility or a well-identified, marketable facility.

Often the biggest problems to overcome in developing a transit facility are the institutional problems generated by political and public policy machinery. In some cases, public agencies find themselves in a competitive, rather than cooperative situation when faced with prospects of consolidating or integrating various modal systems.

In recommending the development of a facility, it is important to encourage the support of businesses, elected officials, and the public. Too often local officials take a rather passive view, in part because the public has not campaigned for improvements. They see only that improvements to the system will cost money, possibly increasing taxes.

At present, no set standards, suggested policies or guidelines exist to support the need for transfer facilities. Planners and designers are without the materials needed to develop the layout, signing, and information systems. Standards and guidelines must be available to assure adequate facilities.

Abridgment

A TRANSIT STATION DESIGN PROCESS

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The state-of-the-art of transit station planning is characterized by a lack of consistency among principles, standards, and techniques (1,2). Design standards and design guidelines as developed by transit operating agencies do not address trade-offs among the different station features or design components. In order to provide for consistency among the procedures used by different agencies to design transit stations and to ensure comprehensive treatment in the station design process, a methodology which uses analytical techniques for designing and evaluating alternative transit stations has been developed (3,4,5).

The performance of the station must be judged relative to a set of predefined objectives which derive from anticipated interests. Typical station design objectives reflect the points of view of the general user, the special user (the elderly and handicapped), and the operator concerning passenger processing, the station environment, and cost (6). The design objectives are then translated into a set of performance criteria which serve to define explicit performance measures that are the basis for comparisons among alternative station designs.

This paper shows a method for analyzing transit interface facilities. The discussion focuses on the procedures which can be used to establish policy for station features, to provide performance measures for subsystems, and to give cost estimates.

Station Design Process

A complete transit station design process requires the following levels of input data:

1. Exogenous Design Data
   a. Local site data
   b. Demand data (passenger flows, vehicle arrivals)
   c. Supply data (access modes and modal technology)
2. Endogenous Design Data
   a. Policy objectives (local and system-wide)
   b. User attitudes and preferences
   c. Performance standards
   d. Cost constraints

The exogenous (or external) data show the loads (in terms of passengers and transit vehicles plus local land use) which the facility must sustain. The endogenous information are requirements that are established by the planning agency prior to the investigation of the physical station configuration

Design Variable Classification

In this transit station design framework, design variables are classified according to the manner by which they enter the analysis process; i.e., as a result of an initial policy decision or as measures of performance or economic efficiency. Table 1 illustrates an example of typical station components classified under this scheme.

Policy Requirements

The process is structured so that before transit station designs are investigated in terms of performance and cost, local policy must be established regarding the construction and operation of the facility. Table 1 indicates the most common areas where public officials must make policy regarding transit stations. Furthermore, some station features may be restricted by their impact on the environment. Other station aspects may be influenced by local Transportation Systems Management (TSM) plans which are directed at providing for short-range transportation needs of urbanized areas at low costs.

Table 1. Transit station component classification for analysis.

Policy Elements	Cost Elements	Performance Elements
Concessions	Fixed Capital Cost	Passenger Processing
Advertising	Operating Cost	Passenger Orientation
Personal Care Facilities	Maintenance Cost	Physical Environment
Telephones	Policy Related Cost	Safety
Aesthetics	User Cost	Security
Construction Materials		
Design Flexibility		
Parking Facilities		
Provisions for Handicapped		

Table 2. Typical station features associated with performance.

Passenger Processing

- Level change facilities
- Entrance-exit facilities
- Area provided per person on flow paths
- Travel distances
- Travel paths
- Fare collection devices
- Vehicle boarding and exiting areas

Passenger Orientation

- Directional signs and maps
- Visibility of major destination points
- Information booths

Physical Environment

- Air flow control devices
- Heating and air conditioning
- Lights
- Weather protection

Security

- Police patrols
- Isolated spaces
- Surveillance cameras
- Alarms
- Entry control

Safety

- Number of levels
- Walking distances
- Curbs
- Stairs
- Escalators
- Platform edges
- Lighting

Selecting and Sizing Station Components

The transit station design process involves component selection and evaluation based on pre-established criteria. Station components that may be included are listed in Table 2.

The designer proposes a set of variables and station configuration plans to be tested against the performance criteria. The performance of a design relative to some standard or expected level is then estimated through use of manual and/or computer models. Manual techniques for estimating lighting adequacy, safety, security, and passenger processing characteristics are reported in Reference (4). The main computer techniques available include the Urban Mass Transportation Administration Station Simulation (USS) Package (7) and the Subway Environmental Simulation (SES) Model (8). The final criteria for selecting elements in a transit station design are associated with cost since the effectiveness of any improvement of a design over minimal performance levels must reflect economic considerations.

Development of Alternative Designs

Constraints on the transit station design process are design standards, established policy and budgetary limits. Accordingly, the standards, policy, and budget for each specific station plan should be available to the design team, a body that includes architects, planners and engineers. At this point alternative design concepts which meet the stated requirements and objectives are developed.

Design concepts are those basic issues which account for major differences in terminal configurations. Examples of these are multi-level vs. single level, underground vs. aboveground, exclusive shopping mall zones, automated pedestrian movement aids, etc. This stage generally includes estimates of environmental impacts, the incorporation of local transportation systems management plans, and a public hearing process to determine community acceptance of alternative proposals.

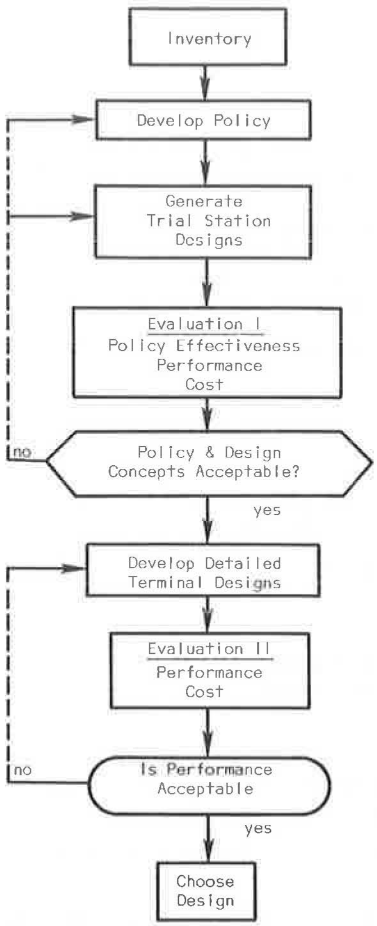
After an acceptable design has been established that is compatible with policy statements and the transportation requirements, detailed designs reflecting alternative facility components and layouts are tested. At this point the analyst can consider variation in the design relative to the physical environment, passenger orientation aids, safety and security.

Detailed station designs are evaluated in terms of performance and cost. The performance and cost measures obtained are interpreted with an effectiveness model to select the "best" alternative (6). This iterative process is repeated until a specific design is selected.

The analytical stages in the transit interface facility design methodology are summarized in Figure 1. This strategy integrates design objectives, criteria, and measures within an evaluation framework with the judgmental, analytical and computerized methods available for developing and analyzing various station designs (3).

The procedural method that has been given for the design of transit terminals can also be adopted for station renovation. The primary difference between these two applications of the methodology is that the station renovation study begins with the execution of Evaluation I and Evaluation II phases, given inventory data, policy, and design detail. Once the existing facility is evaluated, the findings are employed to develop new policy and to redesign the facility. From this point on, the standard procedure is followed.

Figure 1. Stages in transit station design methodology.



Conclusions

This paper has described a formalized, yet flexible, methodology to assist the planning and design professions in the development of efficient and acceptable transit station designs. The framework provides the analyst with various options for arriving at a recommended design relative to the manner through which the various station subsystems are developed. Problems which relate to the interrelationships among the various subsystems can only be checked through applications of an iterative comprehensive design process which assesses the performance of the entire facility relative to specified measures of performance.

Acknowledgements

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PEAK - OFF PEAK REVENUE AND COST ALLOCATION MODEL

Herbert S. Levinson, Wilbur Smith and Associates

This paper develops an approach for allocating bus service operating costs and revenues between peak and off-peak periods. It shows how the economic performance (relative profitability) of peak-period bus service depends on three relative measures--relative peaking, load factors, and schedule efficiency - labor practices.

As an example, when the ratio of additional peak buses to base buses is 1.0 and the pay hours per bus hour for the additional buses are double those for the base buses, each bus in the peak would have to carry more than 1.5 times the base period ridership. When this ratio rises to 3, peak buses would have to carry double the passengers carried on each bus in the base period for the peaks to be as profitable.

The problem of peak-hour costs has been both persistent and pervasive in the transit industry. A 1916 study by the American Electric Railway Transportation and Traffic Association, set out to prove that: "it is the relation of income to expenditure between the hours of 9 A.M. and 4 P.M. that is the most favorable to the company"(1). Current operating experience suggests that high peak-to-base ratios of buses in service without a corresponding increase in load factors can produce a relatively poor cost-revenue picture for peak-hour service. For example, a 1974 analysis of costs and revenues for the Merseyside Transit System (England) found that revenue received from peak travelers did not cover costs of providing peak service, while off-peak revenue was more than covering costs (2).

The increased costs of additional peak services primarily reflects the extra driver costs resulting from increases in split-shifts and penalty payments. Another component relates to the increased costs associated with the extra peak-vehicles.

This paper outlines an approach to allocating costs and revenues between peak and off-peak riders. Its goal is to provide planning guidelines for estimating the economic performance of peak versus off-peak bus service. Accordingly, it develops a basis by which the relative profitability or loss of peak-period service can be estimated based on known operating parameters. It identifies the conditions under which peak-period service would be relatively more profitable than base service.

Relative profitability implies that the ratio of revenues to costs during peak periods is greater than that for off-peak periods. Actual profitability depends upon the relationships between fares, driver-wage rates, ridership, and amount of service provided.

The allocation of peak and off-peak costs are discussed first followed by revenue allocation. The final section develops a formula by which the relative profitability of peak-period bus service can be estimated, based on operating costs and revenues.

Bus Cost Allocation

The bus cost-allocation model context is shown in Figure 1, and the various parameters are further defined in Table 1.

