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Home-Origin Transit Travel Analysis Model

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The major findings of a bus patronage forecasting project to develop a simple short-range planning model for bus transit demand analysis in Albuquerque, New Mexico, are presented. The model would be typically applied by an analyst lacking specialized mathematical expertise by using commonly available data to analyze the ridership impacts of proposed transit service changes. Analysis of the information needs of Albuquerque officials and of the ridership patterns of Albuquerque SunTran users revealed that a focus on residential service requirements should have the highest analytic priority. In response to this need, a linear home-origin transit generation model was developed that could be manually applied to predict ridership response to service changes. The model is sensitive to a wide range of service, policy, socioeconomic, and land use factors. Validation studies on the model indicate that the model predictions are quite accurate. The technique should be transferable to other urban areas, especially rapidly growing multicentered sunbelt cities lacking the radial structure and dominant core of older American cities.

Findings of a project conducted for the Middle Rio Grande Council of Governments (MRGCOG) in Albuquerque, New Mexico, to develop a simple short-range planning model for bus transit demand analysis are presented. The project team developed a linear home-origin transit generation model that could be manually applied by using a hand calculator to predict ridership response to changes in the service and in socioeconomic and land use factors known to affect transit demand.

Specific project objectives for the development of the simple forecasting procedure included emphasis on

1. Policy relevance,
2. Use of available data,
3. Simplicity,
4. Transferability, and
5. Accuracy.

The final model and application procedure satisfactorily meet each of these project objectives. The following discussion of the Albuquerque setting provides perspective on some eccentricities in the model approach.

Albuquerque, New Mexico, is a rapidly growing sunbelt city with a generally mild, but arid, climate. Albuquerque population in 1940 was approximately 35,000. By 1980 the city population had grown to more than 400,000. Like many sunbelt cities developed in the postwar automobile age, there is no single dominant activity core to Albuquerque. Since the late 1950s, virtually all retail activity has migrated from the downtown central business district (CBD) to the uptown malls in the heart of Albuquerque's Northeast Heights (Figure 1). CBD activity is currently limited to government offices and some corporate headquarters. The largest daytime concentrations of population are found at the University of New Mexico (UNM), several miles east of the CBD. The city's largest employment center is the Kirtland Air Force Base (KAFB), located on the southeastern edge of the city.

Public transit service in Albuquerque is provided by the city's SunTran system. SunTran operates 20 regular routes and 5 morning and evening "trippers" to KAFB. The SunTran fleet consists of buses; the peak-period requirement is 72 vehicles.

The SunTran system configuration conforms to the grid system of streets and multicentered activity pattern it is designed to serve. The service policy governing system design was a full-coverage model to minimize the number of areas in the city that are not within walking distance of transit. The system, although not a pure grid due to the existence of outlying routes with radial characteristics, is certainly a grid-and-radial hybrid. Buses serve virtually every major street on 0.5-hr headways. Because of the grid configuration, many bus routes do not directly serve any major trip attractors; transfers are required to reach major destinations. [A 1981 survey of SunTran passengers revealed that almost one-quarter of all trips (23.6 percent) made on the system require one or more transfers.] A flat fare of 50 cents is charged for adult patrons. Up to two transfers are free. However, because of the system configuration, it is possible to go almost anywhere from almost anywhere in the city for 50 cents with no more than two transfers and a 10- to 15-min walk at each end.

SOURCES OF DATA

Most formal travel demand models are based on a simple conceptual model of travel behavior: The travel decisions of individuals are based on the characteristics of the travelers and their travel alternatives.

