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Effect of Operating Policies of Urban Mass Transportation on Demand

by Richard de Neufville and Alex Friedlander**†*

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ABSTRACT

This paper first suggests that transportation systems planning requires a careful consideration of the supply and demand functions, and their interactions. An examination of work to date and in particular of the results of the Federal Mass Transportation Demonstrations indicates the relative lack of information about the effect of supply policies on demand.

Three hypotheses are then developed to predict ridership from transit operating policies: (1) Increasing service at times of peak demand leads to high increases in ridership; (2) the installation of through services to major activity centers has a similar effect; (3) ridership is directly related to frequency of service.

Practical formulas are presented which were tested against data developed from The Demonstrations and obtained by private initiative.

With the ultimate aim of improving urban mass transit design, this paper reports on some attempts to define the effect of transportation operating policies on the demand for service. A theoretical framework for analysis for the consideration of supply and demand interactions is first suggested and then used for the examination of known results. Following a critical survey of relevant experience gained from the Mass Transportation Demonstrations sponsored by the United States Department of Housing and Urban Development, three hypotheses concerning the influence on demand of the level of service, frequency of service, and the elimination of transfer points are

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proposed. It is hoped that these initial findings will both yield some insight into the problem and, in a larger sense, encourage the development of a more complete understanding of the effect of service on demand and thus lead to the design of better transportation systems.

Theoretical Basis

The essential problem of transportation systems planning and design is that of obtaining the most appropriate match between the supply of services and the demand.[1] While the analysis task can be stated in this classical sense, the determination of an appropriate equilibrium is far more difficult for transportation than it is for the usual economic problem. In effect, neither the supply nor the demand for transportation can be adequately characterized by a single parameter such as price.

Transportation service is in general not readily measured in units for which it is meaningful to compare utility. A ton-mile in ship's steerage is not the same as a ton-mile by air. The desirability of any particular mode of displacement—for people or for cargo—depends on a variety of characteristics such as speed, comfort, convenience, in addition to cost.

At least three major dimensions seem, because they are tokens of basically different sets of parameters, to be required in order to define any particular form of transportation technology: cost (C), volume (V) or capacity and level of service (S)[2]. An expanded or different set of parameters may, ultimately, be preferable: it is not important to take a stand on that point. The central issue that transportation quality must be defined by a multidimensional vector of variables.

The supply and demand for transportation are thus each represented by several, common dimensions. In any particular case they may consequently be visualized as defining functions, s (C,S,V) and d (C,S,V) respectively, which form surfaces in a space of characteristics (Fig. 1). At any time, the intersection of these functions will define a line representing many possible equilibrium points. Over time, the demand function shifts exogenously due to population and income changes and, of particular relevance here, endogenously because of changes in the level of transportation supplied. Any initial condition of transportation is thus at the base of a continuously expanding range of alternative equilibrium points.

The essential task of the transportation designer is to select the most desirable sequence of equilibrium points over time. Traditionally this analysis has been performed in the context of single mode alone in a simplified two dimensional space where the service components have been collapsed into the cost dimension, thus resolving the problem into a more usual economic framework[3].

1 See, for example: Manheim, M. L., "Principles of Transportation Systems Analysis," and Hershdorfer, A., "Predicting the Equilibrium of Supply and Demand: Location Theory and Transportation Flow Models," Papers, Seventh Annual Meeting, Transportation Research Forum.

2 See Heflebower, R. B., "Characteristics of Transport Modes" and Nelson, J. R., "Pricing Transport Services, in Transport Investment and Economic Development, Gary Fromm, ed., The Brookings Institution, Washington, D.C., 1965.

3 See, for example, the comprehensive book by Oi, W. Y., and Shuldiner, P. W., An Analysis of Urban Travel Demands, Northwestern University Press, 1962.