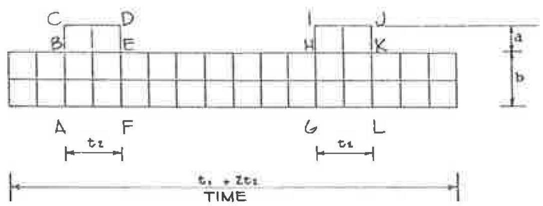
Figure 1 represents a simplified hourly variation pattern of the number of buses required throughout the day. It assumes that a uniform number of buses (b) would be required throughout the day for base service. An additional number of buses (a) would be needed during each peak period to provide the additional or excess peak service.

The costs of providing the additional (excess) peak-service (C_2) are associated with the two rectangles protruding as peaks (B C D E and H I J K). The costs of providing peak-hour service (C_p) represent these incremental costs, plus the pro-rated share of the base service costs (these costs relate to the rectangles A C D F and G I J L).

Bus operating costs typically relate to bus-miles, bus-hours and peak-buses operated. About 60 percent of the total operating cost relates to bus hours, 20 percent to bus miles, and 20 percent to peak-vehicles.

Bus-hours normally account for about 75 percent of the direct costs, and bus-miles 25 percent. Many properties further simplify cost analyses by relating direct operating costs to drivers' wages and bus-miles. For example, the Chicago Transit Authority estimates direct operating costs as 50 cents per bus-mile plus drivers' wages; labor costs account for about two-thirds of the total (3).

Figure 1. Bus Operating Cost Allocation Context.



Notes:

a = additional buses needed for peak.

b = base-period buses operated.

t_2= duration of each peak period.

COST OF ADDITIONAL PEAK PERIOD SERVICE - C_2, relates to rectangles B C D E and H I J K

OVERALL COSTS OF PEAK PERIOD SERVICE - Cp, relates to rectangles A C D F and G I J L

Table 1. Definition of Bus Operating Cost Parameters.

ITEM	(1) BASE SERVICE	(2) ADDITIONAL BUSES REQUIRED FOR PEAKS (Δ)
Time Period	$2t_2+t_1$	$2t_2$
Buses Required	b	a
Pay Hours/Bus Hour	P_1	P_2
Cost/Pay Hour	A	A
Miles Operated	M_1	M_2
Cost/Bus Mile	B	B

Ratio of Δ peak to base Pay Hours/Bus Hour = P_2/P_1 = Y

Ratio of Δ peak to base buses = a/b = X

Ratio of non-peak period to peak period$=\frac{t_1}{2t_2}=$Z

TOTAL BUSES OPERATED IN PEAK = a + b

The model uses these various parameters in a slightly modified form--it distinguishes between peak and off-peak pay hours per bus hour thereby taking into account the effects of labor agreements. Because drivers' wages represent the largest component of direct costs, and since the unit-maintenance-related costs associated with bus miles are essentially the same for peak and off-peak service, bus miles are subsequently eliminated to simplify the analysis.

The comparative operating costs for peak and base service can be derived as follows:

1. Costs of Base Service C_1

$$C_1=(2t_2+t_1)bP_1A+bM_1B \tag{1}$$

$$C \cong (2t_2+t_1)bP_1A \tag{2}$$

2. Costs of Additional (Excess) Peak Service C_2

$$C_2 \cong 2t_2aP_2A+aM_2B \tag{3}$$

$$C_2 \cong 2t_2aP_2A \tag{4}$$

3. Costs of Total Peak Service (Cp)

These costs equal the costs of the extra peak service plus the share of the base service, that should be pro-rated to the peak periods.

$$Cp \cong \frac{2t_2}{2t_2+t_1} C_1 + C_2 \tag{5}$$

4. Total Operating Costs (C_3)

Costs of base plus peak marginal costs

$$C_3 = C_1 + C_2 \tag{6}$$

5. The proportion of the total costs allocated to the peaks, S, is simply the ratio of (5) to (6).

$$S=\frac{\frac{2t_2}{2t_2+t_1} C_1 + C_2}{C_1 + C_2} \tag{7}$$

or, upon substitution of formulas 2 and 4.

$$S=\frac{2t_2\ (bP_1 + aP_2)}{(2t_2 + t_1)\ bP_1 + 2t_2aP_2} \tag{8}$$

Eliminating the component of costs associated with bus miles makes it possible to develop subsequent relationships based on relative values or ratios. Empirical analysis show that this simplified relationship tends to slightly increase the share of operating costs allocated to peak service, and in fact, represents an upper limit for the peak's share of total operating costs.

The preceding formula can be further simplified by substituting three ratios or indices, x, y, and z into the equation. This leads to the following expression for estimating the proportion of operating costs to be allocated to the peak periods (5).

$$S = \frac{1 + x\ y}{1 + x\ y + z} \tag{9}$$

Where:

x = ratio of additional peak to base buses

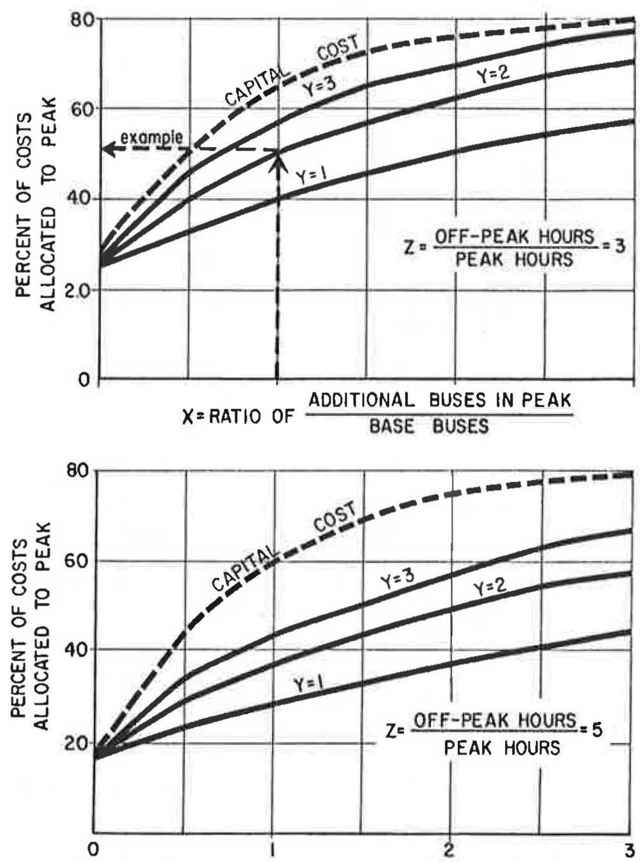
y = ratio of peak to base pay hours/bus hour

z = ratio of non-peak to peak period duration

s = share of daily operating cost allocable to peaks

Typical values of "S" are plotted in Figure 2 for the cases of z = 3 and 5. The curves show that the higher the peaking, the higher the share of costs attributable to peaks. Similarly, the higher the relative driver costs for peak-period service, the higher the share of costs attributable to peaks. When the peaks represent 25 percent of the daily time period (i.e., z = 3), they would account for about 50 to 70 percent of the total costs. When they represent 17 of the daily time period (i.e., z = 5), they would account for 35 to 55 percent of the total costs.

Figure 2. Typical Peak-Hour Bus Cost Allocations.



For example, when there is one additional peak bus, per base bus (x = 1.0) and the pay hours per bus hour for the additional buses are double those for the base buses (y = 2.0) approximately half of all bus costs are allocable to the peak periods for the case where z = 3.0.

The relative shares of capital (bus) costs attributed to the peak hours are also shown on Figure 2. They are based on the following formula:

$$S' = \frac{\frac{2t_2}{2t_2 + t_1} \quad b+a}{b + a} = \frac{\frac{1}{(1 + z)} + x}{1 + x} \qquad (10)$$

This formula shows that the peaks account for a consistently high proportion of total capital cost. For the case where x = 1 and z = 3, the peaks would account for about 63 percent of the capital costs. It should, however, be recognized that the capital costs associated with bus service are normally low relative to operating costs.

Revenue Allocation

The proportion of daily bus revenues which are allocable to the peak periods can be derived from a similar analysis. The basic parameters and ratios utilized are shown in Table 2.

Table 2. Definition of Bus Revenue Parameters.

ITEM	BASE PERIOD (Off-Peak)	PEAK PERIOD
Hours	t_1	$2t_2$
Trips/Hour	n_1	n_2
Passengers/Bus Trip	0_1	0_2
Fare/Passenger	D_1	D_2
Buses Involved	b	a + b
RATIOS		
Passengers/Bus Trip	$e = 0_2/0_1$	
Trips/Hour	$f = n_2/n_1$	
Fare/Passenger	$g = D_2/D_1$	

Extra buses in peak/base service buses $Y = \frac{b}{a}$, as before

Off-peak hours/peak hours $\frac{t_1}{2t_2}$ as before

1. Peak Period Revenues (R_2)

$$R_2 = (a+b)\ n_2\ 2t_2\ 0_2\ D_2 \qquad (11)$$

2. Off Peak Revenues (R_1)

$$R_1 = b\ N_1\ t_1\ 0_1\ D_1 \qquad (12)$$

3. Total Revenue (R_3)

$$R_3 = R_1 + R_2 \qquad (13)$$

4. The share of revenue generated during the peak period, K,

$$K = \frac{R_2}{R_1+R_2} \qquad (14)$$

or upon substitution:

$$K = \frac{(a+b)\ n_2 2t_2 O_2 D_2}{(a+b)\ n_2 2t_2 O_2 D_2 + bn_1 t_1 O_1 D_1} \qquad (15)$$

Substituting the ratios e, f, g, as well as x and z into this formula produces the following result:

$$K = \frac{(1 + x)\ f\ e\ g}{(1 + x)\ f\ e\ g + z} \qquad (16)$$

For the case where the same fare per passenger is obtained (g = 1), and the same number of bus trips are operated per hour (f = 1), the formula becomes:

$$K = \frac{(1 + x)\ e}{(1 + x)\ e + z} \qquad (17)$$

Comparing Costs with Revenues

The question "are the peaks more or less (relatively) profitable?" can be answered by comparing their relative shares of revenues generated and costs incurred. For peak-period bus service to be more relatively profitable than the base-period service, the proportion of revenues generated, K, (Formula 16 or 17) should be greater than the proportion of costs incurred. (Formula 9.)

