TRANSIT SKETCH PLANNING PROCEDURES

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The current urban transportation planning process is highly dependent on a complex set of travel demand models that operate at a relatively fine level of detail. These models ultimately produce travel assignments on alternative modes of travel. Unfortunately, these travel demand estimates are often insensitive to policy variables, and the process is often too cumbersome and time consuming to be used to test a wide range of transportation policy alternatives. This paper describes a complementary analytical method called the transit sketch planning process. Its purpose is not to supplant traditional, more detailed urban transportation planning but to extend the range of existing procedures. The transit sketch planning process uses a much more aggregated data base. A logit modal-choice model is adapted to operate at such a level of aggregation while producing transit-demand estimates that are consistent with detailed estimates. Policy alternatives can be evaluated with respect to their overall impact on central business district, city center, and suburban transit demand. With a complementary cost analysis, the degree of subsidy required for each policy alternative is estimated. Those policies that appear to be most promising can be further tested in the traditional urban transportation planning system to evaluate the detailed impacts at a zone-to-zone and facility level. The procedures do not attempt to advance the state of the art of transportation demand forecasting. Rather they attempt to use the best of existing procedures in a framework that can provide quick responses to transit policy questions that local planners must answer.

•SEVERAL urban areas, especially those of moderate size, are confronted with difficult planning problems precipitated by the need to plan for public transit. Many urban area planners, in the past, have concentrated their efforts entirely on highway planning and have left public transit issues to the private sector or the public operating agency. Even the largest regional planning agencies that have been involved in planning public transit typically have not developed policy-sensitive procedures for evaluating public transit.

The current urban transportation planning process is highly dependent on a complex set of travel demand models that operate at a relatively fine level of detail. These models ultimately produce travel assignments on alternative modes of travel. Unfortunately, these travel demand estimates are often insensitive to policy variables and the process is often too cumbersome and time consuming to be used to test a wide range of transportation policy alternatives. A complementary analytical method, called the transit sketch planning process, is suggested to fulfill the need for a streamlined, policy-sensitive planning procedure. Its purpose is not to supplant traditional, more detailed urban transportation planning but to extend the range of existing procedures.

At the center of this process (Figure 1) is a model or formula that, when calibrated, synthesizes current ridership from base-year trip information and then is used to forecast future transit ridership. The primary objective of the model is to simulate the potential changes in transit ridership resulting from alternative transit capital and operating policies. Because of this, the model is designed to be sensitive to variables that reflect transportation planning policy such as transit accessibility, transit speed and fares, automobile speed, and parking charges. The other nonpolicy variables used are population, work force, and automobile availability, but these are used only to

determine captive transit ridership.

MODAL-SPLIT MODEL

Although several transportation supply variables theoretically could be identified as having an impact on the choice of travel mode, only time and cost of travel have been statistically tested. It certainly would be desirable to evaluate other characteristics of transit, such as travel comfort, but without new data sources these variables cannot be handled quantitatively. Their consideration must be addressed in a more qualitative marketing analysis performed at a more detailed planning level.

All modal-split-model variables used are either travel cost or travel time. Travel cost includes the out-of-pocket automobile costs for gas, oil, and parking charges and transit fares for transit travel.

Travel time for the transit mode is divided into 2 types: (a) access and wait time and (b) line-haul (on-board) time. These are converted into monetary values by using value-of-time estimates that are substantially different for each type of time spent in traveling. Automobile travel time also converts to a monetary value.

