A COMPARATIVE EVALUATION OF INTERCITY MODAL-SPLIT MODELS

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Proposals for improved intercity transportation service, ranging from improved high-speed rail service to short take-off and landing or restricted take-off and landing air service, have been advanced for many intercity corridors in the United States. Transportation planners have been called on to forecast patronage and revenue of new transportation services and the diversion from existing services. Frequently, however, new travel surveys or model development is not possible, and reliance must be placed on existing models and secondary data sources. This paper provides a comparative evaluation of seven intercity modal-split models that have been developed in the last 5 years and recommends models for application in intercity transportation sketch planning analyses. The models discussed are evaluated in terms of their ability to replicate the observed travel patterns and in terms of their implied elasticities for the rail mode. Model CN27 was selected as the best overall model. It is stratified by purpose, which creates a data requirement that cannot always be reliably fulfilled. Thus, unstratified model CN22, second best among those tested, is recommended for use when base year travel data on trip purpose are unavailable.

THE SEVEN intercity modal-split models considered in this paper are all calibrations of the cross-elasticity model (2, 3, 4, 5). This model has the following formulation:

$$S_i = \frac{C_i \prod_j (\chi_{ij})^{\alpha_{ij}}}{\sum_i \left[C_i \prod_j (\chi_{ij})^{\alpha_{ij}} \right]} \tag{1}$$

where

i = index identifying a mode,
j = index identifying a modal attribute,
χ = transportation network variable,
S = variable identifying modal split, and
C_i, α_{ij} = calibrated coefficients.

Equation 1 is calibrated on a base mode (generally automobile). The ratios of the share of each mode i to that of the base mode (mode m) are considered as follows:

$$\frac{S_i}{S_m} = \frac{C_i \prod_j (\chi_{ij})^{\alpha_{ij}}}{C_m \prod_j (\chi_{mj})^{\alpha_{mj}}} \tag{2}$$

In turn, the logarithmic form of Eq. 2 is

$$\mu_i = r_i + \sum_j \alpha_{ij} v_{ij} - \sum_j \alpha_{mj} v_{mj}$$

Table 1. Calibrations of cross-elasticity model.

Model	Description	Remarks
CN22	Abstract mode, 1969	Calibrated early in the NEC Project; rail coefficient was lowered to improve model during NEC work
CN25	Abstract mode, 1969 (6)	Basis for analysis presented in first NECP report (7)
CN26	Abstract mode	
CN27	Stratified, abstract mode, 1971	Used for some analyses in second NECP report (8)
CN28B	Stratified, abstract mode, 1971	Used for some analyses in second NECP report (8)
HSGT	Abstract mode, 1972 (9)	Used in High Speed Ground Transportation Alternatives Study in 1972 (9)
SRI	Abstract mode, 1971 (10, 11)	

Table 2. Parameters for cross-elasticity model calibrations.