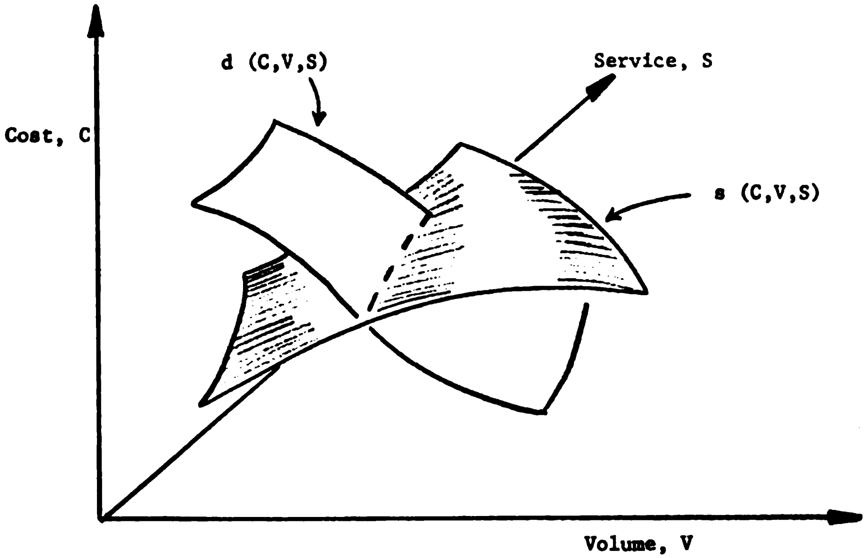

FIGURE 1 Supply and Demand Surfaces in a Space of Transportation Characteristics

Building on this work, efforts along several fronts are now however making it possible to consider the interaction of all modes in terms of their most important dimensions[4,5,6].

In order to use the kind of multidimensional formulations that are becoming available, an explicit understanding of the supply and demand interactions caused by each transportation characteristic is required. Although pieces of the problem are partially understood, no comprehensive picture of the process is yet at hand. Specifically, there is very little hard knowledge about the influence of the service of public transportation on demand. As a rule, service is represented by parameters such as speed or expected travel time which permit a comparison with automobile transportation. But these variables do not reflect the essential difference between private and public transportation: one is continuous, leaving at will and proceeding without interruption until the destination; the other is inherently discrete, operates on fixed routes at scheduled times and thus enforces delays and transfers. The inherent interruptions and uncertainties of public transportation are not adequately reflected by mean values of speed or travel time.

Fares and Travel Time

Because so relatively little exploration of the effect of service characteris-

4 Baumol, W. J. and Quandt, R. E., "The Demand for Abstract Transport Modes: Theory and Measurement," Journal of Regional Science, Vol. 6, No. 2, pp. 13-26, 1966.
5 Domencich, T. A., Kraft, G and Valette, J. P., "Estimation of Urban Passenger Travel Behavior: An Ecomonic Demand Model," Paper presented at the 47th Annual Meeting of the Highway Research Board, Washington, D.C. 1968, also Kraft, G., and Wohl, M., "New Directions for Passenger Demand Analysis and Forecasting," Journal of Transportation Research, Vol. 1, #3.
6 Morlok, E. K., "The Comparison of Transport Technologies," Paper presented at the 47th Annual Meeting of the Highway Research Board, Washington, D.C., Jan. 1968.

tics on demand appears to have been done to date for public transportation, it seems possible to present their major results fairly briefly. The conclusions fall mainly into two categories: the effect of fares on traffic, and the value of time.

The typical, and most widely accepted, description of the effect of changes in transit fares on demand is the rule developed by Simpson and Curtin[7], which predicts that ridership will decrease according to the following equation:

$$Y = -0.30X - 0.80$$

where Y is the percent net change of traffic and X the percent fare change with a regression coefficient, $R^1 = 0.92$. The coefficient of X, which indicates the rate of loss in ridership due to fare changes, is known in the transit industry as the 'shrinkage ratio' or the 'loss ratio'. Repeated analyses for a wide range of American cities have demonstrated the general validity of this formula for twentieth century urban mass transportation in the United States.

Experience derived from fare increases on major transit systems since 1952 suggests a lower loss ratio, however. In a survey of 11 cities, the ratios as low as 0.88 (Baltimore) were observed with values below 0.20 being common (San Francisco, New York, Boston, Philadelphia and Salt Lake City). Overall an average loss ratio of 0.22 was registered for fare reductions on the transit systems of big cities. Curtin himself has thus recommended using 0.20, that is $Y = -0.20X$, as a planning estimate. Likewise, for a related mode the 25% taxi fare raise of 1968 in New York City resulted in a 4% loss in traffic[8]. This corresponds to a shrinkage ratio of 0.16, similar to Curtin's revised estimate.