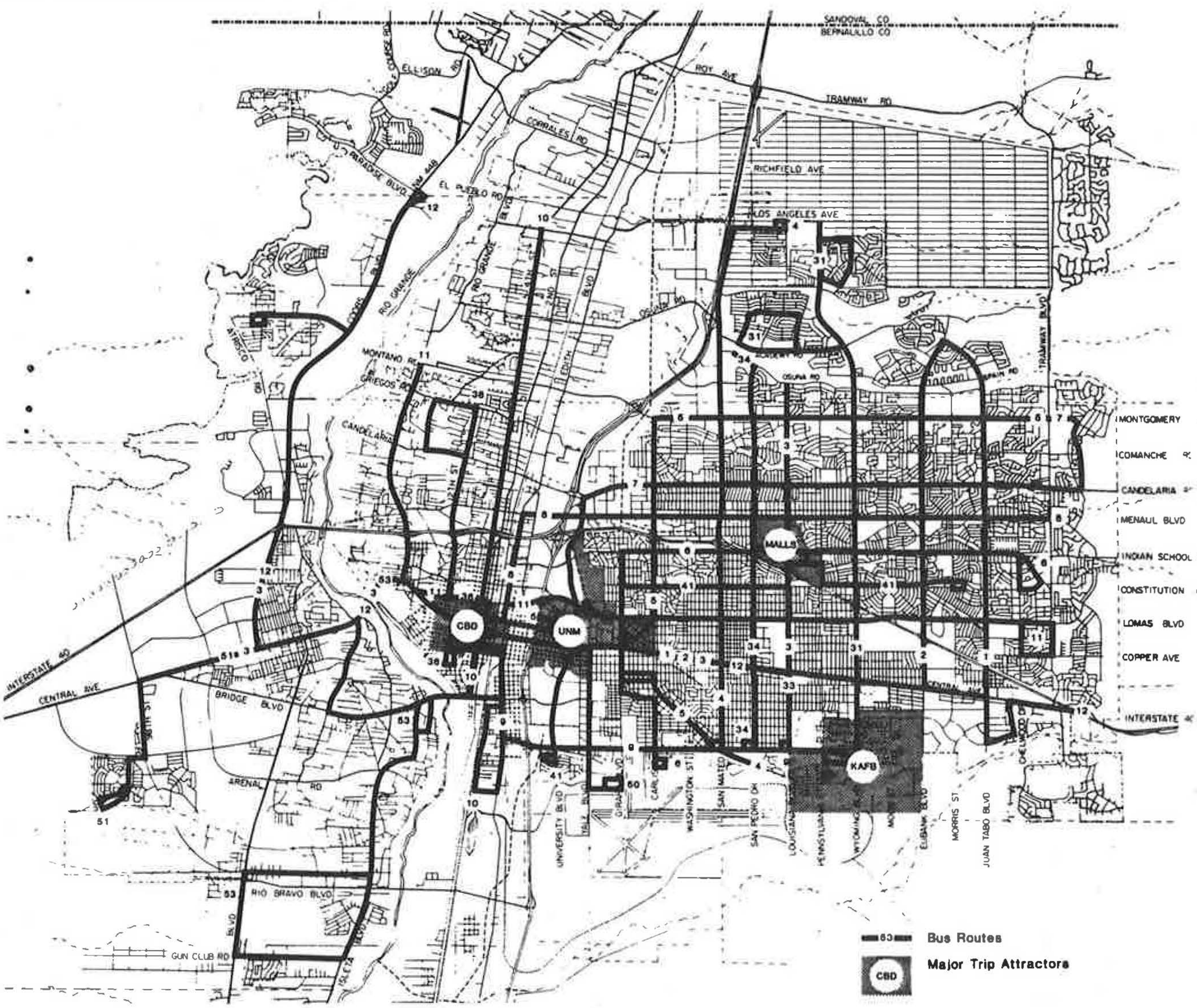
$$T_{ij} = f(SES_i, LOS_j) \tag{1}$$

where

- T_{ij} = trips by individuals of class i by using alternative j,
- SES_i = socioeconomic characteristics of individuals in class i, and
- LOS_j = level of service offered by alternative j.

Consequently, three general types of data are required to develop formal mathematical models of travel behavior: travel, socioeconomic and land use, and level of service.

Figure 1. Albuquerque SunTran system: major destination areas.



Travel Data

The best available travel data were the 1981 on-board survey and ridership counts. From these data the project team developed accurate estimates of the geographic and temporal distribution of travel by trip purpose. Responses to the survey represented nearly 25 percent of total boardings and a substantially higher proportion of total linked trips (due to the high frequency of transfers). The project team expanded the survey results to represent a balanced profile of all riders by using ridership counts as control totals. No systematic comparable data were available about the extent or ridership characteristics of nontransit travel. This limited the modeling approaches that could be used; e.g., probabilistic choice models would have been impossible.