Model	Mode	C	a_1	a_2	a_3	k
CN22	Air	1.01	-2.23	-1.11	0.53	0.12
	Rail	1.46	-2.23	-1.11	1.05	0.12
	Bus	0.83	-2.23	-1.11	0.05	0.12
	Automobile	1.0	-2.32	-1.16	0	0
CN25	Air	1.1144	-1.9102	-0.9551	0.3247	0.12
	Rail	1.1144	-1.9102	-0.9551	0.3247	0.12
	Bus	1.1144	-1.9102	-0.9551	0.3247	0.12
	Automobile	1.000	-1.9288	-0.9644	0	0
CN26	Air	1.8978	-1.9135	-0.8555	0.5536	0.007
	Rail	3.8547	-1.9135	-0.8555	0.5536	0.007
	Bus	1.4486	-1.9135	-0.8555	0.5536	0.007
	Automobile	1.0	-1.9135	-0.8555	0	0
CN27						
Business	Air	1.1232	-3.384	-0.483	2.279	0.12
	Rail	1.4813	-3.384	-0.483	2.279	0.12
	Bus	0.3767	-3.384	-0.483	0	0
	Automobile	1.0	-3.384	-0.483	0	0
Nonbusiness	Air	0.7767	-1.5821	-1.5821	2.0462	0.18
	Rail	1.9881	-1.5821	-1.5821	2.0462	0.18
	Bus	1.3872	-1.5821	-1.5821	0	0
	Automobile	1.0	-1.5821	-1.5821	0	0
CN28B						
Business	Air	0.937	-3.384	-0.483	5.587	0.50
	Rail	1.2368	-3.384	-0.483	5.587	0.50
	Bus	0.3767	-3.384	-0.483	0	0
	Automobile	1.0	-3.384	-0.483	0	0
Nonbusiness	Air	1.1163	-1.5821	-1.5821	5.587	0.672
	Rail	1.4710	-1.5821	-1.5821	5.587	0.672
	Bus	0.9324	-1.5821	-1.5821	0	0
	Automobile	1.0	-1.5821	-1.5821	0	0
HSGT	Air	1.90	-1.9135	-0.8555	0.5536	0.007
	Rail	1.90	-1.9135	-0.8555	0.5536	0.007
	Bus	1.135	-1.9135	-0.8555	0	0
	Automobile	1.00	-1.9135	-0.8555	0	0
SRI	Air	1.50	-1.5	-1.5	0.3247	0.12
	Rail	0.75	-1.5	-1.5	0.3247	0.12
	Bus	0.75	-1.5	-1.5	0.3247	0.12
	Automobile	1.00	-1.5	-1.5	0	0

where

$$\mu_i = \log \frac{S_i}{S_m}$$

$$r_i = \log \frac{C_i}{C_m}$$

$$V_{ij} = \log \chi_{ij}$$

Calibrations of the cross-elasticity model considered in this paper are given in Table 1. The specification for these calibrations is as follows:

$$S_i = \frac{w_i}{\sum_i w_i}$$

$$w_i = Ct^{a_1} c^{a_2} f'^{a_3}$$

$$f' = (1 - e^{-kf})$$

where

t = total average one-way door-to-door travel time in hours,
c = total average one-way door-to-door travel price in dollars, and
f = average number of daily one-way departures in one direction.

(The automobile per-person price is 1 cent per mile for CN22, CN25, and nonbusiness trips for CN27 and CN28B. The price is 1.2 cents per mile for CN26 and HSGT and is 2.3 cents per mile for business trips for CN27 and CN28B. The price for SRI is 1.76 cents per mile.)

The calibrated parameters for the models are given in Table 2.

STRUCTURING THE ANALYSIS

Data for city pairs in and outside the Northeast Corridor (NEC) were used to test the modal-split models. Each set of data consisted of annual volumes and measures of service attributes for each of the four modes serving the city pair.

A list of NEC city pairs that were considered best for testing the models was developed. Each potential city pair for which data were available was examined for the reliability of the modal travel volume information and the uniqueness of the impedance measures. City pairs involving Trenton were generally eliminated, for example, because of the lack of a clear-cut air service alternative. A traveler could use relatively poor service at Trenton Airport or drive for more than an hour and use good service at Newark Airport. A test data set consisting of data for 64 city pairs in the NEC was assembled.

Travel volume data for 44 city pairs outside the corridor were assembled from previous surveys (12, 13). Detailed modal travel volumes were available for 22 city pairs, whereas reliable secondary source travel volume data existed for the other 22.

The following criteria were used to evaluate the models:

1. Total number of trips by mode,
2. Root mean square error (RMSE) between the observed and the estimated modal trips,
3. Correlation between observed and estimated modal trips,
4. Slope of a linear regression fitted between the estimated modal trips (dependent variable) and the observed modal trips (independent variable), and
5. Intercept of the linear regression.