In detail, the Simpson and Curtin formula does not appear so useful in predicting the results on individual routes or for different classes of riders, as Schneider points out[9] on the basis of his analysis of experiments in Los Angeles with special fares for senior citizens. The elasticity of demand with respect to price was there observed to be significantly less for elderly people than for the system as a whole. Less, in other words, than as predicted by the Simpson and Curtin formula. Mass transit thus does not have a unique market whose behavior can be represented by single parameters. The demand for a system's services are an aggregation of the equilibrium points established by the needs of diverse categories of riders: workers and shoppers, rich and poor, school children and retirees. Some of these differential relationships have already been identified, as indicated in Table 1. The general trend that peak hour ridership is less affected by fare changes than off-peak demand was also recently observed in New York City[10].

The same study gave evidence of a significant difference in the impact

7 Curtin, J. F., "The Effect of Fares Upon Transit Riding," paper, 47th Annual Meeting of the Highway Research Board, Washington, D.C. Jan., 1968.
8 New York Times, Feb. 22, 1968.
9 Schneider, L. M., Marketing Urban Mass Transit, Harvard University, Boston, 1965, also his Ph.D. thesis, "Management Policy in a Distressed Industry: A Study of Urban Mass Transit," Harvard, 1963.
10 Lassow, W., "The Effect of the Fare Increase of July 1966 on the Number of Passengers Carried on the New York City Transit System," Paper, 47th Annual Meeting of the Highway Research Board, Washington, D.C. Jan. 1968.

of the fare change on low-income groups. The resulting threefold greater decrease in riding in the low-income areas is further confirmed by annual revenue tabulations for the first year after the fare rise, on both rapid transit and bus lines[11]. In this situation a single formula may be useful as a means for predicting overall system ridership, but it is inadequate as an explanation of the detailed causal relationship between supply and demand of urban transportation.

TABLE 1 Elasticity of Passenger Travel Demand with Respect to Time and Cost of Transit Trips[12]

Trip Purpose	Cost Elasticity		Time Elasticity	
	Line Haul	Access Trip	Line Haul	Access Trip
Work	-.09	-.100	-.39	-.709
Shopping	-.323		-.593	

Travel time is also an important determinent of modal choice and the demand for transportation, as suggested by Table 1. It is usual practice, sanctioned by the Federal Bureau of Public Roads for example[13], to account for the effect of time by imputing to it a monetary value of some sort.

Several recent studies indicate how the value of time is generally estimated. Thomas for example investigated the behavior of industrial workers at 8 localities in 5 states and recommended valueing time at the rate of $2.82/hour/person[14]. The analysis is based upon what really seems to be a fairly special market: commuters of above average income ($9200/family). If the demand of this group is in fact relatively inelastic, as it appears from[12], then it is not appropriate to generalize from them. In particular, these valuations are probably of limited value for an analysis of urban mass transit.

Other recent studies of the value of travel time are fairly similar in that they estimate the marginal value of time. Lisco, for example, has done an extensive analysis of the behavior of commuters in Skokie, Illinois, a middle-income suburb on Chicago's North Side[15]. He reports a marginal value of time between $2.40 to $3.00 an hour. But he also suggests that these figures are most appropriate for commuters with incomes between $10,000 to $17,000 a year, incomes far above national average. In fact, for lower income brackets–those that often predominate the central city and are major users of downtown mass transit services–Lisco indicates that appropriate values of time may currently be from $0.40 to $0.78 for people with incomes between $4,000 and $6,000.

Mass Transit Demonstrations

The immediate and most striking feature of the Federal Urban Mass

11 New York City Transit Authority, "Transit Record," Vol. XLVII No. 8, August, 1967.

12 Adapted from: Domencich, T. A., Kraft, G., and Valette, J. P., op. cit.

13 ____, Road User Benefit Analysis for Highway Improvements, American Association of State Highway Officials, Washington, 1960.

14 Thomas, T. C., "The Value of Time for Commuting Motorists", Stanford Research Institute Report, 1968.

15 Lisco, T. E., "The Value of Commuters' Travel Time—A Study in Urban Transportation," Paper, 47th Annual Meeting of the Highway Research Board, Washington, D.C., 1968.