Socioeconomic and Land Use Data

A wide variety of data on population characteristics and land use was available from MRGCOG. These data are obtained and updated from a variety of sources, including U.S. Census reports, building permits, school enrollments, motor vehicle registrations, and aerial photographs. The unit of analysis for the socioeconomic data is the data-analysis subzone (DASZ). The Albuquerque urban area is divided into 419 DASZs ranging in area from less than 5 acres to more than 11 miles^2 in the outlying, less-developed areas. Each DASZ is generally an aggregation of several census blocks.

Level-of-Service Data

Level-of-service (LOS) considerations known to affect transit demand include in-vehicle travel time (IVTT), headways, walk time, accessibility, transfers, fares, schedule adherence, speed, and comfort and convenience. The policy relevance and analytic utility of a transit-forecasting model depend in large part on the number of factors explicitly reflected in the model specification. Therefore, a primary objective was to include as many service policy variables in the model as possible. However, the number of LOS components that could be considered was limited for several reasons.

First, in order to investigate statistical relationships between two variables, both must vary.

For some factors, such as fare, there was no variation corresponding to variations in ridership.

Second, there is the problem of multicollinearity. When there is high intercorrelation among independent variables in a cross-sectional forecasting model, the condition is known as multicollinearity. Some LOS factors, such as IVTT and walk time, are often highly intercorrelated. The impact of multicollinearity on model results is to confuse the true independent relationships between the correlated explanatory variables and the dependent variable. Parameter estimates for collinear variables will be biased, inefficient, and difficult to interpret. [For more information on multicollinearity, see Statistics for Economists (1, pp. 294-297).]

One suggested treatment for the condition of multicollinearity is to construct a composite explanatory variable from the intercorrelated variables to yield a single measure of the independent effects of the collinear variables. For this project, construction of composite variables was used with considerable success.

A third consideration limiting the number of LOS factors that could be included in the model was data availability. The only available service data were contained in the SunTran schedules and route map, from which the study team developed measures of IVTT, headways, required transfers, and overall accessibility of transit. However, no systematic data were available on walk times, comfort and convenience, or schedule adherence.

METHODOLOGY

The methodological approach to the modeling project was constrained, or jointly determined, by the considerations of the project objectives (especially easy application and high policy relevance), the project setting (multicentered hybrid grid-radial transit system), and the available data. This section briefly describes the methodology developed in response to these influences.

The selected model approach was a home-origin trip generation model that could be manually applied by using work sheets and a hand-held calculator to forecast ridership changes in response to changes in service, land use, or population. The model uses the DASZ as the unit of analysis. Fortunately, DASZ populations tend to be small and relatively homogeneous. (Fewer than 15 percent of all DASZ resident populations exceed 2,000 individuals.) This helps reduce the problem of aggregation error in the use of zonal data.

Circumstances influencing the selection of an aggregate model approach included the accuracy and currency of the DASZ data; the practice of regularly updating DASZ data; the unavailability of systematic data on nontransit users, required for individual-choice models; the unavailability of adequate survey data on frequency of transit use, required for individual trip-frequency models; and the easy application characteristics of aggregate models.

The selection of a zonal trip-generation approach was necessitated by the grid configuration of SunTran service, in which the possibility that users will substitute one route for another in reaction to service changes is much more salient than with radial configurations. Our approach to this problem is separate transit trip-generation and route-assignment procedures rather than a single route patronage forecasting model. The trip-generation model predicts transit ridership rates for DASZs as a function of all transit service offered to that area. The trips can then be apportioned by a route-assignment procedure that considers the relative service attributes of the routes. The advantage of a zonal trip-generation approach over a route-forecasting approach is that a direct route-forecasting model cannot handle the problem of users' substitutions of transit services as a response to changes in level of service. If a route is dropped, all ridership on the route is presumed lost with an ordinary route and zone trip analysis model. With a trip-generation model, all ridership is not lost; some users simply patronize the other route, which offers a lower level of service to their particular destination.

Because Albuquerque has no single dominant activity center, the project team developed and used multiple LOS measures reflecting service to the variety of trip attractors. However, simply representing the multiple service measures to each destination separately, such as IVTT to each of four major destinations, is seldom possible due to multicollinearity. Instead composite variables were constructed to measure the joint impacts of IVTT, wait times, and transfers to major destinations. The major destinations most salient in analyzing Albuquerque transit demand were identified through analysis of the 1981 on-board survey and consultations with local officials. These destinations were described earlier in this paper (see Figure 1). The composite measures were constructed by taking the weighted average of each LOS measure (IVTT, wait time, and so on) to each destination for each DASZ. The composite weights were derived from the estimated total daytime population of each major destination area.