That is, $K > S$ (18)

Upon substitution, this inequality becomes

$$\frac{(1+x)\ e}{(1+x)\ e + z} > \frac{1+xy}{1+xy+z} \qquad (19)$$

Algebraic simplification leads to the following approximate relationship which defines the conditions when peak period service is more profitable in relative terms.

$$e > \frac{1 + z\ y}{1 + x} \qquad (20)$$

Where:

e = ratio of peak to base passengers per bus

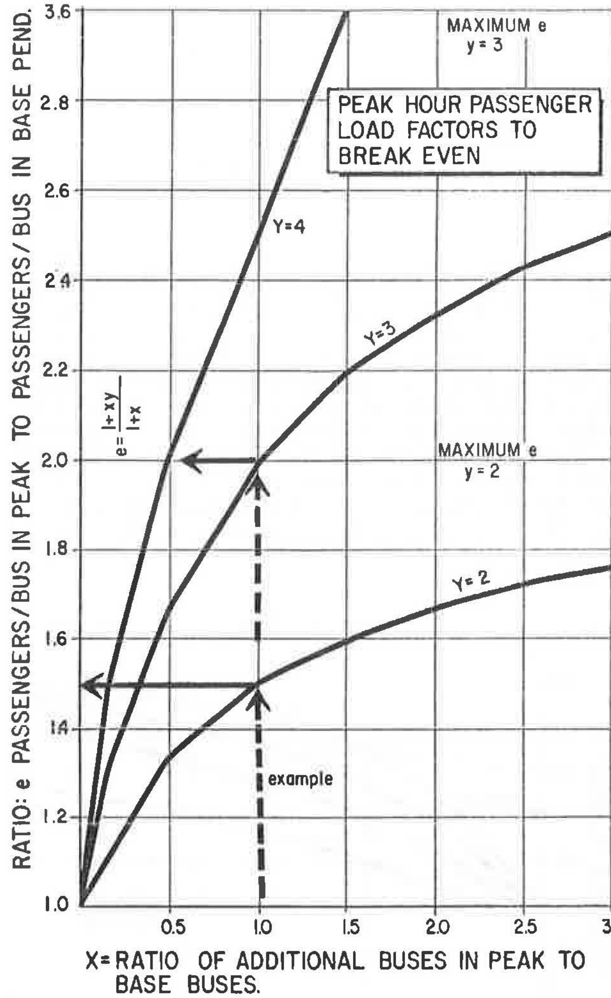
x = ratio of additional buses to base buses

y = ratio of pay hours/bus hour additional peak buses to base buses

This function is plotted in Figure 3 for the cases where y equals 2, 3, and 4. The term y is significant since the extent that it deviates from unity is a function of labor contracts and scheduling inefficiency.

(a) If the base ratio of pay hours per bus hour could be realized by peak period tripper services, then the peaks would be equally as profitable (or unprofitable) as the base, when equal load factors are attained.

Figure 3. Peak Hour Passenger Load Factors to Break Even.



(b) In contrast as the ratio, y, increases, there is a rapid rise in the relative peak-hour loads required for buses.

(c) Typical values, based on experiences of a range of cities are as follows:

x - ratio of additional buses to base buses, 1.00 to 2.00 (corresponds to peak-to-base ratios of 2.00 to 3.00)

y - ratio of peak to base pay hours per bus hour, 1.30 to 2.00

As an example, when the ratio of additional peak to base buses (x) is 1.0, and the pay hours per bus hour for the additional buses are double those for the base buses (y = 2) each bus in the peak periods would have to carry more than 1.5 times the base period ridership. When the ratio y rises to 3, peak buses must carry more than double the passengers carried in the base buses for the peaks to be as profitable. The corresponding value for y = 4.0 would be 2.5.

Summary and Significance

The analysis has shown how the relative profitability of peak-hour bus services can be approximated from three basic ratios. These are:

- the ratio of additional buses required for peak service as compared with those required for base service (x). This is, in essence, a peaking factor.
- The ratio of pay hours per bus operated for the additional peak buses required as compared with that for the base buses (y). This reflects schedule efficiency and work rules regarding split shifts and overtime.
- The ratio of peak-hour passengers per bus to off-peak passengers (z). This reflects peak and off-peak load factors.

It is clear that peak-hour service can be relatively profitable where peaking is limited, high levels of bus schedule efficiency can be attained, and peak-loads per bus are substantially higher than those during base service. However, in many communities, the peaks will be relatively unprofitable--a condition that could be alleviated by charging higher fares during the peak hours.

The analyses involve simplifying assumptions with regard to certain cost components. However, such simplifications do not appear to substantially change the relationships. Moreover, excluding bus-mile related costs partially counterbalance excluding capital cost elements. There are also some varitions resulting from the simplifying assumptions regarding the demand curve (i.e., omission of owl service).

The target cost-revenue ratios can serve as a management tool, and provide a point of departure. It is realized that many other factors must also be considered--and may take precedence, where service is to be reduced or eliminated.

In application, analysis should be done on a line-by-line basis and then aggregated for the total system. Interpretation and refinement of results should take into account base-period policy headways and service operated because drivers are available. Further adjustments for these practices would provide a clearer picture of the true economic performance of peak-period urban bus services.

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2. Arthur Anderson & Co., Bus Route Costing for Planning Purposes - Volume 1 - Report for the Transport and Road Research Laboratory, London, 1974.
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CONTRACT MANAGEMENT IN THE TRANSIT INDUSTRY

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During the past decade, there has been a growing trend toward public acquisition of failing private transit companies. Many government agencies and public entities have turned to transit management companies to run the daily operations of their systems. The transit management companies offer a range of services which include assistance in a number of functional areas in transit management. The purpose of the study was to examine the organizational structure, the decision making process and certain attributes of the organization performance for transit systems operated under contract management. The study has focused on 26 transit properties managed by three major contract management companies. The study showed that management companies mesh into three basic types of local organization structures. Each of these types possesses certain characteristics. Each management company was also found to be more associated with a certain type of property and local organization. The organization, often, reflected the company's own operating philosophy and perspective on transit management. Results of the study could also be used to look at the merits of contract management in situations similar to those experienced by the transit industry.

During the last decade, many cities have been faced with the task of taking over ailing bus companies, and developing transit plans to provide continued and improved service to their communities (2,6,8,10,11). Rising costs and declining revenues continue to plague private and publicly owned transit systems. Publicly owned systems, however, are service-oriented rather than profit-dependent and enjoy many financial advantages over a private company. These advantages include the following.

1. Purchase of new buses, facilities, and capital equipment with 80% federal assistance.
2. Operating subsidies can be obtained if necessary.
3. Additional sources of funding from federal grants, state grants, commercial loans and bond issues are available.
4. Fuller utilization of operating revenues because no federal, state, or local taxes, excise taxes, franchise taxes or gross receipt taxes are required.

The major difficulty experienced with public ownership and with the attempt to revive existing transit systems has been the lack of qualified local government personnel with the necessary knowledge and experience in transit operation. The shortage of managerial manpower has been a result of previous years of decline in the transit industry. With the large number of systems being rejuvenated through public ownership and government subsidy, a large demand for qualified transit management personnel has developed. At the same time, the new sphere of operation of a transit system has developed a need for a broader set of managerial skills than used to be available in the transit industry. The operation of a transit system as a public enterprise made it necessary for transit managers to be more responsive to public demands and to the local political system.

Despite the need for qualified managers, many systems found it difficult to support a staff of full-time managers and specialists. The result was that a number of transit systems opted to contract management services. The most significant advantage of contract management is seen as its ability to supply and support the managerial talent needs of local transit systems. This talent is supplied at the local level, and through nonresident technicians and specialists, to help administer the operation of the system. The range of services offered by management companies includes areas of such diversity as the assistance in developing transit policy and plans, and the assistance in the purchase of spare parts and supplies.

Services Offered by Contract Management Companies

The services offered by management companies could be performed by the resident manager, a resident management team, or by the corporate staff (separately or jointly), depending upon the needs of the property.

The resident manager and his team are responsible, in general, for the following services:

1. Policy and Planning: Short range planning, coordination with other planning agencies, development of specifications and bid evaluations of new equipment and services, development and recommendations of new routes, route changes, service frequencies and traffic operations improvement.

2. Finance: Operating budget, financial statements and statistical reports, money control and processing, general accounting, internal audits, payroll, and assistance in preparation of applications for state and federal funds.

3. Marketing and Public Relations: Market research and surveys, promotions and public information, telephone information programs, and advertising.

4. Transportation: Supervision of bus operators, on street supervision, dispatching of equipment and manpower, training program for bus operators, safety programs, development of schedules and cut runs, compilation and analysis of service parameters, preparation of line-up working list for operators, preparation of timetables and route maps, and charter contracts.

5. Maintenance: Garage and plant layout, general shop supervision, equipment repair, building repair, preventive maintenance programs, unit repair, and servicing of vehicles.

6. Personnel and Administration: Employee and labor relations (including union contract negotiations), recruitment, hiring and discharge of employees, insurance and claims, general administration, purchasing of minor equipment and supplies, and computer utilization.

The non-resident staff, through direct service or assistance to the resident management team, provides some of the following services:

1. Planning and Policy: Service and route planning, research and planning, technical studies, and short and long-range planning assistance.

2. Finance: Budget preparation and analysis, fare structures, capital grant applications, fiscal control procedures, accounting methods, fleet purchases and specifications, money processing and control, and audits.

3. Marketing and Public Relations: Promotional techniques, advertising contracts, demonstration projects.

4. Transportation: Leasing contracts, schedule making techniques, special charter, school and contract services, and rapid transit (such as freeway express buses).

5. Maintenance: Maintenance procedures and programs, shop garage layout and design.

6. Personnel and Administration: Labor relations, office management and procedures, stores and purchasing, and management development programs.