EVALUATION OF MODELS WITH NEC DATA

A comparison of the models with respect to the NEC data is given in Table 3. A comparison of the overall accuracy of the models suggests that, with some notable exceptions, all of the models exhibit similar error tendencies. Each of the models underestimates the total number of automobile trips. Bus travel is overestimated and air travel is underestimated by all models except CN25. Five of the models overestimate and three underestimate rail travel. The correlation between observed and estimated trips by automobile and air is above 0.9 for all models, and the correlation between observed and estimated rail travel is approximately 0.9 for all models, whereas the correlation for bus travel is generally lower than 0.9. This result and the fact that the ratio of RMSE to aggregate trips is high for rail and bus travel for all models indicate that the models generally estimate bus and rail travel more poorly than they estimate automobile and air travel.

Each model produces a positive value for the intercept of the linear regression [estimated = f (observed)] for all modes, which indicates that the models tend to overestimate modal travel for low-volume modal trip interchanges. The slopes of the linear regressions are less than one for automobile and air travel, the two largest segments of the intercity travel market, for all models. This suggests that the models tend to compensate for the overestimation at low volumes by underestimating automobile and air travel at higher volumes. In general, the variation in observed versus estimated modal volumes is sufficiently high to invalidate any conclusions drawn strictly on the basis of the regression parameters.

Table 4 gives a ranking of the models according to their ability to replicate modal totals (1 is best; 7 is worst). The models perform relatively unevenly among modes. CN28B ranks first for automobile, bus, and rail trip totals but last for air travel. CN27 is best for air travel but fourth for the other modes. CN22 and CN27 are the most consistent, for they are the only models that rank among the top four for all modes.

A comparison of the weighted average RMSE (weighted by observed modal split) and the RMSE for each mode estimated by each model is given in Table 5. The average ranking of all models is almost identical to the ranking for automobile travel because the automobile captures approximately 70 percent of the travel market in the test data set and the values of RMSE are higher for the automobile than for the other modes. CN27, a stratified model calibrated with the most recent data prior to the effort undertaken for this project, is ranked first overall. CN22, ranked third overall, is the most consistent for the four modes.

EVALUATION OF MODELS WITH NON-NEC DATA

The modal-split models were applied to the data for the 44 city pairs outside the Northeast Corridor, and the modal estimates were compared to observed travel volumes. The results are given in Table 6. In general, model performance was similar to that obtained by using the NEC data. Total automobile travel was underestimated by all models, and common carrier travel was overestimated in all but two cases.

The models may be ranked in order of prediction accuracy for modal trips (Table 7). The HSGT model is most accurate for rail, least accurate for bus, sixth for automobile, and second for air. This characteristic of the HSGT model is not unexpected, for it is an adjusted version of CN26 used for forecasting travel patronage for candidate high-speed ground transportation systems outside the NEC; the rail forecasting accuracy of the HSGT model is consistent with its principal application. Models CN22 and CN27 are relatively consistent.

The rank of each model on the basis of the RMSE measure for each mode is given in Table 8. Model CN22 is best overall. Model CN27 provides the least amount of variability between observed and estimated rail volumes and is ranked third for both automobile and bus; it ranks a relatively poor sixth, however, for air travel. As was the case for the test using NEC data, CN22 is the most consistent model among the modes, ranking in the top four for all modes.

Table 3. Summary statistics for model comparison using NEC data.