The two principal advantages of the composite LOS variable approach are, first, that it allows explicit consideration of level of service to multiple destinations without the complication of multicollinearity and, second, that it helps introduce greater variability into some LOS measures with relative low variance (e.g., wait times and transfers), thereby increasing the potential of detecting a statistically verifiable relationship (2).

MODEL DEVELOPMENT PROCESS

The dependent variable for the home-origin transit travel analysis model was home-origin transit trips per 1,000 DASZ residents, calculated by using the expanded on-board survey data. Model development was an exploratory process guided by general urban travel demand theory and the findings of previous researchers. Model calibration used an ordinary least-squares approach with the standard SPSS multiple-regression computer package.

The calibration data set consisted of 298 residential zones with accurate socioeconomic data; 102 zones with fewer than 25 households were eliminated from the calibration data set because of their generally nonresidential character and because trip rates and socioeconomic and land use measures are more influenced by sampling error when one is working with smaller populations. Nineteen other zones were eliminated because of their institutional character or unavailability of accurate socioeconomic data.

LOS Findings

In analyzing the level of service, a wide variety of variables was tested in alternative empirical specifications. Three principal criteria guided the valuation of alternative specifications:

1. Magnitude and sign of model coefficients: Conformance with a priori theory and research results was important.
2. Significance and stability of model coefficients: Estimated model parameters should be signif-

icantly different from zero. Parameter estimates should not change dramatically with the insertion or deletion of an unrelated variable.

3. Explanatory power of model: The best model explains the most variance in home-origin trip rates subject to constraints imposed by criteria 1 and 2.

Two graphic devices also provided guidance in the model-development process. First, bivariate scatterplots showing the relationship between independent variables and the home-origin trip rate were analyzed for insights concerning alternative variable specifications. Second, geographic plots of residuals by DASZ showed where the model fit worst and best. Residuals analysis suggested useful additions of both LOS and socioeconomic (SES) variables. In some instances, the residuals analysis indicated coding errors in the variables that, when corrected, helped improve the model's overall fit. Coding errors in the assignment of home-origin trips to DASZs were particularly critical.

After testing dozens of alternative variable combinations, transformations, and specifications, we determined that the most satisfactory LOS model was the simple linear combination of five LOS variables. Each variable is described below:

1. IVTTC: Composite in-vehicle travel time by transit to major destination areas based on SunTran system schedules (an excess travel-time penalty of 10 min was added for outlying zones more than 0.5 mile from the nearest bus route; 20 min was added for zones more than 2 miles out);
2. WAITC: Composite transit wait time based on one-half the peak-period headway on the minimum-path route to each major destination (a penalty of 10 min was added for each zone not contiguous to a transit route but within 0.5 mile);
3. TRNUMC: Composite number of transfers required to reach major destinations along the minimum transit path to each destination;
4. NUMRT: Number of transit routes serving the zone based on inspection of SunTran system map; and
5. EXTERNAL: A dummy variable assigned to zones at the end of each major regional transportation corridor to control for the coders' assignment of transit trips originating outside the study area and boarding at the route end point as originating in that zone.

Each parameter estimate had the theoretically correct sign and magnitude. All were statistically significant at the 0.05 level of confidence. [For more detail, see report by Nelson and O'Neil (2).]

SES and Land Use Findings

We systematically searched the SES data available from MRGCOG for significant correlations with the home-origin trip rate by using the same evaluation criteria and graphic data-analysis techniques developed for the LOS model component. SES factors affecting home-origin transit use were categorized into seven classes, described in the following discussion.

Density

More densely settled areas would be expected to provide a more hospitable environment for transit use because walk times would be reduced for many inhabitants. Therefore, several measures of zonal density were developed and tested. Inspection of the modeling data set's correlation matrix indicated multicollinearity problems between the more traditional density measures (e.g., population or households per square mile) and LOS measures. Consequently, a less traditional density measure, the percentage of single-family homes (PCTSF), was used. In bivariate analyses and multivariate model specifications, PCTSF had a significant negative relationship with the home-based trip rate and was included in the final model specification as a density measure and a surrogate variable for wealth.