Study of Contract Management

The role and influence of contract management became an issue due to their increasing share in transit management, and due to the supporting efforts of the Federal Government in developing mass transportation. The present work was organized as an effort to study a number of local transit organizations, to determine the following.

1. The types of organizations and organizational characteristics which are commonly found in transit management when contract management becomes a part of the local organization.

2. The relationship between management company and the characteristics of property which it tends to contract. The previous relationship was to be examined in light of the company's own philosophy and perspective on transit management. This objective was to help determine if specialization based upon characteristics of the local property is a prevailing factor in the choice of a management company.

3. The role and contribution of contract management to the decision making process, and to the effectiveness of the system.

Conduct of the Study

An initial survey of a number of transit properties which are managed under contract revealed a variety of organizational arrangements to accommodate the transit system into the existing municipal organization. Interviews with transit managers and municipal officials indicated that because of the newness of transit services to local governments, organizational and procedural arrangement tend to crystallize over a period of time, and are mostly influenced by political initiatives and developments at the local scene.

After examining the organizational structure in a sample of transit properties, a general model was developed for the organization of a transit system when managed under contract. Minor modifications were made to the model after the survey was completed. The organization model is based upon the common features between different transit organizations. Comparison of transit organizations and development of a general model were possible since all transit (bus) systems offer similar service to the commuter and employ, basically, the same level of technology in systems operation and management.

Three basic management levels are commonly found in a transit (bus) organization according to survey. An upper management, a middle management and an operating management. Upper and middle management are existing public entities such as the city council and the public works department, or an authority, board or a commission, specifically created to deal with transit decisions. Under contract management, the general manager is always, and key members of his staff are often, contracted from the management company. The non-resident corporate staff of the management company provide direct assistance to the resident management team. They could also provide consultation and staff assistance to higher management levels in the transit organization.

Considering the general objectives, method of operation and organization structure of a transit system, an overall decision process was constituted and verified in interviews with a sample of transit managers and transit public officials. The decision process includes a fixed set of decisions which are commonly used in the planning, operation and control of a typical transit system. The decisions were categorized by functional area, and decisions commonly requiring more than one step were recognized at three levels of completion (initiation, review and final). Initiation decisions are considered to be those which are necessary to raise an issue or introduce the need for and help formulate a decision. Review decisions are those recommending, advising against or helping modify a decision so that it would be acceptable. Final decisions are those accepting or rejecting a preformulated decision. The previous steps are considered to be typical of the decision process in a municipal organization.

The previous work provided the foundation for the development of a survey questionnaire, which was used as the principal instrument in the study. In addition to the survey questionnaire a number of interviews were conducted with transit managers and transit public officials in a sample of properties representing various characteristics of service areas and various management companies. An attempt was also made to develop a profile for each of the three management companies under study. These companies were found to dominate the transit management field. This was accomplished by reviewing the companies' own literature, and by interviewing key operating officers and executives at each company.

Survey Instrument and Method

The survey instrument, **organized stepwise,** examines the role played by different organizational units, transit managers and public officials in making the decisions required to carry out the managerial duties in a transit system. The decisions are grouped by functional area and are arranged within each group to reveal the decision steps and participants when more than one step is expected. The questionnaire was designed and tested in cooperation with the management of one of the participating systems. An emphasis was placed on making the language of the instrument short, and easily understandable by property managers and transit public officials.

Survey Method

The survey questionnaire was sent to the managers of a number of transit properties that were managed under contract. Since in many cases the decision process was not well developed and documented, transit managers were requested to construct the present table of organization first and then to attempt identifying the organizational units or persons responsible for making various decisions. A sample transit organization chart was forewarded for reference purposes. Available objective performance data such as ridership, cost, revenue and capital improvement, since public takeover, was also requested. In addition, a short questionnaire was directed to the principal public official responsible for the transit system.

A sample of the previous properties was selected for interviews. In these properties, interview questions were directed to the local transit manager and the principal public official responsible for the transit system. The survey questionnaire was used as a basis for the interview, except that in this case, after guaranteeing confidentiality, managers were asked to comment on the quality of communication and cooperation in the decision process. Responses were unstructured and are only used in a qualitative form in this research.

Results of the Survey

Twenty-six transit properties, representing a cross section of those managed under contract, responded to the survey. Most of these properties have been under contract for at least two years. The decision data obtained from the questionnaire was coded and superimposed on the organization chart.

Types of Organization in a Contract Managed System

A close examination of the organization structure of all the properties surveyed revealed three types of transit organizations. They are coded as Types I, II and III. Type I is identified by an upper and middle management which are existing government entities (city council as upper management and public works department as a middle management). Type II is identified by an upper management which is an existing government entity, while middle management is a special government entity (authority, board or commission) created to handle the middle management functions in a transit organization. Type III is found when both upper and middle management are special purpose public entities created to handle transit decisions.

Measurement of Organizational Effectiveness and the Decision Making Process

Effectiveness has to do with the measurement of results in relation to the resources expended to achieve them. The question of organizational effectiveness is a complex and multifaceted one. In the case of public transportation, the basic purpose is to provide transport services to the public at a reasonable cost. Service could be measured in terms of such factors as headways, route miles, bus hours, reliability of bus schedule and adequacy of public information. On the cost side a number of cost factors such as drivers' wages, maintenance and fuel cost constitute the bulk of the operating expenses. Under normal circumstances the previous data would be useful in evaluating the ultimate organizational effectiveness. However, an attempt to use the previous data in evaluating organizational effectiveness ran into many difficulties because of the variance in method of reporting, and the difference between operating circumstances of various properties.

Although most transit managers felt that service and cost performance would provide useful input in determining organizational effectiveness, if the variance in circumstances between properties could be factored out, they, however, had serious reservations about the validity of the approach at the time of the study. Most felt that transit management is still struggling with the help of federal and local subsidies to reverse the declining trend of the past decade, and that the circumstances under which mass transit is being revived have imposed new social responsibilities on the system which in most cases resulted in a higher operating cost. Most transit managers felt that the primary concern should be the quality of organizational performance in terms of "decision making ability" during the present transition period. Transit was conceived by most as being revived in a fairly dynamic environment, constituted by heightened expectations on the part of the commuting public and transit labor, while facing a shrinkage of tax dollars available to support the system. Most of the transit managers interviewed (majority have years of experience in the private transit sector) have indicated that the main problems facing them are the long lines of communication and delays in decision making which are symptomatic of local government, as well as, the vulnerability of their organizations to unjustified political intervention. The same note was echoed by public officials who interface with the transit system and take on the responsibility to expedite the decision process.

Organization Attributes Indices

Focusing on organization structure, the decision making process, as well as, their impact on performance (1,3,4), and considering the special case of a contract managed transit organization, a number of indices were developed to reveal the characteristics of the organization and decision making process. The purpose of the indices was to provide an organization-decision making profile that could be used to evaluate contract management. Emphasis was placed on simplicity of definition, ease of interpretation and on inter-property comparison of these indices. In general, standard measures of organizational characteristics do not exist. A useful attempt at standardization has been made by Price (7). Evidence of persisting difficulty of measurement, however, is still apparent (9, p. 10-26 and 5, p. 686-704).

The organization attribute indices are described in the following.

Organizational Centralization Index (CI1).

$$(CI1) = \frac{\sum \text{Number of Final Decisions Made at Level (i) X Weight Assigned to Level (i)}}{\text{All Final Decisions Assigned to Level (i)}} \quad (1)$$

Weight Assigned to Level (i) = 1 For the Operating Management Level , = 2 For the next higher level, ... and so on. Maximum i = 5.

This Index reflects the degree to which final decisions are elevated in the organizational hierarchy above the resident manager. The weighting factor of each decision increases, as the decision is made at a higher level in the organization. This index, therefore, represents the degree of centralization as it is felt by the transit operating manager. It does also reflect the number of levels in the organization.

Upper Management Centralization Index (CI2).

$$(CI2) = \frac{\text{Number of Final Decisions Made at the Top Level of the Organization}}{\text{Total Number of Final Decisions}} \quad (2)$$

This index reflects the degree of concentration of final decision authority at the top level of the organization.

Operations Autonomy Index (OAI).

$$(OAI) = \frac{\text{Number of Final Decisions Made by Operations Management at the Transit Property}}{\text{Total Number of Final Decisions}} \quad (3)$$

This index reflects the degree of autonomy enjoyed by operating management at the transit property. The resident manager heads the operations management group.

Management Company Autonomy Index (MCAI).

$$(MCAI) = \frac{\text{Number of Final Decisions Made by Operations Management including the Management Company's Home Office}}{\text{Total Number of Final Decisions}} \quad (4)$$

This index reflects the degree of autonomy enjoyed by the management company as a whole, and includes decisions which are made at the transit property and at the management company's home office. This index reflects the degree to which the management company could directly influence the local transit system.

Management Company Participation Index (MCPI).

$$(MCPI) = \frac{\text{Number of All Types of Decisions Made by Operations Management Including the Home Office (Initiative, Review and Final Decisions)}}{\text{Total Number of Final Decisions}} \quad (5)$$

This index reflects the degree of total participation of management company in the management of a local transit system. This index is sensitive to the share of the management company in all types of decisions made (Initiate, Review and Final Decisions). It is also sensitive to the number of intermediate decisions per final decision. The index, therefore, reflects the tendency of transit system's management to take advantage of the available expertise at the management company, and to accept the initiation and review of more decisions by contract management.

Decision Steps (DS).

$$(DS) = \frac{\text{Total Number of All Decisions (Initiate, Review or Final Decisions)}}{\text{Total Number of Final Decisions}} \quad (6)$$

This index reflects the degree of complexity existent in the decision process. Complexity results from the increase in the sources of decision initiation and review steps. A higher value of (DS) would indicate greater steps in decision review, while a lower (DS) would indicate simple review or direct decision making.

While other indices could be devised to identify the organization and decision making characteristics of a transit organization, the previous ones were felt to be the most meaningful in evaluating a transit organization when contract management is included. No attempt was made, at this stage, to take the relative weight of a decision into account.

Statement and Discussion of Results

The previous organization attributes indices were derived for the 26 responding properties. This was accomplished by computing the various number of decisions on a coded decision process for each system. A study of correlation between organization indices and variables was used to examine general relationships for transit organizations. In addition, analysis of variance was conducted to determine the effect of organization type and management company. The previous findings were examined in light of the survey data.