Mode	Statistic	Observed	CN22	CN25	CN26	CN27	CN28B	HGST	SRI
Automobile	Trips[a]	40.79	39.08	36.85	36.32	38.50	39.20	36.99	38.53
	RMSE[b]		178.0	215.6	213.9	175.7	176.7	218.0	194.4
	r		0.98	0.97	0.98	0.98	0.98	0.98	0.98
	Slope		0.92	0.86	0.83	0.89	0.91	0.85	0.90
	Intept[b]		27.2	28.1	39.4	36.6	34.2	36.6	31.5
Bus	Trips[a]	3.28	5.04	7.19	4.77	5.16	3.83	9.62	7.56
	RMSE[b]		70.4	125.6	83.8	72.7	51.8	185.1	136.9
	r		0.82	0.80	0.77	0.81	0.80	0.79	0.82
	Slope		1.21	1.74	1.27	1.22	0.93	2.22	1.92
	Intept[b]		17.0	22.9	9.4	18.1	12.3	36.7	19.8
Air	Trips[a]	6.18	5.77	6.48	5.60	5.99	7.08	5.53	5.95
	RMSE[b]		75.7	88.1	69.4	56.4	81.1	70.5	93.0
	r		0.96	0.91	0.97	0.97	0.91	0.97	0.92
	Slope		0.66	0.63	0.68	0.78	0.76	0.68	0.59
	Intept[b]		26.7	39.9	21.3	18.6	37.7	20.5	36.2
Rail	Trips[a]	8.15	8.52	7.89	11.71	8.74	8.29	6.27	6.36
	RMSE[b]		157.5	183.2	178.9	144.2	160.8	193.9	202.2
	r		0.91	0.90	0.88	0.92	0.91	0.89	0.92
	Slope		0.65	0.54	0.85	0.72	0.62	0.50	0.45
	Intept[b]		50.6	54.8	75.3	44.8	50.0	33.8	41.7

[a] Millions of annual trips. [b] Thousands of annual trips.

Table 4. Ranking of models according to their ability to replicate modal totals (NEC data).

Model	Automobile	Bus	Air	Rail
CN22	2	3	4	3
CN25	6	5	3	2
CN26	7	2	5	7
CN27	4	4	1	4
CN28B	1	1	7	1
HSGT	5	7	6	6
SRI	3	6	2	5

Table 5. Ranking by root mean square error between observed and estimated trips (NEC data).

Model	Automobile	Bus	Air	Rail	Average
CN22	3	2	4	2	3
CN25	7	5	6	5	6
CN26	5	4	2	4	5
CN27	1	3	1	1	1
CN28B	2	1	5	3	2
HSGT	6	7	3	6	7
SRI	4	6	7	7	4

Table 6. Summary statistics for model comparisons using non-NEC data.

Mode	Statistic	Observed	CN22	CN25	CN26	CN27	CN28B	HSGT	SRI	PML
Automobile	Trips[a]	35.76	33.59	30.96	33.97	33.83	33.51	31.06	32.83	26.30
	RMSE[b]		133.2	234.1	137.8	137.8	152.5	242.7	181.0	569.8
	r		0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98
	Slope		0.94	0.86	0.92	0.92	0.91	0.85	0.90	0.61
	Intept[b]		1.8	3.2	23.1	22.7	23.5	12.9	15.1	104.0
Bus	Trips[a]	1.31	2.72	3.85	1.69	2.69	1.95	5.78	3.26	10.57
	RMSE[b]		82.4	124.5	44.0	82.1	57.6	197.6	103.0	437.0
	r		0.63	0.70	0.74	0.62	0.63	0.69	0.69	0.72
	Slope		1.26	2.01	0.99	1.21	0.93	2.83	1.71	6.21
	Intept[b]		24.2	27.6	8.8	24.9	16.7	47.2	23.3	55.3
Air	Trips[a]	2.36	2.88	3.32	2.72	3.10	3.70	2.43	2.39	1.71
	RMSE[b]		56.7	71.6	62.3	87.1	97.5	64.0	65.1	122.8
	r		0.86	0.78	0.82	0.77	0.75	0.80	0.81	0.19
	Slope		0.73	0.70	0.71	0.94	0.98	0.61	0.54	0.14
	Intept[b]		26.4	37.8	23.8	19.8	31.7	22.3	25.6	31.1
Rail	Trips[a]	0.58	0.82	1.88	1.64	0.39	0.84	0.73	1.53	1.44
	RMSE[b]		24.7	69.0	60.1	16.9	38.0	19.7	52.9	76.4
	r		0.83	0.80	0.82	0.86	0.88	0.84	0.74	0.86
	Slope		1.13	2.15	2.03	0.68	1.71	0.94	1.57	2.68
	Intept[b]		3.8	14.4	10.5	-0.1	-3.4	4.3	14.0	-2.6

[a] Millions of annual trips. [b] Thousands of annual trips.