Land Use

We hypothesized that the character of adjacent nonresidential activity in a neighborhood could have a significant impact on residential transit ridership. For instance, note that more thickly settled mixed-use areas with higher concentrations of population-serving (commercial, retail, and so on) activity tend to be more conducive to transit use. This may be due to a variety of influences and interactions, including the more pedestrian scale of such areas, the tendency of transit captives to locate where more population-serving activity is within walking distance, a possible ameliorative effect of store-front activity and visual stimuli in reducing the tedium of walking to and waiting for the bus, and finally a possible synergism between successful urban transportation nodes and population-serving activities (e.g., the corner convenience store is aided by the bus stop and the bus stop is aided by the store). Consequently, a measure of population-serving business activity was tested in the model development process. The measure, COMMERCE, was the density of population-serving jobs on a square-mile basis. Population-serving jobs were defined as any employment with a standard industrial classification (SIC) code of Retail and Wholesale; Service; or Finance, Insurance, and Real Estate. In all tests the density of population-serving activities was positively related to residential transit use.

Prototypical land use types that are not popularly associated with high residential transit use are industrial areas and outlying rural areas. Neither of these sorts of neighborhoods is at a pedestrian scale. Automobile ownership is required in such areas to meet the requirements of daily living. Observed ridership from industrial areas was consistently lower than predicted, which led to the development of a hypothesis of industrial land use and residential transit use correlative to the population-serving postulate. The study team determined that the ratio of industrial jobs (SIC code names: Manufacturing, Transportation, Communications and Utilities, and Construction and Contracting) to households best conveyed the notion of industrial intensity. This variable was called INDUSTHH. (Measures such as industrial jobs per acre would be inadequate because most industrial activity is rather land intensive.) Tests of INDUSTHH revealed a consistently strong negative relationship with the home-origin trip rate.

Labor-Force Participation

The analysts had mixed expectations concerning the relationship between labor-force participation and residential transit use. On the one hand, as employment increases, so would transit travel; there would be a general rise in travel and greater competition for household automobiles. It could also be argued that where larger proportions of the population hold jobs, incomes would be lower, which would lead to greater transit use. Child-care responsibilities could also be less common, which would lead to increased travel. On the other hand, it could be argued that increased labor-force participation would increase individual incomes, which would increase automobile ownership and decrease transit ridership.

Empirical evidence from Albuquerque suggests that increases in labor-force participation generally have a positive effect on transit ridership. In the final model specification, the selected labor-force participation measure is the percentage of persons over age 18 estimated to be employed (PCTEMP). This particular denominator was selected due to its good fit in the model and its accurate portrayal of the population at risk.

Dependent Population

It could be argued that the relationship among children, population, and residential transit use also shows mixed effects. On the one hand, as household size increases and there are more babies, children, and dependents, the chores of child rearing may reduce the household's mobility, which lowers overall travel. Also, as family size increases, the home economics of urban travel tend to favor automobile use, because the marginal cost of an additional private automobile passenger is often negligible for family-sized groups but substantially higher for bus travel. On the other hand, as household size increases, overall transit use could rise, because there would be more transit-captive adolescents on the SunTran system. Similarly, because family size would prevent purchase of a second family car, the bus would tend to serve this function.

The empirical results from Albuquerque support the former arguments that as the dependent population and average household size increase, transit ridership decreases. Several measures of the dependent population were developed from U.S. Census and Albuquerque Public School data, including a general measure of household size. Each of these measures of dependent population tended to be inversely correlated with the home-origin trip rate. The simple average household size measure (HHSIZE) was included in the final model specification due to its ease of calculation and generally intuitive appeal.

Elderly Population

Based on other experience, one would expect transit ridership to be positively correlated with the size of the elderly ridership base. Older retired individuals are often transit captives. In Albuquerque and elsewhere in the southwestern sunbelt, this conventional wisdom may not necessarily be true. As retirees have flocked to New Mexico over the last decade, the elderly population in Albuquerque has been growing 20 percent more rapidly than the population as a whole. These older individuals may be more affluent or less mobile than the average Albuquerquean, because no data in this study clearly indicated that the elderly are more or less likely to use transit than the average person.