The results obtained from analysis of the data indicated that the type of organization, number of administrative levels and management company are the three major factors which have an influence on the transit organizational performance. The influence of these factors is discussed in the following.

Type of Organization

Three types of organizations have been identified in the organizations surveyed, as have been defined before. The characteristics of these types of organizations are described in Table 1.

Number of Administrative Levels

A study of the correlation between all the organizational variables, Table 4, reveals that the number of administrative levels (LEVELS) has a dominant influence on the transit organization. This was evidenced by the high correlation between (LEVELS) and (CI1), (CI2), (OAI), (MCAI) and (DS).

Organizations having large number of administrative levels, as well as those with only few levels were found to exhibit a higher degree of centralization, than those with an intermediate number of levels. This is evidenced by the significant positive correlation between the number of administrative levels and (CI1), and the significant negative correlation between the number of administrative levels and (CI2).

The high degree of centralization associated with the large number of administrative levels manifests itself by pulling more final decisions to the middle levels of the organization (Middle Management), thus reducing the number of final decisions made by both top and operating management. Organizations having a large number of administrative levels exhibited lower degree of operations management autonomy, lower degree of management company autonomy and a notable increase in the number of intermediate steps to make a final decision.

The high degree of centralization associated with a small number of administrative levels was found to result from a larger proportion of the final decisions being made by upper management. This type of centralization was not correlated with other organization attribute indices. The results, therefore, indicate that in the case of an organization with few administrative levels, top management has a more active role in decision making, since middle management is relatively small in size. The top management involvement, however, did not seem to hamper operating management or management company autonomy.

Management Companies

The interest in the study was focused on the three major contract management companies which dominate the transit contract management market; for anonymity purposes, these companies will be referred to as A, B and C. In general the three companies offer similar management services to cities and municipalities. Typical contract management services have been described before. Operating philosophy and perspective on transit management of each company was determined from various sources. Company's literature was examined at first, this was followed by interviewing company's operating executives and transit officials in systems managed by the company.

Although management companies including the ones surveyed compete actively for management contracts with transit properties of all types and sizes, the analysis of organization attribute data has revealed that each company tends to gravitate towards properties and organizations with certain characteristics. These characteristics were found to mesh well with the operating philosophy and perspective on transit management of the management company. These findings substantiate the assertion that a major factor in selecting a management company is its conceived ability to mesh with the local organization. Profiles of the three major management companies and characteristics of the properties which they tend to contract are described in Table 2.

Role and Contribution of Contract Management

The analysis of decisions made, or participated in, by contract management in the organizations surveyed has indicated that contract management handles most of the operating and short-term planning, decisions, as well as advise and assist in the handling of long-range planning and financing decisions. The overall quantitative participation of contract management in the decision process has been discussed before, the qualitative influence of contract management has been determined in a sample interview and survey of the transit public officials in the properties under study. In general the survey results revealed enthusiastic support for contract management arrangements. The extremely high contract renewal rate (close to 100%) is indicative of the value of contracted personnel and services. Advantages of contract management considered by public officials as most important include:

a. Relieving the public entity from the burden of operating problems, leaving them free to concentrate on long-range planning and government responsibilities.

b. The management company brings to the operation the expertise and know-how accumulated from years of experience, including extensive experience in the negotiation of labor contracts and public takeover.

c. A management company can supply technical staff support for special situations and as a back up for the resident management team without requiring the retention of these personnel on a full-time basis.

d. A management company can provide procedures and techniques proven in other operations and the benefits of intra-group exchange of ideas with regard to operating problems common to the industry.

e. Contract management is also considered by public officials to be more objective in its management and operations approach, than would be appointed public management.

Conclusions

Results of the previous work show that the transit organization and the decision making process are dependent upon the size of the service area. The graduation in service area size tends to be associated with the emergence of three types of organizations, Types I, II and III. At the small service area end of the scale an existing government agency oversees the system, while at the other end of the scale an authority, a commission or a board is created to undertake complete responsibility for the transit system. The organization type, as well as the management company involved in contract management, were found to be associated with exhibited organizational characteristics. This association appears to result in part from the management company selection process, which

Table 1. Organization type and characteristics under contract management.

<table>
<tr><th></th><th>TYPE I (GOVT)</th><th>TYPE II (GOVT/AUTH)</th><th>TYPE III (AUTH)</th></tr>
<tr><td>ORGANIZATION</td><td>Upper and middle management are existing government entities (city council and department of public works as an example).</td><td>Upper management is an existing government entity, while middle management is a special government entity, created to handle the middle management functions in the transit organization.</td><td>Upper and middle management (when) middle management exists) are special public entities, created to handle the upper and middle management functions in the transit organization.</td></tr>
<tr><td>ROLE OF TRANSIT</td><td>Transit is developed to service a limited industrial sector and central business district. Other services include transportation for local schools.</td><td></td><td>Transit is developed to provide access to a major central business district, industrial parks and shopping centers. Emphasis on the role of transit in providing mobility and access to work and shopping.</td></tr>
<tr><td>ORGANIZATION AND SERVICE AREA ATTRIBUTES</td><td colspan="3"><u>Attributes Common to The Three Types of Organizations</u>:
The three types of organizations demonstrated similar degrees of autonomy to operating management (OAI) and to the management company as a whole (MCAI). The decision for contract management include mostly routine operating and short range planning decisions. The three types of organizations also exhibited a comparable number of intermediate decision steps in arriving at a final decision (DS).
<u>Population of Service Area</u>:
The organization type was found to depend upon the population of the service area. Average population for each of the organization types is given below.</td></tr>
<tr><td></td><td>247,667</td><td>346,111</td><td>704,545</td></tr>
<tr><td></td><td colspan="3"><u>Number of Administrative Levels</u>:
Number of administrative levels (LEVELS) were found to be higher in organizations Type I and Type II in comparison with Type III.
<u>Degree of Decision Centralization</u>:
Organizations Type I and III showed a higher degree of upper management centralization of decision making (CI2) than in the case of Type II.
Organizations Type I and II showed a higher degree of organizational centralization (CI1) in comparison to Type III.
<u>Management Company Participation</u>:
A higher degree of management company participation in local transit decisions (MCPI) was found in the case of Type I and Type III organizations, as compared to Type II.</td></tr>
<tr><td>ORGANIZATION PROFILE</td><td>Transit organization is part of the existing municipal organization. Transit services are considered in the same order as other municipal services. Organization has a large number of administrative levels and decisions are more centralized. Transit decisions tend to queue in with other municipal decisions.
Organization structure and decision process tend to favor a balanced view of transit and other municipal services.</td><td>Organization Type II is an attempt to recognize the importance of transit services to the community by creating a middle management entity to handle transit decisions. The total organization has a relatively large number of administrative levels. Results show that more decisions are drawn to the middle levels of the organization. As a whole a similar degree of organizational decision centralization, as in Type I, exists, while top management is less involved in decision making. Middle management also reduces the management company involvement in the local transit decisions.</td><td>Organization is totally devoted to transit services. Despite the small number of administrative levels, organization is flat at the top and the decision process is participative. It has a low degree of organizational decision centralization, with more decisions centralized at the top level of the organization. This type of organization allows a higher degree of autonomy to operating management and invites more participation of the management company in the decision process.</td></tr>
</table>

Table 2. Management company and associated organizational characteristics.

<table>
<tr><th></th><th>COMPANY A</th><th>COMPANY B</th><th>COMPANY C</th></tr>
<tr><td></td><td>Subsidiary of a Large Corporation</td><td>Subsidiary of a Diversified Transportation Corporation</td><td>Independent Corporation</td></tr>
<tr><td>OPERATING PHILOSOPHY AND PERSPECTIVE ON TRANSIT MANAGEMENT</td><td>Beside the general management services, the company offers contracting properties the opportunity to join a national contract for the purchase of insurance, equipment, replacement parts, fuel and tires.

Operating decisions are generally handled by the resident management team. In many cases budget preparation, planning recommendations are studied and prepared at the home office.

Company considers small cities to be more pragmatic in their transit development, by waiting for the demand to materialize before additional services and capital investment are made.

Company views the most effective way to manage a transit system is through a politically independent board of authority which has a taxing power.

Company views public management of larger transit systems as a trend due to the tendency to expand the municipal bureaucracy.</td><td>Operating decisions are generally handled exclusively by the resident management team.

Company demonstrated considerable flexibility as to whether other contracted services will be performed by the resident management team, the home office staff or a combination of both.

Company advocates the need for operating a transit system on a balanced budget. Large operating subsidies are looked at as a way to turn the public against the system.

Company views the tendency towards increasing the number of administrative levels between operating management and final decision makers as resulting in lengthening the lines of communications, retarding the decision process and making the system less responsive to the needs of the public.</td><td>All top managers and many middle managers share the ownership of the company.

Company believes in the importance of providing a strong resident management team which meshes with the local organization and receives consulting advice only from the home office.

High degree of communication between resident managers and between resident managers and the home office staff is encouraged.

Company encourages city employed transit personnel to further their formal education.

Company believes in the importance of having fewer administrative levels between the policy making body and operations management.

Company values the importance of a sound demand analysis and marketing program for transit services.</td></tr>
<tr><td>ORGANIZATION AND SERVICE AREA ATTRIBUTES</td><td colspan="3"><u>Attributes Common to Organizations with a Contract Management</u>:

Organizations managed by the three management companies did not show a significant difference in upper management centralization of decision making (CI2), in management company autonomy (MCAI) and in companys' participation in the decision process (MCPI). The same situation was found in the number of intermediate decision steps required for arriving at a final decision (DS).

<u>Population of Service Area</u>:

Population of the service area which might be considered as an indicator of the transit market was found to vary significantly with the management company. The average service area population for the three companies is given below:</td></tr>
<tr><td></td><td>143,143</td><td>405,500</td><td>685,846</td></tr>
<tr><td></td><td colspan="3"><u>Number of Administrative Levels</u>:

The number of administrative levels (LEVELS) was found to be largest with Comapny A (average of 4.0), smallest with Company C (average of 2.62) and had an intermediate value for Company B (average of 3.33).

