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**		
	b	Std. Error of b	F-level	b	Std. Error of b	F-level
Independent Variables, annual changes in:						
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.