Income or Wealth

Traditional wisdom in the transit planning field holds that income and wealth are generally inversely related to bus transit use. Bus transit is an inferior economic good, generally replaced by the luxury of automobile travel as incomes rise.

Several zonal measures of wealth or income were available. The most promising of these measures were derived from the 1980 Census questions on the values of owner-occupied homes and rents. From these data it was possible to create two housing-value or wealth measures: SFMEAN (average reported value of single-family home) and MFMEAN (average rent). These measures should be inversely correlated with the home-based trip rate. However, no significant relationships with residential transit use were detected in bivariate or multivariate tests. In the light of these results, the housing-value measures were dropped from the final model specification.

Automobile Ownership

Many researchers have discovered relationships between automobile ownership and availability and use of transit. The Albuquerque 1981 on-board survey data indicate that more than one-quarter (26 percent) of all transit trips are made by individuals living in households without automobiles. Clearly such individuals appear more likely to use bus transit. Consequently, the study team anticipated that the condition of being without an automobile would be negatively correlated with residential transit use. Measures were constructed by using current motor vehicle registration data; however, statistical tests revealed no relationship between automobile availability and transit use. The study team's interpretation of these results is that the measures of automobile availability were probably inadequate in that they contained significant errors and biases. [For more information, see report by Nelson and O'Neil (3).]

A set of five SES and land use variables was included in the final model specification:

1. PCTSF: the ratio of single-family homes to all homes in the zone times 100;
2. COMMERCE: the number of retail, wholesale, finance, insurance, real estate, and service jobs per square mile;
3. INDUSTHH: the total number of jobs in manufacturing, transportation, communications, utilities, construction, and contracting per household in the zone;
4. PCTEMP: the ratio of estimated employed residents to persons over the age of 18 times 100; and
5. HHSIZE: the ratio of total residents to total households.

Other factors are not included in the model due to insignificant or inconclusive statistical results. Errors in some explanatory variables, such as automobile ownership, are the principal reason for the failure to detect a usable statistical relationship.

FINAL MODEL SPECIFICATION AND RESULTS

The final model specification contains a total of 10 explanatory variables described in the previous section. The dependent variable is home-origin transit trips per 1,000 residents. As can be seen from the tabulations below, the model provides a rather good statistical fit; nearly 75 percent of the variance in trip rates is explained ($R^2 = 0.738$). Each of the model coefficients is statistically significant at the 0.05 level with the theoretically correct sign and a reasonable magnitude.

Variable	Parameter Estimate	SE of Estimate
IVTTC	-0.1011	0.0338
WAITC	-0.2721	0.1005
TRNUMC	-5.205	1.424
NUMRT	2.489	0.3624
EXTERNAL	22.42	3.027
PCTSF80	-0.0401	0.0198
COMMERCE	0.001625	0.00028
INDUSTHH	0.5203	0.1695
PCTEMP	0.3034	0.0501
HHSIZE	-3.766	1.003
Constant	16.97	Not available

Summary statistics are as follows:

Statistic	Value
Multiple R	0.859
R^2	0.7380
Adjusted R^2	0.7289
SE	7.0638

The analysis of variance statistics are given below:

Type	Df	Sum of Squared Errors	Mean Squared Error	F
Regression	10	40,339	4033.950	80.8443
Residual	287	14,320	49.897	

Partial validation of the model was conducted by using the model's predicted trip rates to calculate the anticipated number of trips originating in each zone and by comparing the model predictions with the actual numbers of home-origin trips recorded. The recorded daily average systemwide total was 7,918; the predicted daily average was 8,106 for a total error of 188 overestimated. The overall error rate equals 2.4 percent systemwide for the entire set of 419 DASZs. In only 58 cases (13.8 percent) was the discrepancy greater than 10 trips. In only 22 of these cases (5.2 percent) was the prediction error greater than 20 trips.

Figure 2 is a scatterplot of actual and predicted home-origin trips by zone. The correlation between actual and predicted trips is very strong (R = 0.931). The bivariate regression between actual and predicted numbers of trips indicates close correspondence; R^2 was 0.867, beta was 0.932, and the constant was 0.870. The SE of the estimate is 8.55 trips per zone. Although this level of performance may not be optimal, it represents a significant improvement over guessing or less-sophisticated analysis approaches that may require as much or more time to implement.

