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Intercity Rail Travel Models

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Using a 1975 aggregate data base of 31 pairs of cities, forecasts are made of 1975-1980 rail patronage in the New York City-Buffalo corridor. A two-stage modeling process is used to estimate total city-pair volume by purpose, using gravity formulations relating annual volume to city size, government employment, and hotel and motel sales receipts. Binary logit models are then developed in which rail competes differentially with air, auto, and bus in order to avoid independent irrelevant alternatives assumptions. Rail service and terminal quality variables are included with time, cost, and frequency. The total rail share is then determined algebraically from the binary models. Pivot-point analysis is used to increase the accuracy of the forecasts. Results show that rail competes differently with each mode. Against air, the key variables are frequency and time ratios; against auto, the frequency, cost, and time ratios and terminal quality are important; against bus, train service quality, frequency ratio, and time difference are important. Elasticities of demand vary considerably by mode and distance. Forecasts show that if train, track, service, and terminal improvements are implemented as planned in the corridor over the next 5 years, 1980 link volumes will increase 58-105 percent over 1975 levels, with most diversion coming from short-distance auto trips. The net effect of this diversion will be to reduce 1980 corridor energy requirements by 9 percent over 1975.

The Planning Research Unit of the New York State Department of Transportation (NYSDOT) recently cooperated with Union College to study the energy efficiency of train service in the New York City (NYC)-Buffalo corridor. NYSDOT's role was to develop a workable model of train passenger demand and to analyze energy and passenger-kilometer efficiencies of alternative train, track, and service improvements in the corridor. This report summarizes the rail passenger demand models developed in the study. It briefly describes the data used, the developed models, and the pivot-point and normalization procedures used to increase the accuracy of forecasts. Rail demand forecasts and the potential for modal energy savings in the corridor are also discussed.

DATA

The data collection effort (1) concentrated on cities within the NYC-Buffalo corridor (Figure 1), with selected other city pairs included for continuity or availability or both of data. In total, 31 city pairs were included in the data base. Each city pair is described by a wide range of data elements (1) that include city size and spatial separation variables and modal service variables such as travel times, costs, and frequencies. In addition, the following quality-of-service data describing train and terminal service characteristics were also included:

Quality of rail service—snack car availability, sleeper car availability, lounge car availability, baggage service, package express, on-time performance, schedule match, dining car availability, and car type.

Terminal quality—parking availability, number of spaces, parking fee, parking lot lighting, terminal snack bar, local transportation, distance to downtown, and modernness of terminal.

Three central findings of the preliminary research conducted for the study (1,2) were as follows. First, when all factors are considered, a hybrid modeling approach—forecasting total intercity volume and then separate modal shares—appears to be the most productive. Second, care must be taken to avoid formulations that contain the so-called independence of irrelevant alternatives assumptions (IIA assumptions). Third, since quality of service influences modal choice, models developed should consider quality-oriented data on the rail system, including rail terminals. Ideally, such data should also be available for the other modes.

These principles led to the development of a new approach to intercity rail passenger demand modeling, which has been fully documented (3). The approach is to use two total travel models that forecast travel via all four modes between each city pair. These were developed for business and nonbusiness travel. The models have a simple gravity format. Estimates of total volume, however, will not replicate observed total volume because of residual errors caused by incomplete model specification. The slippage between estimated and true total volume in the base year (1975) can be eliminated for future forecasts, using pivot-point procedures.

Within each trip purpose, three separate competition models are developed for rail versus air, auto, and bus. The model form is binary logit. Each model includes only those variables relevant to the binary choice, for example, rail versus bus. These models are then used to derive a consistent estimate of the rail share. These rail shares, however, will not replicate the observed rail shares because of residual errors caused by incomplete model specification. The slippage between estimated and true rail shares in the base year (1975) can also be eliminated using pivot-point analysis.

The future modal volumes, in particular the rail volumes, are then obtained by multiplying the total volumes (as computed by the total models) by the modal share (as computed by the share models). Pivot-point analysis, described later, is used to reduce forecasting

Figure 1. NYC-Buffalo rail corridor.

from the residual error between the estimated and actual observations, which is contained in the calibrated models.

When forecasts of rail volume are made, the future modal shares, estimated with pivot-point, will no longer total 1.0. To ensure that they do, a normalization factor must be applied to all forecasts.