<u>Degree of Decision Centralization</u>:

Organizations associated with Company A were found to exhibit the highest degree of organizational decision centralization (CII), those associated with Company C were found to have the lowest, while organizations associated with Company B have held an intermediate level.

<u>Operations Management Autonomy</u>:

Properties managed by Companies B and C exhibited similar degrees of operations management autonomy (OAI), while those managed by Company A had a significantly lower value. This could be partly explained by the closer involvement of the home office in local transit decisions, in the case of Company A.</td></tr>
<tr><td>ORGANIZATION PROFILE</td><td>• Hierical
• Many administrative levels
• Organizational decision centralization
• More decisions are handled by the home office.</td><td></td><td>• Few administrative levels
• More decisions made by upper management (decision process is participative)
• More decisions are made on the scene, by operating management.</td></tr>
</table>

indicates that transit properties tend to contract companies who have a demonstrated experience in interfacing with a similar operating environment.

Considering the national effort by the federal government to revive mass transportation, private management companies seem to be able to fill the gap in the depleted transit management ranks and hence provide opportunity for a greater number of communities to benefit from such federal programs. Contract management in the transit industry represents a good case where private enterprise has been able to interface and play an active role in the bureaucratic government environment. Although it is too early to judge the overall effectiveness of contract management, it is reasonable to conclude that many small communities would have been without transit services had contract management services not been available. The effectiveness of contract management in the long run would depend upon their ability to make the necessary adjustments for the transition from the initial building-up period to the long-term maintenance stage. Judging by the results obtained so far, the chances of making the adjustment seems to be good.

The present study of contract management was to some degree influenced by the present state of development in the transit industry. The lack of comparative objective performance data has limited system evaluation to more subjective measures of performance. Future research should make another attempt at the use of objective performance data in the study of the effectiveness of different types of organizations and management companies. An attempt should also be made to compare contract managed transit systems to those managed by public organizations.

Acknowledgment

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TOWARD THE DEVELOPMENT OF AN ACCOMMODATION SERVICE POLICY

George T. Mauro, United States Railway Association
Lewis Polin, Orange County Transit District

Continued public support for ever-increasing operating deficits of transit service demands that uneconomic services be curtailed. Nevertheless, a certain amount of service may be justified in terms of community welfare as "accommodation" to particular user groups -- those which are dependent upon public transportation for mobility. This paper suggests that transit agencies no longer need make this judgment intuitively. A rigorous set of decision-making rules which test uneconomic routes or services for their efficacy in meeting community-welfare demands is presented. Under these rules, routes are successively evaluated against five criteria: operating ratio, effectiveness, intensity, captive riders and community welfare. A case study of the application of this algorithm to a medium-size transit system is presented to illustrate the method. The procedure, by specifying the threshold values for each parameter, may be adapted to the needs of any transit system -- every segment of the system can be continually re-examined to determine whether the drain on financial resources is justified by the contribution made to community mobility.

Only recently has the downward trend of transit ridership been reversed in American urban areas. Between World War II and 1972, the number of public transportation users declined by nearly 70%. Principally because of the energy crisis and the attendant high cost of gasoline, transit usage increased by 514 million annual trips between 1972 and 1976 (Table 1).

That more people are coming to recognize the necessity and virtues of public transportation is a long overdue realization. Transit patronage gains have been accompanied, however, by more than proportional increases in cost. As indicated in Table 1 (1), vehicle kilometers between 1972 and 1976 increased twice as fast as ridership. While operating revenues registered a significant gain during the period, operating expenses increased nearly four times faster. The nationwide operating ratio reached 1.92 in 1976, meaning that only 52% of costs were met from operating (largely farebox) revenues. And there is no evidence that this trend of ever-increasing deficits has been halted.

Thus, while citizens are clamoring for service extensions and entirely new services, and are in fact using these services in increasing numbers, transit agencies are caught in the difficult position of making increasing demands on the public monies which support them. Even the long-awaited passage of the 1974 amendments to the Urban Mass Transportation Act, permitting the use of federal formula grant funds to meet operating deficits, has been insufficient to stem the tide.

To keep abreast of public requests for service while keeping the operating deficit under some control, a number of cities including New York, Washington, New Orleans, San Diego, Baltimore and Philadelphia have recently increased the fares on their transit systems. This is a drastic step for public agencies to take, particularly when so many of the public acquisitions of the Sixties were conditioned upon lowering, or at least stabilizing, fares. The impact of these increases can be seen in the quantum increase in average fare between 1975 and 1976 -- in a single year, fares increased by nearly twice as much as they had in the preceeding four years.

The last general round of fare increases this country saw represented the final attempts of private transit operators to stem the tide of red ink. Despite the haunting similarity in the cries of the riding public, there is a fundamental difference today. The deficits of the Fifties and Sixties were brought on by shrinking patronage, followed and exacerbated by deterioration in both quantity and quality of service. The contraction of the industry begun decades before had reached the critical stage. Today, under public ownership, service has been improved, extended and expanded until it is out-distancing the public's ability or willingness to pay. Still, a public agency has an obligation to serve: it is difficult to say no to a constituent whose tax money is being used to support the system.

Accommodation Service and Present Policies

Yet, because of economic constraints, hard decisions must be made concerning who will be served and how much service will be provided. In the past, systems offered certain services with the knowledge that revenue generated would not be suf-

Table 1. Recent trends in american mass transit operations.

OPERATING CHARACTERISTICS	1972	1973	1974	1975	1976	PERCENT CHANGE 1972-1976
PASSENGERS (MILLIONS)	6,567.0	6,660.0	6,935.0	6,972.0	7,081.0	7.8%
VEHICLE KILOMETERS (MILLIONS)*	2,926	3,058	3,179	3,316	3,377	15.4
AVERAGE FARE	$ .3142	$ .3180	$ .3220	$ .3297	$ .3571	13.7
OPERATING REVENUE (MILLIONS)	$1,728.5	$1,797.6	$1,939.7	$2,002.4	$2,161.1	25.0
OPERATING EXPENSE (MILLIONS)	$2,128.2	$2,419.8	$3,102.4	$3,534.9	$4,139.4	94.5
OPERATING RATIO (EXPENSE/REVENUE)	1.23	1.35	1.60	1.77	1.92	56.1

Note: 1 kilometer = .6 miles

ficient to offset costs of operation. Such routes were termed "accommodation" services because the service was maintained as an accommodation to the traveling public. In a privately owned, profit-making transit enterprise, the operator could schedule a sufficient level of profitable service to more than offset the losses arising from accommodation routes.

Today, however, most services -- and, in fact, entire transit systems -- are deficit operations. The problem of determining which lines constitute atypical demands on system resources, which today may be regarded as accommodation services, is extremely difficult in the absence of the acid test of profit or loss. Most transit systems have no policies which guide them or other public decision-makers in defining the existence and the extent of accommodation service provided, other than ad hoc determinations usually based on political expediency. (2) This is true despite the very real responsibility of a publicly supported transit system to provide accommodation service to those user groups dependent upon public transportation for mobility.

As a notable exception to this rule, the Massachusetts Bay Transportation Authority adopted a "Service Policy for Surface Public Transportation" in January, 1976. (3) While not dealing explicitly with an accommodation service policy, the document contains a set of "Economical/Social/Environmental Standards." Taken together, these standards define differential levels of satisfactory economic performance depending upon what other social needs the service might be satisfying.

Starting from a similar premise -- that accommodation service must be justified on non-economic grounds if it is to be offered -- the authors have developed a comprehensive methodology for identifying and evaluating accommodation services. This three-step procedure is described below.

Methodology

The methodology was designed in the recognition that passenger service and community welfare measures, in addition to fiscal criteria, should be major determinants in defining true accommodation routes. The three steps in the process are:

Step One

Determine the important characteristics of each of the routes in the system. The following categorical information is compiled for each transit line:

Fiscal Performance. Normally expressed as the operating ratio (cost/revenue).

Passenger Market Performance. Encompassing both effectiveness (defined as the ratio of passengers/kilometer) and intensity (defined as the percentage of system passengers using the particular service or route).

Captive Rider Performance. Some measure of the route's function in serving the transit dependent -- e.g., the ratio of users with no automobile available/total route users.

Community Welfare Performance. Some measure of the aggregate mobility needs of the specific area or community served -- e.g., the percentage of households with no automobiles in the service area or some comparable measure of immobility or economic deprivation.

Step Two

The second procedural step involves the formulation of minimum acceptable threshold values or standards for each characteristic that should be met by every route in the system. This step is the policy determination element of the process, but standards can be rigorously determined. Any one of several different approaches can be chosen but it is important for the measure to be dynamically related to the economic, operational and social service characteristics of the services offered. Static measures (e.g., labeling a route as unsatisfactory if it carries less than 2.0 passengers per kilometer) are inherently inflexible and subject to continual redefinition over time. Such statistical measures as system mean values and standard deviations may be more satisfactory. Another approach is to specify a threshold value which divides each set of characteristics so that one third of the routes fall below this level.

Step Three

The final step consists of the comparison of individual route performance against the minimum acceptable values established above. This comparison is a successive filtering process in which each route failing the test on one characteristic is tested on the next parameter. Routes failing all five tests are not justified in terms of their economic performance or contribution to community mobility. They are thus candidates for redesign or abandonment.

Case Study Application

This procedure was developed and applied in a recent study of a medium-sized transit system. Route statistics for each of the five characteristics for the 17 routes in the system are set out in Table 2. Using the "worst third" method described above yields the threshold values for each parameter shown at the bottom of the table.

The filtering decision process is illustrated schematically in Figure 1 as a sequential series of five questions. The analysis proceeds as follows:

Operating Ratio Criterion. All routes must have an operating ratio of 3.31 or less. If the operating ratio exceeds 3.31, consider the:

Effectiveness Criterion. Services failing the first criterion must have an effectiveness measure of at least 1.59. If the route's effectiveness is less than 1.59, consider the:

Intensity Criterion. Services failing the preceding criteria must have an intensity measure of at least 2.9%. If passenger intensity measures less than 2.9%, consider the:

Transit Dependency Criterion. Services failing the preceding criteria must have a user group more than 17.6% of whom do not have an automobile available. If transit dependents constitute less than 17.6% of the riders, consider the:

Community Welfare Criterion. Services failing the preceding criteria should serve a community in which households with no automobile available constitute more than 5.9% of total households. Services not meeting this final standard would be considered candidates for possible elimination or re-design to improve their performance.