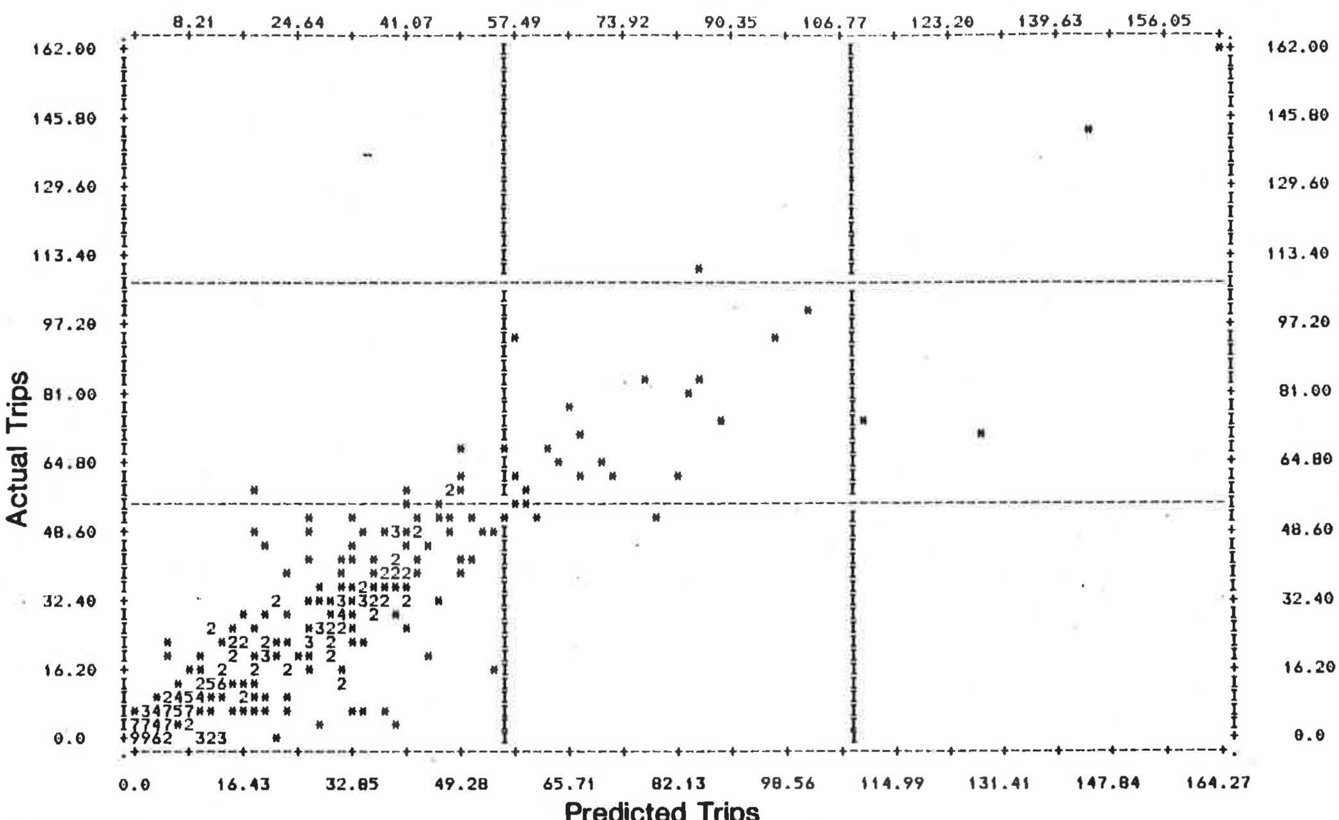
MODEL VALIDATION

The true test of a short-range planning analysis model is how well it predicts ridership response to changes in service or land use. This section documents the predictive validity of the forecasting procedure against the empirical results from an actual service change. The validation check results suggest that the procedure is quite accurate in predicting ridership changes due to changes in transit service.

Selected Service Change

During the spring of 1980, service was extended north on Route 4 from its terminus on Osuna Boulevard to Pino Avenue (March 1980) and then east to Louisiana Boulevard (June 1980) (Figure 3). The change improved service to a total of nine residential DASZs. No substantial changes in land use or the SES characteristics of the residents accompanied the service change. The service extension had no impact on transit headways or travel times for other neighborhoods or routes. Consequently, this service extension can be conveniently analyzed as an isolated service change affecting only a single area or neighborhood.