One reason for using this step-down approach, rather than the alternative approach of constructing direct-demand modal models such as the Kraft-Sarc or Baumol-Quandt, is that, although city attractiveness and city-pair impedance measures are generally the variables that influence the total travel volume, they are not the primary variables influencing mode choice. The construction of a sequence of models thus enables the analyst to better isolate the effects of changes in many variables on both total travel and mode usage.

TOTAL TRAVEL

Gravity-like models were constructed separately for business and nonbusiness travel. These models are of the form

$$\text{Total annual trips}_{ij} = [K(\text{attractiveness of i and j})^a] \div (\text{travel impedance of i and j})^b$$

Some of the several different measures tested are

P_iP_j = population product;
In_iIn_j = median income product;
Gov P_iP_j = $(Gov_i\ P_i)(Gov_j\ P_j)$; that is, population product weighted by percentage of government employment;
25+ P_iP_j = $(Inc\ 25+_i\ P_i)(Inc\ 25+_j\ P_j)$; that is, population product weighted by the percentage of families earning $25 000+;
Au P_iP_j = $(Auto_i\ P_i)(Auto_j\ P_j)$; that is, population product weighted by the percentage of families owning an auto;
Hot P_iP_j = $(Hot_i\ P_i)(Hot_j\ P_j)$; that is, population product weighted by the percentage of total receipts that are from hotels and motels;
D = distance;
ATT = air travel time;
AUT = auto travel time;
BTT = bus travel time;
RTT = rail travel time;
Avg BT = average business travel time; and
Avg NBT = average nonbusiness travel time.

The last two variables are volume-weighted averages of the travel time by all modes.

All models were calibrated by using the aggregate data documented in (1). Stepwise linear regression techniques (BMD02R) were used for estimating coefficients. Results are more fully documented elsewhere (3).

The use of the variables (Hot P_iP_j) and (Gov P_iP_j) generally resulted in models with a slightly (0.05) higher R^2 than the other attractiveness measures. In addition, they permit additional analysis of the effect of changes in variables other than merely city size. In most cases there was little difference in model strength for different travel impedance measures. Generally the strongest models contained bus travel time, but only slightly weaker models were obtained using auto time, rail time, or over-the-road distance. Average business time produced significantly weaker models than average nonbusiness time, and the models using air travel time as the measure of travel impedance were far weaker than the other models. This is because of the combined effects of (a) a high proportion of air traffic in the business market and (b) the much faster air speeds for longer trips, which results in an anomaly that long-distance interchanges (e.g., Buffalo-Albany) may actually have a shorter average business travel time than shorter distance interchanges (e.g., Albany-Rochester). Average nonbusiness travel time, however, is generally monotonic with distance, is a reasonable proxy of intercity spatial separation, and permits policy analysis. The models finally selected were

$$T = 37.15\ (Gov\ P_iP_j)^{0.70}(Avg\ NBT)^{-2.57}$$
$$F = \quad (58.97) \qquad (64.77)$$
$$R^2 = 0.758$$

for business trips and

$$T = 12.88\ (Hot\ P_iP_j)^{0.94}(Avg\ NBT)^{-2.69}$$
$$F = \quad (55.92) \qquad (59.36)$$
$$R^2 = 0.746$$

for nonbusiness trips. Here, T is in hundreds of trips, Gov P_iP_j and Hot P_iP_j are in thousands, and Avg NBT is in hours. These models were chosen for several reasons.

The attractiveness measures have intuitive appeal. It seems reasonable that business trip volume should be influenced by both the populations of the cities and the proportion of government workers. For example, Albany and Washington have a much greater volume of business travel between them than might be expected if one merely considered their population and distance. Similarly, the percentage of hotel and motel receipts partially reflects a high proportion of tourist trips in nonbusiness travel.

The travel impedance measure used, average nonbusiness travel time, also had several virtues. Unlike distance, it is policy sensitive, since travel-time changes in a given mode will influence the overall city

separation. The implied elasticities are more reasonable; for example, if one considers the best business model using rail time as an impedance measure, it appears that a 1 percent decrease in rail travel time will result in an increase in total volume of 1.8 percent. This is clearly an unrealistic level of induced travel. In contrast, if one considers the best business model using average nonbusiness travel time, a 1 percent decrease in rail travel time will result in an increased volume equal to 2.57 times the rail share (mean value ~0.02), or 0.051 percent.