Evaluation of the transit routes in this community by this method is shown in Table 3. Comparing all route operating ratios to the standard of 3.31 reveals five routes -- F, G, I, L and P -- which exceed this level and are thus condidates for further examination. On the second measure, effectiveness, we find that Route G exceeds the standard and thus should be retained. The other four routes fail this test as well and must be scrutinized further.

Both Routes F and L carry a higher proportion of the system's passengers than the threshold of 2.9%. Routes I and P just fail this test, and also fall below the standard for usage by the transit dependent. Again on the criterion of community welfare, these two routes are deficient. Thus, from a group of five routes with unsatisfactory financial performance, three were found to be contributing sufficiently to the community's benefit to warrant their retention. Only two routes were identified as candidates for abandonment or significant revision. Subsequent detailed analysis of each of these routes led to their major redesign in order to improve their operating characteristics.

Figure 1. Sequential Evaluation of Transit Routes.

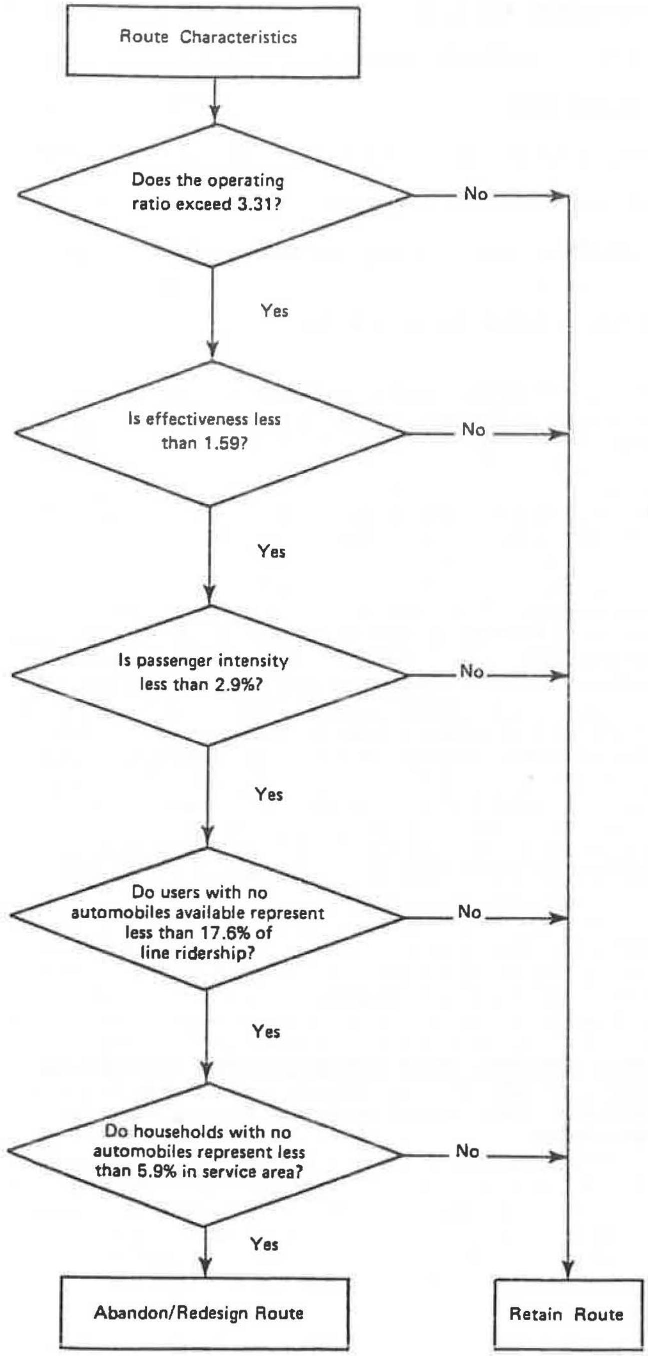

Table 2. Characteristics of Transit Routes (Sample System)

Characteristics / Routes	Fiscal	Passenger Market		Captive Riders	Community Welfare
	Operating Ratio	Effectiveness	Intensity	% Users With No Automobile	% Households With No Automobile
A	2.13	2.28	5.7	57.9	19.3
B	0.99	4.66	14.5	25.1	8.4
C	2.55	2.19	6.6	24.7	8.2
D	2.26	2.12	6.5	58.0	19.3
E	1.83	3.65	6.4	34.1	11.4
F	3.35	1.59	4.9	12.1	4.0
G	3.37	2.08	1.1	25.6	8.5
H	2.45	2.03	3.9	25.0	8.3
I	5.12	0.94	2.9	14.1	4.7
J	1.56	3.70	10.6	25.6	8.5
K	2.50	2.15	8.1	58.0	19.3
L	3.68	1.13	3.7	18.2	6.1
M	1.78	3.25	2.6	8.8	2.9
N	2.65	1.60	1.3	8.8	2.9
O	1.45	3.56	17.4	44.5	14.8
P	3.31	1.32	2.9	8.6	2.9
Q	1.51	2.82	0.6	17.6	5.9
Threshold Value	3.31	1.59	2.9 %	17.6 %	5.9 %

Conclusions

This procedure represents a rational attempt to identify those routes which constitute atypical demands on transit system resources without commensurate returns in terms of community service. In addition to fiscal criteria, the technique gives consideration to passenger service and community welfare factors -- elements which should be contemplated prior to decisions relating to service abandonment. By quantifying the policy considerations which apply, a rigorous algorithm is developed to guide the decision process.

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Table 3. Application of Evaluation Method.

Characteristics / Routes	Fiscal: Operating Ratio	Passenger Market: Effectiveness	Passenger Market: Intensity	Captive Riders: % Users With No Automobile	Community Welfare: % House-holds With No Automobile
A	2.13				
B	0.99				
C	2.55				
D	2.26				
E	1.83				
F	3.35	1.59	4.9		
G	3.37	2.08			
H	2.45				
I	5.12	0.94	2.9	14.1	4.7
J	1.56				
K	2.50				
L	3.68	1.13	3.7		
M	1.78				
N	2.65				
O	1.45				
P	3.31	1.32	2.9	8.6	2.9
Q	1.51				
Threshold Value	3.31	1.59	2.9	17.6	5.9

Abridgment

FUTURE RIDERSHIP ON NEW YORK CITY'S RAPID TRANSIT SYSTEM

Jeffrey M. Zupan and Boris Pushkarev, Regional Plan Association

As a necessary step in the analysis of possible future requirements for the New York City rapid transit system a model to estimate ridership on the system is developed. Analysis of historic data reveals that annual ridership on the system is positively related to employment in the Manhattan Central Business District (CBD) and to the level of transit service, measured in car-miles; it is negatively related to the number of autos registered in New York City and to the transit fare, measured in constant dollars. These four variables explain 80 percent of the year-to-year variation in ridership. A relationship for peak hour ridership was also developed.
The elasticity of demand with respect to CBD employment is found to be +0.75, with respect to fare, -0.12, with respect to auto registrations, -0.25, with respect to service, +0.13. Statistically, the relationship of subway ridership to fares and to CBD employment is very strong. The relationship to auto registrations is weaker and to service weaker still.
Because the model developed relates to the economic health of the CBD and to the ownership of the automobile, it is particularly relevant to the current National goals of downtown revitalization and energy conservation. For example, it is shown that a resurgence in Manhattan CBD employment to 1969 levels would increase ridership by some 10 percent. similar increases in transit would occur if a gasoline shortage eliminated the automobile as a CBD commuting mode.
To explore alternative estimates of future ridership eight combinations of the independent variables are examined, including stable and declining CBD employment, stable and declining fares, and unconstrained and energy-constrained automobile ownership. The results suggest long-term changes in current ridership ranging from a 9 percent loss to a 34 percent increase.

Planning prudently for a transit system obviously requires some mechanism to estimate ridership under a variety of future conditions. If the ridership estimates are expressed in terms of peak period demand at the points of maximum load on the system, then they assume still greater value; it becomes possible to evaluate the adequacy of the system's capacity, to estimate future equipment, manpower and power needs. It was with these purposes in mind that a model to estimate ridership on the New York City rapid transit system, currently about 70 percent of the Nation's, was constructed. That model and its applications are described in this paper. The work was part of a larger project described fully elsewhere (1).

Rapid Transit Ridership Model

Estimating future rapid transit ridership requires developing a relationship which would link it to factors that are likely to impact ridership. Such factors might logically include Manhattan Central Business District (CBD) employment, transit fares, service on the system, and the availability of the major competing mode--the automobile.

Data were compiled for these four factors and for annual ridership on the New York City Transit Authority rapid transit system, for the 1947-1976 period. It shows that total ridership over the period declined in half; employment in the CBD dropped about 23 percent; subway service, expressed in car-miles operated annually, dropped about 18 percent; meanwhile, auto registrations in New York City essentially doubled, and fares increased three times in constant dollars. Our task was to determine how much of a role can be attributed to each of these factors for the year-to-year change in annual and peak period ridership. Historical series were constructed of two measures of ridership, annual rides and weekday peak hour (8-9 a.m.) turnstile registration. The former is a sum of all revenue rides during the year while the latter is based on a system-wide turnstile count on a sample day of the year. Historical series were also constructed for a number of "independent" variables, to be used as indicators intended to explain the variation in the dependent variables. Included are: 1) subway fare, adjusted to remove the historical reduction in buying power of a dollar, by using the New York Area Consumer Price Index, 2) employment in the Manhattan Central Business District; 3) automobiles registered in New York City; 4) per capita automobile registrations in New York City; 5) annual subway car-miles; and 6) subway cars entering the CBD during the 8-9 a.m. peak hour. Of these last two service variables, the former is the more appropriate indicator of annual service and the latter of, peak period service. Two indicators of automobile ownership are suggested, each with their merits: total automobiles registered and automobiles registered per capita. The latter, perhaps a better indicator of a trend away from transit, suffers from the crudeness of annual population estimates that were extrapolated from decennial census data before 1970.