Transportation program is its diversity, as McGrath points out[16]. As of the beginning of 1967, about $440 million of federal and local money had been spent and some 125 federal contracts ranging in size from $14,833 to $23,-420,000 had been let. Each city has determined and dealt with its own needs as it saw them. Each project is thus not only distinctly individual in concept but also, as can be seen from the Mass Transit Demonstration reports, has proceeded without substantially benefiting from results obtained elsewhere.

About one fifth of the Urban Mass Transit money has gone into demonstrations. Fifty-eight projects were started from 1961 through June 1967, ranging in size and nature from an attempt to use transit passes ($14,433) to the operation and evaluation of an over water air cushion vehicle (over a million dollars) to engineering and design studies of track and rail equipment for the San Francisco Bay Area Rapid Transit District (over $10 million, including supplemental costs)[17]. In all fairness it should be noted that, since so many projects have been running concurrently, it would have been difficult to develop, let alone use, the findings of one demonstration for the design of another—even if it had been directed.

Unfortunately, relatively little information has been developed and disseminated from the urban transportation demonstrations. Grantees are obliged to prepare quarterly and final reports for the Department of Housing and Urban Development and these can generally be obtained. These documents make interesting reading and the results of the experiments they describe are frequently applicable to a number of cities with similar transportation problems. But, except in rare cases, the information is not interpreted, it is not translated into useful criteria or guidelines for transportation planners elsewhere.

More tragically, much of the data collected cannot—even with additional outside effort—be converted into practical functional relationships between supply and demand. By and large, the demonstrations were not designed to make this possible[18].

Their local sponsors intended them to solve particular local problems, not to perform experiments and test whether, for example, there were perceptible interactions between population density and demand, or between schedule frequency and demand. Since the kind of data which would be required to test such hypotheses was not deliberately collected, it is almost impossible to state firm conclusions.

It is a hopeful sign, however, that more generally applicable studies of the dependency between the operation of transit services and its demand recently seem to have been funded. Specifically, in March 1967 contracts were signed for the field test of a mathematical model to predict bus ridership and for the development of an information system to facilitate management decisions[19]. Results of these new efforts are scheduled to be available by the end of 1969.

16 McGrath, W. R., "Urban Transportation is an Urban Problem," Traffic Quarterly, p. 307-320, July 1967.
17 ----, "A Summary of Urban Mass Transportation Demonstration Projects," U.S. Department of Housing and Urban Development, Washington, D.C. Jan. 1968.
18 For an interesting discussion of this point see Hooper, W., "Why Demonstrate?," Papers, 6th Annual Transportation Research Forum, San Francisco, California, 1966.
19 Cited in (17). These studies are being conducted by the State of New York and Kent State University in Ohio.

The reason why little has been learned from the demonstrations is easily adduced. The management of the mass transit industry is over-whelmingly concerned with the development of smooth, workable arrangements for running its services and is not particularly interested in complicating its planning by worrying about the interaction between its operations and demand. Interviews indicate that, in some major eastern cities at least, the transit authorities assume that demand is unaffected by operational changes and need not be taken into account when determining routes and schedules[20]. It is not surprising that this apparent lack of concern of the mass transit authorities is reflected in the demonstrations which they proposed, planned and executed.

Thus although about sixty four million dollars have been spent on mass transit experiments of one sort or another, the results have been minimal in terms of knowledge transmitted to the profession. Perhaps as Smerk suggested after his extensive examination of the program, information vital to the fortunes of public transportation in Keokuk or Butte is hidden, for instance, somewhere in the vast study conducted by Massachusetts[21]. But these and other results cannot be useful unless they are systematically analyzed.

A few studies have explicitly indicated an interest in developing correlations between the supply and demand of transit service. These include those conducted by the Bi-State Transit System of Saint Louis[22], the City of Detroit[23], and the Southeastern Pennsylvania Transportation Authority of Philadelphia[24]. This last is most easily considered: its eleven findings are mainly qualitative and obvious. The first two are, for example[25]: (1) "Location of in-city destination exerts the principal influence on the choice of rail carrier wherever competitive rail services are available" (You take the line that goes where you want); (2) "Location of in-city destination governs the choice of travel-to-work mode from suburban areas" (People take the mode that gets them to work).