Although the R^2 values of the recommended models are not the largest obtained, the proportion of variation explained is only slightly lower. The R^2 values of most of the models obtained have approximately the same magnitude as those of the recommended models.

MODE CHOICE

There are several reasons for the use of binary logit competition models. By developing binary competition models the planner can obtain additional insight into the variables that influence particular mode choices. For example, the results suggest that rail can best compete with bus by concentrating on improving the amenities it offers but can best compete with auto by improving travel time.

The approach appears to reduce the problems caused by the independence of irrelevant alternatives axiom.

The models can be readily calibrated by using a standard stepwise linear regression program (BMD02R). Thus, a greater insight into the relative importance of the variables in the model can be obtained. Present multilogit models do not offer stepwise selection of variables.

Direct demand models such as Kraft-Sarc are less suitable when 0-1 dummy variables representing availability of service items are used.

Although the model is not a constant elasticity model, the formula for determining the elasticity of demand with respect to a particular independent variable does have a simple intuitive form and is analytically tractable.

The general form of the models is a binary logit model describing the mode choice between rail and one other mode. For example, using the typical logit form, the competition of rail versus air may be expressed as

$$\mathrm{LN}\left\{[\text{rail volume}/(\text{rail} + \text{air volume})] \div [(1 - \text{rail volume})/(\text{rail} + \text{air volume})]\right\} = G_{air} = a_0 + a_1 x_1 + \ldots \quad (1)$$

where G_{air} is calibrated by using linear regression techniques and the x's are variables describing the rail-air trade-off. The rail versus auto and rail versus bus competitions are similarly calibrated. These three equations can then be solved simultaneously, resulting in the principal equation used for forecasting the rail share.

$$P_{rail} = [\text{rail}/(\text{rail} + \text{air} + \text{auto} + \text{bus})] = [1/(e^{-G_{air}} + e^{-G_{auto}} + e^{-G_{bus}} + 1)] \quad (2)$$

where the total rail modal volumes can then be estimated by

$$\text{rail volume} = [\text{prob (rail)}]\ (\text{total volume, from total models}) \quad (3)$$

Many variables were considered as potential predictors of mode choice, including relative travel times, costs, and frequencies for all four modes. Various forms of these variables were considered, including costs per kilometer, relative times, costs and frequencies, and time differences. The only successful combination for the cost variables was relative cost. Generally, the cost variables proved unsatisfactory, since the cost and cost per kilometer variables for all four modes are generally highly positively correlated with trip length and hence negatively correlated with rail share.

Other variables considered were rail quality variables. These variables included terminal descriptors such as the nature of restaurant and parking facilities and train or system descriptors such as on-time performance and proportion of trains with snack cars. As was the case with cost variables, the use of cross-sectional data resulted in the need to discard certain potential variables because their correlations with the dependent variable had the wrong (illogical) sign. For example, sleeping cars are generally used on particularly long routes. It is on these routes that rail is least competitive with air. Thus, the data show that, as the percentage of sleeping cars increases, the proportion of rail use to air use decreases. Therefore, a variable such as percentage of sleeping cars will not be a useful variable for making policy-sensitive forecasts, since its introduction will result in absurd forecasts.

Preliminary calibration efforts showed that, in several cases, variables describing rail terminal characteristics would provide more insight into choice decisions if they were combined into an index of terminal quality. When possible, indexes were evaluated on the basis of logic, contribution to model strength, and ease of forecasting. The most effective index proved to be

$$\text{index 1} = \text{park} + \text{dine} - \text{dist.} \quad (4)$$

where

park = a 0-1-2 variable describing parking conditions at each terminal [described in (2)],
dine = a 0-1 variable describing dining facilities, and
dist. = distance (kilometers) from rail terminal to downtown.

Table 1 summarizes the models. The air versus rail competition models generally had the highest R^2. In both the business and the nonbusiness models, most of the variance was explained by the ratios of air-to-rail time and air-to-rail frequency. Train quality-of-service variables were not important in the business model. We hypothesize that air already holds a very significant competitive edge. For nonbusiness trips, terminal characteristics also appear to be a significant predictor of mode choice, as indicated by the presence of index 1.

The F-statistics suggest that frequency appears to be more significant for business trips, and time for nonbusiness trips. The business and nonbusiness auto-rail competition models were similar. Rail frequency, however, was a strong variable for business trips but did not appear in the nonbusiness model. In contrast, index 1 (terminal quality) was a more significant variable in the nonbusiness model.