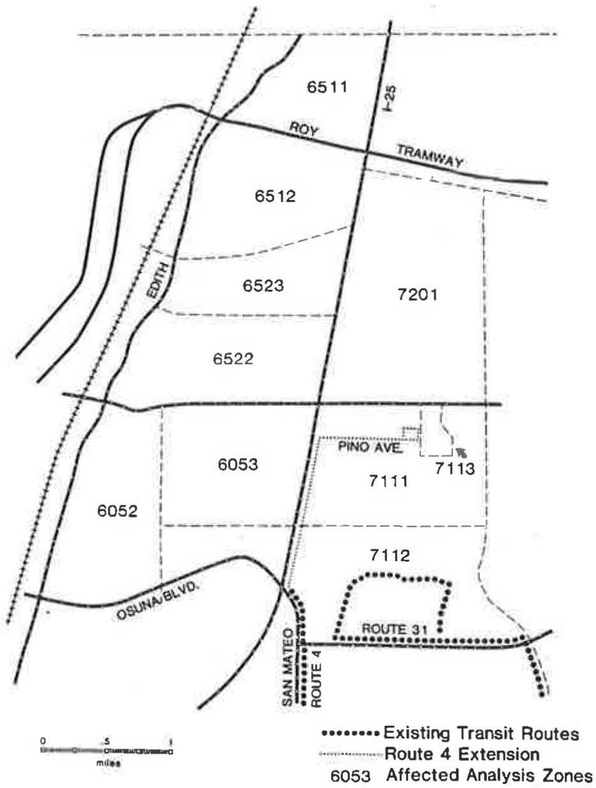
Figure 2. Model validation scattergram: actual and predicted home-origin transit trips by analysis zone.



STATISTICS..

CORRELATION (R)-	0.93125	R SQUARED -	0.86722	SIGNIFICANCE -	0.00000
STD ERR OF EST -	8.54907	INTERCEPT (A) -	0.87005	SLOPE (B) -	0.93189
PLOTTED VALUES -	419	EXCLUDED VALUES-	0	MISSING VALUES -	0

Figure 3. SunTran system: Route 4 extension.



Application Procedure

Because the route extension affected only transit LOS values, it was possible to use the model in a short-cut fashion to predict changes in ridership as a consequence of service improvements. That is, the change in level of service for each analysis zone could be calculated and multiplied times the relevant parameter estimate to determine the expected change in the zone's home-origin trip rate. This rate change could then be multiplied against the zone population to determine the expected change in zonal travel. Expected changes could then be summed for all affected zones and compared with observed changes in route ridership.

The predicted change in home-origin transit trips due to the Route 4 extension was 33.78 trips. This estimate must be doubled to get the anticipated change in all home-based trips, 67.56 daily trips. A final adjustment is then required to account for non-home-based trips. (Because non-home-based trips account for approximately 17 percent of all SunTran trips, an adjustment of 10-20 percent is probably appropriate for estimating the increased number of non-home-based trips.) With the adjustment, anticipated ridership responses range from 74 to 81 trips. This represents the best model estimate of induced ridership on Route 4 due to the service improvement.

Validation Results and Conclusions

The actual ridership change was calculated from monthly route ridership summaries for two 4-month periods: December 1979 to March 1980, before the service change, and July to October 1980, after the service change was completed. The average daily route ridership in the before period was 735 passengers. Afterwards, the count increased to 816 riders. This yields a net ridership increase of 81, which is within the predicted range of response.

These results are extremely encouraging. The model was easy to apply. Only a few hours were required to collect the necessary data and perform calculations. The model was also accurate in predicting the anticipated ridership change. It certainly would be sufficiently accurate for short-range bus service planning. The validation also highlights the need for a non-home-based travel analysis model to reduce uncertainty in making ridership predictions.

CONCLUSIONS

Based on the model results and validation exercise, the Albuquerque home-origin transit travel analysis model appears to be a valuable transit planning tool for analyzing the demand impacts of service, population, and land use changes. The model is intuitively simple, requires a minimum of data, and is flexible and easy to apply. It also appears that the model approach, if not the model itself, should be transferable to other urban areas, especially rapidly growing multicentered sunbelt cities that lack the radial structure and dominant activity core characteristic of older industrial cities.

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