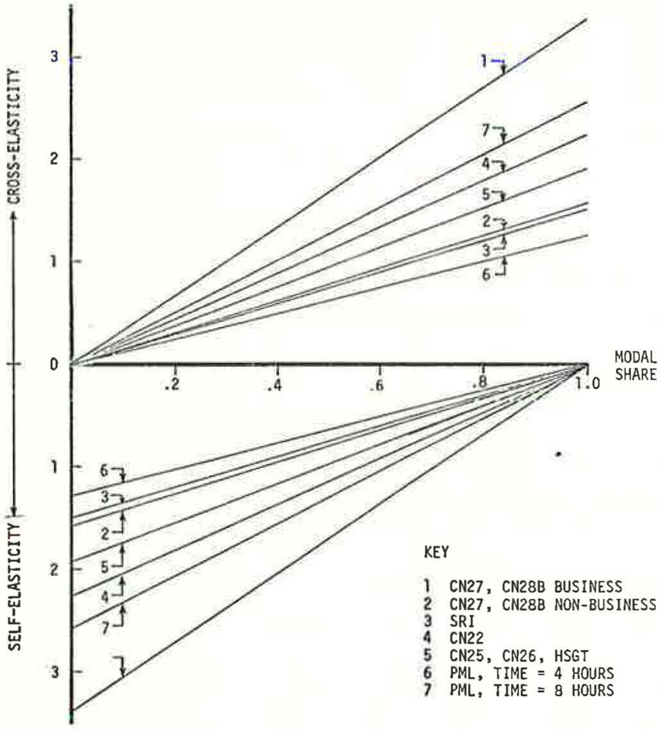
Table 7. Ranking of models according to their ability to replicate modal totals (non-NEC data).

Model	Automobile	Bus	Air	Rail
CN22	3	4	4	3
CN25	7	6	6	7
CN26	1	1	3	6
CN27	2	3	5	2
CN28B	4	2	7	4
HSGT	6	7	2	1
SRI	5	5	1	5

Table 8. Ranking by root mean square error between observed and estimated trips (non-NEC data).

Model	Automobile	Bus	Air	Rail	Average
CN22	1	4	1	3	1
CN25	6	6	2	6	6
CN26	2	1	2	3	2
CN27	3	3	6	1	3
CN28B	4	2	7	4	4
HSGT	7	7	3	2	7
SRI	5	5	4	5	5

Figure 1. Elasticity with respect to rail time.



ELASTICITIES OF THE MODELS

The rate of change in modal share with respect to each variable can be measured by the elasticity of modal share. The elasticity of modal share is defined as the percentage change in modal share resulting from a percentage change in a given modal attribute and is specified mathematically as follows:

$$E_{ij} = \frac{dS_i}{S_i} \Big/ \frac{d\chi_j}{\chi_j}$$

where

S_i = share for mode i,
χ_j = modal attribute χ for mode j, and
E_{ij} = elasticity of mode i with respect to modal attribute χ_j.

Self-elasticity connotes the change in a mode's share resulting from a change in its own attributes, and cross-elasticity is the change resulting from a change in another mode's attributes.

The values of rail elasticity with respect to travel time are shown in Figure 1 for each of the models. Cross-elasticity (nonrail mode elasticity) values are plotted as positive, and self-elasticity values are negative. The values are plotted as a function of modal share. The most sensitive models for travel time are the business purpose portions of models CN28B and CN27. The most time-sensitive unstratified model is CN22; CN26, HSGT, and CN25 are approximately equal, and the nonbusiness portions of CN27 and CN28B are relatively less sensitive and approximately equal to the SRI model. If the elasticities for each mode are algebraically added for any given set of modal-split fractions (adding up to 1.0), the result will be zero because the total demand does not change.

Figure 2 shows the relationship between price elasticity and modal share. The most price-sensitive models are the nonbusiness portions of the two stratified models, CN27 and CN28B, followed by SRI, CN22, CN25, CN26, HSGT, and finally the business portions of CN27 and CN28B.