The elasticities for relative time are quite large in both models, undoubtedly due to the numerous short-distance interchanges in the corridor. This suggests that a significant increase in rail speeds would greatly increase rail's ability to compete with auto.

The G(x)'s for both business and nonbusiness bus-rail competition models are functions of relative fre-

Table 1. Modal competition share models for rail versus air, auto, and bus.

Model	R^2	G(x)				
Rail versus air						
	0.79	-4.14 - 0.39 (air:rail freq) + 5.33 (air:rail time)				
F		29.74	11.13			
Elasticity		-0.46	-0.61			
	0.80	-4.02 - 0.25 (air:rail freq) + 0.30 (index 1) + 6.46 (air:rail time)				
F		17.77	3.63	23.37		
Elasticity		-0.10	0.69	0.26		
Rail versus auto						
	0.67	-15.27 + 0.008 (rail freq) + 0.235 (index 1) + 1.99 (auto:rail cost) + 7.67 (auto:rail time)				
F		14.41	2.21	9.0	17.23	
Elasticity		0.39	0.40	1.92	4.99	
	0.66	-15.32 + 0.32 (index 1) + 1.60 (auto:rail cost) + 9.56 (auto:rail time)				
F		5.03	7.18	33.77		
Elasticity		0.69	1.78	7.16		
Rail versus bus						
	0.71	-9.21 + 10.54 (food) - 0.23 (bus:rail freq) + 0.45 (bus:rail time)				
F		11.74	46.25	15.27		
Elasticity		0.15	-0.03	0.004		
	0.62	-11.60 + 11.09 (food) - 0.094 (bus:rail freq) + 0.55 (bus:rail time)				
F		8.45	9.94	13.05		
Elasticity		0.67	-0.05	0.02		

quency, travel time differences, and a measure of rail service amenities. This measure of rail amenities is the variable "food service," which is the proportion of trains that have either a snack bar or a dining car. All variables have large F-values, but the R^2-values for both models are moderate. This suggests that the unexplained variance is in large part attributable to a specification error; i.e., some of the factors that influence the mode choice between rail and bus are not included in the model.

Some of these factors that were not included in our study are bus service quality variables, relative proportion of advertising expenditures, and bus terminal characteristics.

PIVOT-POINT

Pivot-point is a procedure for adjusting a forecast so that it does not contain the residual error between the estimated and the actual observation, which is contained in the calibrated model. To illustrate, consider model $Y = a + b(x)$, representing the best-fitting line that can be drawn through the data.

Let (x_o, y_o) be an actual observation used to calibrate the model. Now, $\hat{Y}_o = a + bx_o$ is the estimated value of Y_o. In an actual forecast the pivot-point argument reasons that the best estimate for Y_F is

$$Y_F = (Y_o/Y_o)(a + b_1 x_{1F} + \ldots) \quad (5)$$

Note that the pivot-point line is not parallel to the best-fitting line. Rather than preserve the slope, the method preserves the elasticity of Y with respect to x.

FORECASTS

To determine the future condition of rail service, extensive use was made of the Amtrak 5-year plan, New York's statewide master plan for transportation, and the proposed uses of the funds available form the recent New York State Railroad Bond Issue.

The statewide master plan and the New York State Railroad Bond Issue provide for a gradual improvement in rail service over the next decade. Rail costs (fares) are forecast to increase at a rate of approximately 5 percent per annum, and auto costs are projected using a transportation price index developed by the U.S. Department of Commerce (also projected to grow at about a 5 percent rate).

Generally it is anticipated that there will be a gradual turnover of trains, with Turbotrain and then Amfleet rolling stock being substituted for conventional equipment. Rail frequency is not anticipated to be increased in proportion to ridership increases in the next decade.

Travel times will increase somewhat between 1975 and 1977, chiefly because of slow orders imposed by reconstruction of sections of deteriorating track. After 1977, however, travel times are expected to decrease by 7-15 percent by 1980, with more significant improvements between 1980 and 1985. For example, it is anticipated that the travel time between NYC and Albany will decrease by about 20 min (-10.6 percent) between 1975 and 1980. These improved travel times reflect equipment and track improvements anticipated in the next decade (Table 2).

Forecasts of intercity rail traffic are made by adjusting an initial forecast by the pivot-point and normalization factors. The results of this calculation give city-pair volumes for the future year and are then added to obtain link forecasts. The effect of service improvements on ridership is clearly shown in Table 2 and in Figure 2.