To quantify the relationships an equation form was used that permits a direct derivation of elasticities. An elasticity is a measure of the percent change that will occur in one variable with a percent change in another. For example, if the elasticity of CBD employment with respect to ridership is 0.75, then an increase in employment of 10 percent will result in an increase in ridership of 7.5 percent (10 x 0.75). If the elasticity is negative, then an increase in one variable means a decrease in the other. The equations were derived using stepwise multiple regression analysis, key results of which are shown in Table 1. Other combinations of variables--including for example, New York City population--were tried, but were less satisfactory.

The two equations estimate annual ridership changes as a function of changes in fare, CBD employment, subway car-miles and either automobiles registered (equation 1) or automobiles registered per capita (equation 2). Both equations, using F-levels as a statistical measure, show that CBD employment changes and fare changes are strongly related to ridership while subway car-miles are only weakly related. Automobile registrations show up as a significantly stronger explanatory variable than per capita registration. This is likely to be so because annual population estimates before 1970 were merely interpolated decennial census counts. The four variables of equation 1 explain close to 80 percent of the variation in annual ridership; the four variables of equation 2 explain about 73 percent.

Two additional equations, not shown in Table 1, were developed for peak hour turnstile registrations. These equations were less satisfactory, explaining only 47 and 45 percent of the variation in peak hour turnstile registrations. This may be due to the inherently poorer quality of an hourly turnstile count, with possible errors in readings or in the timing of those readings at each token station, in addition to random day-to-day fluctuations inherent in the count.

The elasticity values calculated are, of course, of great interest. Table 1 shows that fare changes have a relatively modest impact on ridership with elasticities of about -0.12. This demand elasticities with respect to fare are similar to those reported for transit travel in other large cities, most notably for Montreal and for Boston work trips. Higher elasticities are found for bus travel in New York, for non-work trips in Boston and in small cities (2).

Employment changes in the CBD are shown to have a marked impact on subway ridership with elasticities of +0.69 and +0.75. With such elasticities, a 10 percent change in employment would produce about a 7 percent change in annual subway ridership. The elasticities for automobile registrations are about -0.25. The elasticities of service--about +0.13--must be interpreted with caution since ridership drops often precede service cuts.

The better of the two "annual equations, equation 1, was selected for further use with the intention to convert annual ridership to peak hour demand.

Relating Peak Hour CBD-Bound Travel to Annual Ridership

Any transit system's maximum requirements depend on the peak hour passenger load at the maximum load point, which usually occurs at entryways into the CBD. Such data is available in New York from once-a-year counts taken in the rapid transit system but are difficult to model effectively because errors inherent in the counting procedure mask small year-to-year changes. Since a model for annual rapid transit ridership sensitive to a number of relevant variables is available, it is preferable to develop a "bridge" linking annual rapid transit travel to rapid transit trips entering the CBD during the peak hour. This is done in four steps.

First, annual ridership is related to the annual average weekday ridership, which, in turn, is com-

Table 1

Transit Ridership Changes Related to Changes in Central Business District Employment, Transit Fares, Automobile Ownership and Transit Service

Equation form: $Y = e^k \cdot x_1{}^{b_1} \cdot x_2{}^{b_2} \cdot x_3{}^{b_3} \cdot x_4{}^{b_4}$

where: Y = ratio of year's value to previous years value, dependent variable
x_1, x_2, x_3, x_4 = ratio of year's value to previous years value, independent variables
b_1, b_2, b_3, b_4 = coefficients of regression (elasticities)
k = constant of regression
e = base of natural logarithm

Dependent Variable	**Annual Change in Rides**					
	Equation 1			**Equation 2**		
Independent Variables, annual changes in:	b	Std. Error of b	F-level	b	Std. Error of b	F-level
Fare	- 0.1170	0.0256	20.8	-0.1253	0.0298	17.7
CBD Employment	+ 0.7543	0.1703	19.6	+0.6946	0.1697	16.7
Subway car-miles	+ 0.1353	0.1086	1.6	+0.1250	0.1098	1.3
Auto registrations	- 0.2536	0.0834	9.2	--	--	--
Autos per capita	--	--	--	-0.2367	0.1353	3.1
Constant, k		-0.0054			-0.0054	
Coefficient of determination, R^2		0.7928			0.7289	
Years covered		1948-1975			1951-1975	
Number of observations		28			25	

Note: The coefficient of determination, R^2, gives the fraction of variation in the dependent variable explained by the independent variables.
The standard error of the coefficient is the error in the true value of the coefficient that has approximately a one-third chance of being exceeded.
The F-level is statistical measure of the reliability of the coefficient. Values in excess of 2.0 suggest an 84 percent chance, values in excess of 4.0 suggest a 98 percent chance, and values in excess of 9.0 suggest a 99.8 percent chance, that the sign of the coefficient is correct.

pared to the average weekday ridership for the month of October, the month when the counts are taken. Next, the ratio of rides entering the CBD to total rides is determined. Finally, the ratio of peak hour CBD entries to daily entries is calculated.

Examination of this chain of relationships over a time produces factor of 0.0004322 to convert from total annual subway ridership to peak hour weekday inbound crossings of the CBD cordon. Quite stable over a period of 20 years, this factor gives means to convert from annual ridership to peak hour riders at the maximum load point.

The Impact of Auto Restraints

The transit ridership model presented earlier makes it possible to estimate diversions from auto to rapid transit under different assumptions of auto restraints, but only if expressed as reductions in auto registrations in New York City. It is very difficult to estimate the drop in automobile registrations that might accompany a serious gasoline shortage. Our only substantial evidence is from the World War II period when automobile registrations in New York City dropped by 34 percent, from 881,000 to 585,000 in the two-year period, 1941 to 1943, and remained essentially at that level until 1945. Meanwhile, subway ridership grew by 6 percent from 1941 to 1943 and by 12 percent over the 1941 and 1946 period, by the end of which gasoline and new cars become widely available again. The automobile registration elasticity for equation 1 suggests that subway ridership increases between 1941 and 1946 should have been about 10 percent, a reasonably close estimate.

Another way of getting a grasp of the magnitude of subway ridership increases, if automobile use is curtailed, is to examine the maximum potential market for diversion from auto to transit. Using the 1970 Census Journey-to-Work data and assuming that if virtually all auto trips to the Manhattan CBD were to switch to rapid transit in areas with rapid transit service, the increase in ridership would be on the order of 10 percent. This is in scale with both the data on hub-bound travel data and with the elasticity discussion above. However, a much larger relative increase in transit use might be expected in other cities in the Nation, all more dependent on auto travel than New York. This phenomenon is also evident by the greater percent diversion to the New York Region's commuter railroads, about 29 percent, that would occur if all auto commuters to the CBD from rail service areas were to switch to rail.

Future Rapid Transit Ridership

To investigate the possible range of future ridership on the rapid transit system, two alternative estimates of each contributing factor are used. Manhattan CBD employment is assumed to stabilize at 1.8 million jobs or to experience a resurgence to 2.1 million jobs. Future transit fare level is assumed to increase at the same rate as inflation in the overall economy, i.e. to remain stable in constant dollars, or to remain at 50¢ in current dollars, meaning that it declines in real terms as the cost of living is assumed to increase at 4 percent per annum. Automobile registrations in New York City are assumed to increase by roughly 5 percent to reflect the relative shift of population to the less dense boroughs of New York, or to decline by 35 percent to reflect a serious gasoline shortage and generally higher real costs. In addition, the results of each of the combination of alternatives are adjusted to reflect the further impact on ridership of service changes instituted as a result of the above assumptions.

Eight estimates of the change in annual ridership where calculated based on the elasticities of equation 1 and reflecting all combinations of the assumptions described above. The impact of each assumption is easily estimated. Thus, a stable employment level of 1.8 million, some 5 percent lower than 1975 employment, produces a 3.4 percent drop in ridership while a rise of employment to 2.1 million signals a 10.2 percent rise in ridership. Fare increases equal to inflation produce a 3.4 percent drop in ridership. This decline reflects the late 1975 fare increase from 35¢ to 50¢. If the fare were to remain at 50¢ until 2000, ridership would increase by 7.9 percent assuming 4 percent inflation. The assumption of modest increases in automobile registrations in New York City would yield small ridership declines of 1.0 to 2.4 percent. The slightly larger 2.4 percent decline reflects the added automobiles of a larger population associated with the resurgent employment alternative. The 35 percent decline of automobile registrations induced by gasoline unavailability would cause ridership to increase by 10.5 percent in the stable employment alternative and 8.9 percent in the resurgent employment alternative due to its slightly higher auto registrations. The combined impact of the three factors, employment, fare and autos would range from an 8.0 percent decline to a 29.4 percent increase in annual ridership given the changes assumed. If it is further assumed that the service offered on the system rose in proportion to these ridership changes as they occurred, there would be an additional change in ridership levels reflecting the service changes. This is calculated using the elasticity of ridership to annual transit car-miles from equation 1. Thus the change in ridership, based on the combined effect of the four factors of employment, fare, autos and service, would range from 9.0 percent lower to 34.1 percent higher than 1975 levels. This translates to a range of 959 million to 1.413 billion annual riders. Not reflected is the impact on ridership if higher space standards resulting from more frequent service or larger subway were installed or new lines were constructed. A range of 414,000 to 611,000 peak hour riders entering the CBD were calculated based on the conversion factor described earlier. It is these volumes that are most useful for examining future system requirements.

It must be stressed that all these estimates are based only on the limited scenarios examined. But a tool has been developed to examine a large variety of scenarios for the future of New York City rapid transit system and, indirectly, for the future of the City itself.

1. Regional Plan Association, Power for the MTA: An Examination of Future Ridership, Service, and Electric Power Requirements for Metropolitan Transportation Transportation Authority Facilities: RPA Bulletin 126, June 1977.

2. Pushkarev, Boris and Zupan, Jeffrey M., Public Transportation and Land Use Policy, Indiana University Press, Bloomington, Indiana, 1977.