The studies for Saint Louis and Detroit are more interesting. The Bi-State report suggests that it should be possible to estimate potential ridership by counting houses and estimating ease of access along a proposed route. Ratios are suggested which, although they do not take income levels or other characteristics into account, may be valid if conditions similar to those prevailing in Saint Louis are encountered. The studies also found that, as in Philadelphia, ridership was drawn from a narrow zone around the transportation route. They were even able to define this sector fairly precisely: (a) about three quarters of the bus traffic came from within a quarter of a mile and (b) this traffic appears to decrease exponentially with distance.

The Detroit study attempted "to determine the extent to which passenger usage is affected by the frequency of service on a given line." At first blush,

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20 As obtained by Friedlander in visits to each of the major eastern cities with mass transit.

21 See for example, Smerk, G. M., "Federal Urban Transport Policy: Here—and Where do we go from here? Traffic Quarterly, p. 29-52, Vol. XXI, No. 1, Jan. 1967.

22 ----, "The Radial Express and Suburban Crosstown Bus Rider", Final Report, Mass Transportation Demonstration Project INT-MTD8, Saint Louis, Mo., 1966.

23 ----, "Grand River Avenue Transit Survey", Final Report, H.H.F.A. Demonstration Grant, Detroit, Michigan, 1963 (See p. 4-12 especially).

24 The latest report available at time of writing is: ----, "SEPACT II Demonstration Project Commuter Rail System Study," Report 106 (D), Mass Transportation Demonstration Project PA-MTD-4, Phila., Pa., Nov. 1966.

25 Ibid., Volume I, p. 9-12.

the effects of additional service were dismal[26]: citywide mileage increases of over 50% increased revenues by less than 10%. But the story is far more complex because increases by line segment, time of day and day of week varied widely. In addition, since Detroit's supply of men and equipment was strained to capacity in attempts to meet the special schedules, little or no slack was available to make up for breakdowns or even to boost service at times of peak demands when such raises would presumably have had the most effect. In any event, system wide averages are not particularly informative and specific modes of operation for identifiable segments of the potential ridership should be considered.

Hypotheses

Three hypotheses were formulated in a preliminary effort to extract general conclusions from data gathered by the mass transportation grants, and from such statistics as were otherwise available or could be collected by private initiative. They are each described qualitatively and quantitatively and are supported by figures for several cities. It is hoped that these initial formulas will lead to further analysis and improved or revised expressions. The hypotheses are:

(a) Increasing service at times of peak demand leads to high increases in ridership. Specifically, it appears that when a transit line is operating at practical capacity any given percent increase in service defined in terms of capacity, C, yields an almost equal increase in the number of people carried, Y:

$$Y = 0.87C + 0.04$$

The factual bases for this conclusion are indicated in Figure 2 and Table 2.

In this context, practical capacity was operationally defined as the average number of passengers carried per vehicle at the peak point during the crowded rush hours. This is always less than total capacity simply because of irregular arrivals and loading of passengers.

TABLE 2 Increase in Ridership as more Service is Provided on Congested Routes

Location	Direction	Vehicles Before	Vehicles After*	Passengers Before	Passengers After*	C (%)	Y (%)
Detroit[27]	Inbound	51	78	1600	2400	55	50
	Outbound	55	88	2570	4242	60	65
Boston to	Boston	4	6	200	270	50	35
Cambridge	To Boston	4	7	200	315	75	57
Mass. Ave.[28]	To Harvard Square	8	12	400	570	50	43
Boston[29]	No. Station	16	21	1030	1352	28	32

26 See (23) above, in particular pp. 4 and 5 and Tables II and III.
*The Mass. Ave. data represents observations on different days under the same scheduled headway.
27 Data from the Mass Transportation Demonstration Project report (23) and Detroit Street Railway Department schedules obtained by Friedlander.
28 Data from street observations by Friedlander, 1966-67.
29 Data from MBTA files collected in conjunction with Mass Transportation Demonstration Project Mass-MTD, July 1964.

The correlation between ridership and service at rush hour has important policy implications for the designers of urban systems. It may be possible to alleviate peak traffic congestions at the expense of paying for more men and equipment for the rush hours alone. The proportions of the tradeoff between larger municipal benefits and the convenience of more balanced transit operations are not clear. At present the issue is probably only considered summarily since the decisions lie with the transit operators who may presumably suboptimize their own operations. Yet the question deserves to be explored: public resources may in fact be better spent on the operation of rush hour services than for the provision of highway capacity to service rush hour automobile traffic.