The elasticity of rail's modal share with respect to the frequency of rail service is shown in Figure 3. For both the business and nonbusiness segments of the stratified models, modal share is very sensitive to frequency for low values of frequency. The elasticity for the business portions of the stratified models remains above the nonbusiness portions for the entire range of frequency values. The difference between CN27 and CN28B is that the CN27 elasticity does not drop so quickly with increased frequency. The CN26 and HSGT elasticities remain virtually constant throughout the range of frequency values, which suggests that a percentage change in frequency at any level has virtually the same impact on ridership. This assumption can be challenged on an intuitive basis. The CN25 and SRI models show a descending elasticity with increased frequency, as does the CN22 model. CN22 is roughly twice as elastic to frequency as CN25 and SRI.

For forecasting purposes, a model that is "well-behaved" with respect to frequency elasticity in the expected range of variation is desirable. It appears from the accuracy testing that those models with low frequency elasticity throughout the range of frequency values (CN25, SRI), elasticities that precipitously drop to low values as frequency increases (CN28B), or relatively constant frequency elasticity (CN26) do not validate so well as the more gradual, decaying frequency elasticity functions of CN27 and CN22.

MODEL SELECTION

In general, model CN27 performs better than the other models based on the NEC data and the RMSE rankings. This model ranks first for modal accuracy for all modes except bus, for which it ranks third. Also, models CN22, CN28B, and CN26 are second in overall accuracy. Choosing among these models for second, third, and fourth position depends on the importance placed on the accuracy for each mode. An average accuracy weighted according to the volume of travel on each mode places CN26

Figure 2. Elasticity with respect to rail price.

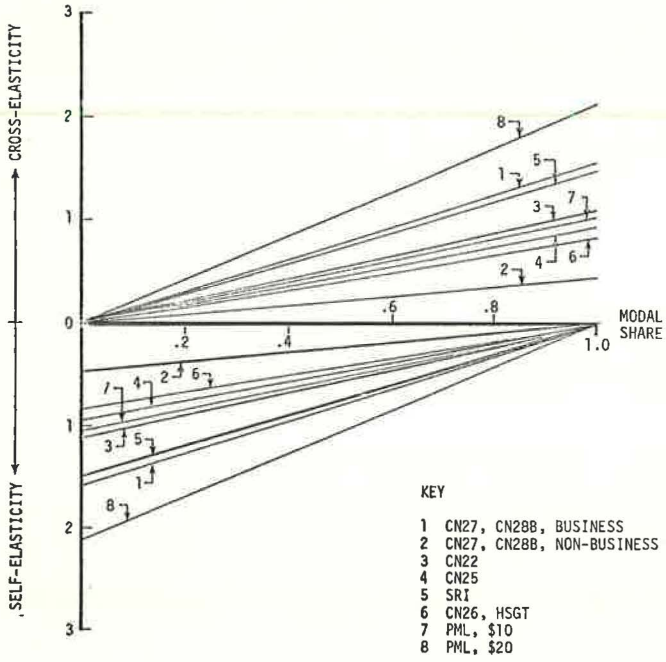
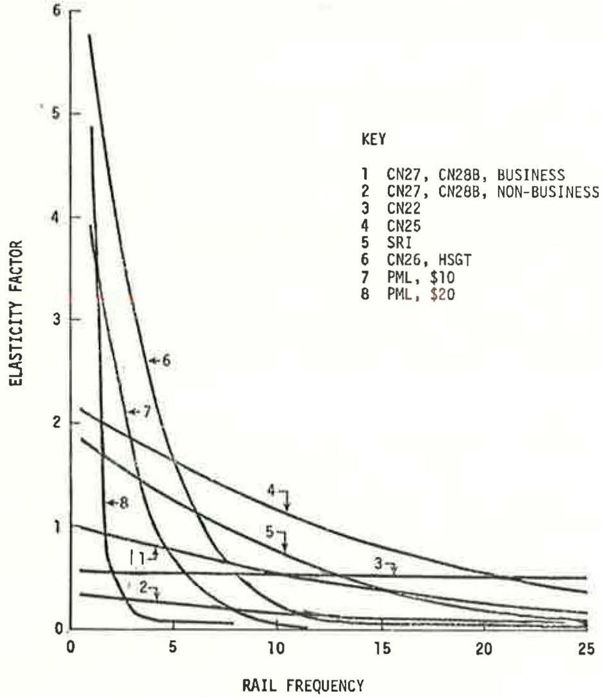


Figure 3. Elasticity of rail share with respect to rail frequency.