For most links, the lowest rail volume occurred in 1977. The drop ranged from 29 percent for the NYC-Albany link to 2 percent for the Rochester-Buffalo link. By 1978, however, the situation will have improved: rail travel times will have greatly decreased and frequency will have increased or remained the same, but rail costs will be up. The effect of these improvements is to increase rail ridership substantially over 1975 levels, for most links. The trend will then continue in 1979 and 1980.

In terms of energy, the effect of this growth is shown in Table 3. The net effect is to reduce the total 1975 corridor energy requirements by 9 percent in 1980. The bulk of this energy savings comes from a 15 percent reduction in auto energy consumption, as a direct result of auto patronage shifts to rail. The increase in rail energy accounts for only 2 percent of corridor energy, while air and bus account for 31 and 5 percent respectively. Thus, the improvements would generate a ten-to-one energy savings: for every joule added to rail energy, about ten are saved from auto. It is clear that the proposed improvements to rail, which cause only small increases in total rail energy themselves, reap large reductions in total corridor energy consumption. This finding is consistent with most published opinions on modal energy consumption, in that the greatest energy savings can be accrued by those policies or acts that divert auto travel to other modes.

Table 2. 1980 NYC-Buffalo rail corridor percentage of use for 1975.

Link	Service (%) Frequency of Service	Travel Time	Rail Cost	Patronage Forecasts (%)
NYC-Albany	14.3	-10.6	50.0	57.8
Albany-Utica	25.0	-7.8	42.9	79.0
Utica-Syracuse	25.0	-11.8	63.6	84.5
Syracuse-Rochester	33.3	-14.8	40.0	105.6
Rochester-Buffalo	33.3	-9.6	43.8	93.0
Total corridor				66.6

Figure 2. Intrastate link volumes.

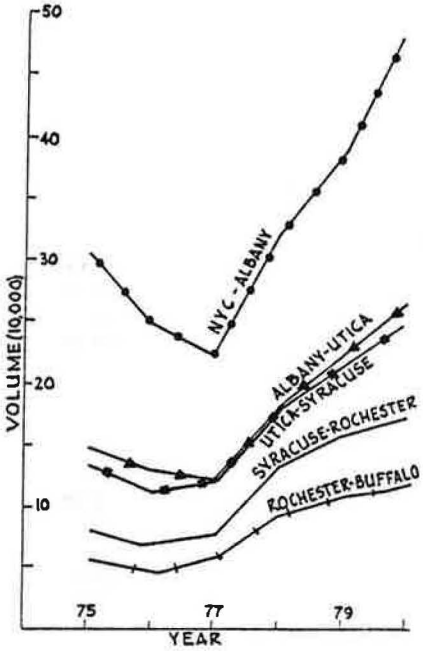

Table 3. Corridor energy consumption.

Mode	1975 Rate (GJ)	1975 Rate (%)	1980 Rate (GJ)	1980 Rate (%)	Difference (GJ)	Change (%)
Air	9 825	24.2	9 831	26.7	2.1	+0.02
Auto	28 948	71.2	24 685	67.1	-4263	-14.73
Bus	1 646	4.1	1 647	4.5	1.0	+0.06
Rail	199	0.5	622	1.7	423	+212.11
Total[a]	40 623	100.0	36 787	100.0	-3836	-9.44

Note: 1 GJ = 9.47 × 10^9.

[a]These totals were converted from BTUs (1 BTU = 1.05 kJ) and are therefore not the actual column totals, which were given in billion BTUs.

CONCLUSION

The analysis shows that planned rail service improvements in the NYC-Buffalo corridor will have a substantial effect on rail patronage in the corridor over the 1977-1980 period. Rail traffic in this corridor is particularly sensitive to relative travel time (rail versus the other three modes), because the generally short-distance interchanges now favor auto use. If improvements in rail travel time are made, diversions will come primarily from auto.

Improvements in the quality and relative frequency and relative cost of rail service will also encourage diversion but will generally have a smaller impact than increase in travel time. As a result, rail patronage is expected to increase substantially, resulting in a 9 percent reduction in the 1975 corridor energy requirements by 1980.

This means that the best policies for improving rail passenger service and increasing energy efficiency are likely to be those that seek to significantly attract diverted patronage through improved travel times.

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