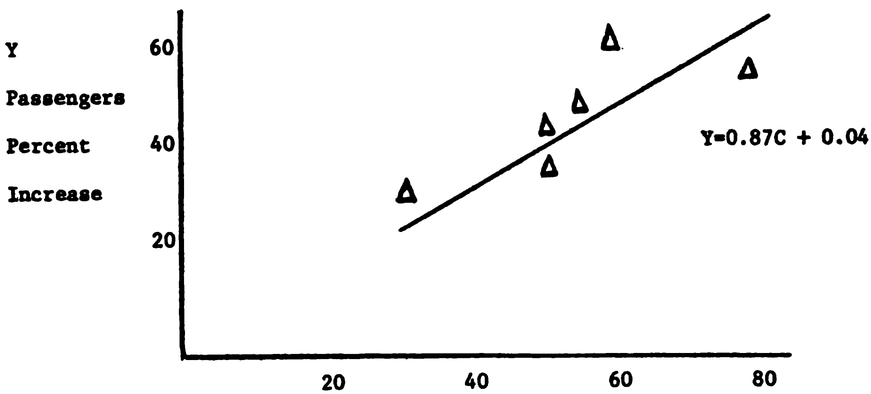

FIGURE 2 Increase in Ridership at Rush Hour on Heavily Used Routes

The above hypothesis also suggests that increasing the reliability of service on heavily used lines by more evenly spaced arrivals of vehicles (eliminating "bunching" of buses, for example) will produce additional riding. Potential passengers who now walk or take other modes when no vehicle is in sight (or when they consider, it unlikely, from past experience, that one will soon come) would likely be the main source of such additional riding. The second set of data in Table 2 illustrates this kind of situation. (29)

(b) The installation of through service to rapid transit stations or major activity centers leads to significant increases in ridership. In particular, this change increases demand about 90% during the midday off-peak hours (10 a.m. to 2 p.m.) and approximately 30% during the rush hours (7 to 9 a.m. and 4 to 6 p.m.). As indicated before (5), rush hour traffic is more inelastic than off-peak traffic.

These results were obtained by examination of the records of the Massachusetts Bay Transportation Authority on head counts at peak load points both before and after through service was provided[30].

The analysis examined the ratio, R, of the number of passengers carried when there was no transfer point along the line to number carried when

30 Obtained by Friedlander through the courtesy of the Massachusetts Bay Transit Authority Timetable Office.

there was. The hypothesis that the elimination of transfer points increased riding was accepted at the 95% level using one-sided t-tests. (Table 3) This acceptance is conservative because the increases occurred while ridership over the system as a whole had decreased due to a fare increase.

These results also agree with an analysis of the effects of providing through service to midtown Manhattan on three New York City rapid transit lines in Brooklyn and the Bronx formerly operated as shuttles, the Dyre Avenue, Macdonald-Culver, and Fulton-Liberty subway lines. Twenty-four hour turnstile registrations on a typical weekday changed by + 125%, + 18-1/2%, and −22% respectively between 1951 and 1961[31]. The trend on three control lines, the Woodlawn-Jerome, Queens IND and Sea Beach lines, in this same period was −36%, −46% and −51% respectively.

TABLE 3 Increase in Ridership due to the Elimination of Transfer Points.

MBTA Lines	Ratio of Traffic after transfer elimination (1961-1962) to Traffic Before (1960-1961)	
	Midday (10-2)	Rush (7-9, 4-6)
54	3.10	1.66
8 and 13	2.20	1.40
51	2.00	1.33
35, 37, and 50	1.40	1.20
100, 103 and 108*	1.66	1.22
106, 107 and 108**	1.50	1.30
97 and 99	1.40	1.12
96	1.75	1.12
Mean	1.88	1.29
Standard Deviation	0.57	0.17

The policy implication of this analysis seems reasonably clear: transit operation should be designed to permit direct service through interchanges for trip paths where increases in volume could be sufficient to overcome additional costs if any. Specific decisions would naturally rest upon explicit analyses of projected passenger volumes and costs.