ELASTICITY = (ELASTICITY FACTOR) (1-RAIL SHARE) second, CN28B third, and CN22 fourth. If an equal weight is placed on accuracy for each mode, however, this ranking is reversed: CN22 second, CN28B third, and CN26 fourth. The second rank of CN22 on this basis reflects its tendency to perform uniformly across all modes as opposed to the more uneven performance of CN26 and CN28B. Model CN22 also performs better than CN26 or CN28B for rail travel, which reinforces its position as the best of the second group of models for use in rail-oriented intercity planning work.

Based on the implications of the model coefficients in terms of sensitivity, the time and price elasticity equations for CN27 appear to capture a basic behavioral difference between business and nonbusiness travelers. Business travelers value time much higher than nonbusiness travelers and are relatively cost-insensitive; nonbusiness travelers are most cost-sensitive and are less willing to trade time for cost. The time and price elasticities of model CN22 fall between the corresponding elasticity values of the stratified models, as would be expected. It is interesting to note that the better models, CN27 and CN22, have a more moderate elasticity change with respect to frequency as opposed to the precipitous changes, low values, or constant elasticities demonstrated by the other models.

Choosing between the best two models, CN27 and CN22, for forecasting, requires that the different input requirements be understood. CN27 is stratified and therefore requires that a business-nonbusiness purpose split be available for input. These types of base year data are not available for many city pairs outside the NEC, which precludes forecasting purpose split. Given this constraint, model CN22 appears to be the best choice among the models compared for testing transportation improvements in intercity corridors for which data stratified by trip purpose are not available. If such data were available for a given intercity corridor, model CN27 would be the most appropriate for intercity transportation planning.

MODEL APPLICATION

Each of these models has been calibrated with data for several city pairs, and the parameter values of the models therefore reflect the aggregate travel behavior for the calibration set of city pairs. The models are normally applied to each city pair individually, and significant variation between model estimates and actual behavior will normally occur if the model is examined at the city pair level. Even though the models exhibit variability by city pair, they are quite useful in examining the relative changes in modal patronage, given changes in the travel time, travel cost, and frequency of any of the competing modes. For example, a given model may predict 3,000 rail trips per day for a particular city pair when the actual rail travel is 3,600 trips per day. If the model were applied to a set of transportation alternatives including high-speed rail service and the ridership prediction were 4,500 trips per day, this could be viewed as a 50 percent change in ridership.

A pivot point technique is recommended for application of the modal-split model to correct for city pair variability and sensitivity errors. Use of this technique requires that base year data on the travel volumes by mode (further stratified by trip purpose if the model is stratified) be available.

A DIRECTION FOR FURTHER RESEARCH

Calibration of all of the models considered in this analysis was based on an aggregate rather than a disaggregate approach. For this reason, they are not adequately sensitive to certain important variables: income of the traveler, size of the travel party, and variations in access-egress impedances for individual travelers within metropolitan areas. Previous research (14) indicated that these variables are of importance in understanding the intercity travel market and forecasting intercity travel. Effective consideration of these variables requires that a disaggregate calibration technique be used; otherwise, the data requirements would become overwhelming. Further, none of the intercity modal-split models developed to date for the Northeast Corridor distinguishes two rail modes—Metroliner and conventional rail—in spite of the fact that these two rail services have significantly different travel times, costs, and frequencies. Such a distinction between Metroliner and conventional trains would appear important if a new disaggregate modal-split model were developed.

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