(c) Ridership is directly related to frequency of service. In particular, expressions relating passengers per thousand inhabitants, P, and the frequency of service expressed in terms of headway between scheduled runs H, were derived by cross-sectional analysis of data for Metropolitan Boston. The trends deduced were later confirmed by a longitudinal analysis for the same area.

The analysis explicitly recognized the behavior of different groups travelling for different purposes at different times. The data was disaggregated by times (midday, rush hour, and Saturday midday) which were taken as proxies for different activities, and also by the destination (to a feeder station, through a feeder station to a shopping area, and to the central business district).

31 Turnstile counts courtesy of the New York City Transit Authority.

*at Wellington Square

**at Malden Square

Seventy-one lines were considered in total and the sample size for each distinct category ranged from twelve to thirty-six. Head counts of passengers for 1960 in Boston at the station or shopping center nodes[32] were divided by the population of the service areas as derived from block data of the 1960 census to obtain an estimate of P, the passengers per 1000 served. The service area in this context is as defined by the St. Louis study: the zone within a quarter mile of each line. This data was subjected to a least-squares linear regression analysis and the results are as shown in Table 4.

TABLE 4 Passengers per thousand served, P; as a Function of Headway, H; Activity; Type of Service (Boston, 1960)

Activity	Service Type	Regression Equation	R^2	Sample Size
Midday (10-2)	Feeder	P = 51.5-1.16H	0.72	32
	Shopping	P = 80.7-2.18H	0.89	20
	CBD	P = 80.0-2.10H	0.90	16
Rush (4-6)	Feeder	P = 96.7-1.71H	0.58	32
	Shopping	P = 141 -6.8H	0.88	23
	CBD	P = 121 -3.73H	0.84	16
Saturday (10-2 p.m.)	Feeder	P = 87.7-2.66H	0.81	24
	Shopping	P = 103 -2.73H	0.97	12
	CBD	P = 120 -2.62H	0.79	13

The principal features of this analysis can be illustrated by aggregate expressions for the relation between ridership and scheduled headway:

$P = 117 - 3.8H$ Rush hour

$P = 100 - 2.7H$ Saturday midday

$P = 67 - 1.7H$ Midday in week

Specifically, for instance, demand for public transportation is highest at rush hour and it is also most sensitive to the frequency of service. Similar conclusions can be extracted by looking at the different kinds of service. Qualitatively the results agree with what one might expect; quantitatively they are rather interesting.

Correlation with observations in other cities, both large and small, are quite reasonable. In Memphis, for example, it was found that about 2 to 5% of the residents of an area used the bus when headways of between 20 and 30 minutes were scheduled[33]. This is well within the range suggested by the analysis. Likewise, in Saint Louis, limited express bus operation (8 buses inbound 6:30 to 10:00 a.m., 8 buses outbound 2:30 to 6:00 p.m.) on several routes produced 5 to 26 passengers one-way per 1000 population served in segments with no competition from local routes[34].

32 Obtained through the courtesy of the Massachusetts Bay Transit Authority Timetable Office.

33 ----, "Mass Transportation Studies in Memphis, "Memphis Transit Authority, Final Report, TENN-MTD-1, p. 100ff, March 1965.

34 ----, "The Radial Express and Suburban Crosstown Bus Rider", Bi-State Transit System and Development Agency, Final Report INT-MTD 8, p. 5, 1966. Based on an assumed 3.3 persons per housing unit.

Conclusions

The analysis of data obtained from the Federal Mass Transportation Demonstrations and supplemented by the authors led to the development of the following hypotheses:

(1) At times of peak demand, increases in capacity, C, lead to nearly equal increases in ridership, Y:

$$Y = 0.87\ C + 0.04$$

(2) The installation of through service to major activity centers leads to significant increases in ridership;

(3) Ridership in terms of passengers per 1000 in the area served, P, is directly related to frequency of service or scheduled headway, H:

$$P = A - B\,H$$

where A and B are constants depending on the type of demand and where $A \simeq 100$ and $B \simeq 2$. Specifically, for rush hour traffic:

$$P = 117 - 3.8\ H$$

It is hoped that these initial findings will both yield some insight into the problem and, by encouraging a more complete understanding of the effect of transit supply on demand, lead to the design of better transportation systems.