The difference between the total cost of transit travel and automobile travel is used to determine the percentage of noncaptive trip makers who select the transit mode. A nonlinear modal diversion curve is used for this purpose:

$$P_i = \frac{1}{1 + e^{-aX_i}} \tag{1}$$

where

P_i = probability of transit mode choice for trip purpose i,
a = calibration factor, and
X_i = difference between automobile and transit cost for purpose i (equation 2).

$$X_i = C_{hwy} - C_{tr} - W_{Ai} A_{tr} + W_{Li}(L_{hwy} - L_{tr}) \tag{2}$$

where

C_{hwy} = out-of-pocket automobile costs = D at \$0.05/mile (\$0.03/km) + parking + tolls where D = typical trip distance,
C_{tr} = transit fare,
W_{Ai} = value of wait or walk time for each trip purpose i,
A_{tr} = accessibility time to and from transit service (includes half headway time),
W_{Li} = value of vehicle trip time for each purpose i,
L_{hwy} = automobile trip time, and
L_{tr} = line-haul trip time on transit.

The modal-split formula is a logit probability model. When graphed as a function of its independent variables, X_i, the resulting diversion curve appears as shown in Figure 2. It should be noted that the possible values of the dependent variable (probability of modal choice) range between 0 and 1. This formula has certain properties that are consistent with common sense or intuitive notions regarding modal choice. For example, a cost differential of 0 between automobile and transit ($X_i = 0$) implies an equal split between automobile and transit use ($P_i = 0.5$). Also, at this point where transit and automobile are equally attractive, changes in either automobile or transit costs will have the largest impact on modal use. At the point on the diversion curve where $P_i = 0.5$ and $X_i = 0$, the curve has the steepest slope.

The slope of the diversion curve is quite flat at the extreme values of X_1. When transit service is poor relative to automobile travel, the variable takes on a large negative value. In that range, improvements in transit service bring about a very small increase in transit diversion. Similarly, if transit service is far better than automobile service (X_1 has a large positive value), improvements in transit service also bring about a small increase in transit diversion.

Because the logit function is asymptotic to the extreme probabilities 0 and 1, the estimated probability of transit usage is never 0 and 1. Even under the most extreme cost differentials, some individuals may choose to take the most costly mode even though the probability of such a choice is low.

MODEL CALIBRATION

The modal-split model can be calibrated by using a trial-and-error process instead of the usual approach of using regression analysis when thousands of travel interchanges are involved. Only 3 parameters need to be determined:

1. W_A, the value of wait or walk time,
2. W_L, the value of in-vehicle time, and
3. a, the exponential factor in equation 1.

In all of the applications of the model thus far, the exponential factor a has been set equal to 2. This factor can be interpreted as determining the spread of the diversion curve in Figure 2 along the x axis. A high value of a produces a diversion curve that is quite steep, which indicates a great sensitivity of modal choice to the differences in transit and automobile trip costs. A low value of a produces a gradual diversion curve that shows a relative insensitivity of modal choice to travel cost differences. These effects are shown in Figure 3.

The value-of-time parameters W_A and W_L are unknown but are reasonably bounded by the research already available on the value of traveler's time. Often this research determines the value of time as a function of the traveler's income. However, because of the large areal aggregations used in this sketch-planning process and the uncertainty involved in forecasting future income levels, income was not used explicitly to set the value of time.

Initial trials for the value-of-time parameters used $3.00/h for walk and wait time and $1.00/h for in-vehicle time. The final value-of-time parameters selected differed only slightly from these levels.

Calibration Process

The overall process of calibrating the model to estimate base-year transit trips is illustrated by using work-trip data for Nashville, Tennessee.

The Nashville urban area was divided into 3 sectors (Figure 4).

1. Sector A is the central business district (CBD).
2. Sector B is the remainder of the Nashville city center.
3. Sector C is the suburbs.

A 9-cell trip table showing the number of base-year trips made between and within all sectors was assembled from home-interview travel survey data for the home-to-work and home-to-nonwork trip purposes. The base-year home-to-work trip tables for total trips and transit trips are given in columns 2 and 3 of Table 1.

The modal-split model estimates the probability of choosing the transit mode over the automobile mode. It presumes that there is a choice of mode, but many individuals do not have access to the automobile mode for many of their trips and are captive transit riders. To properly calibrate the modal-split model, one should subtract captive

Figure 1. Transit sketch planning process.

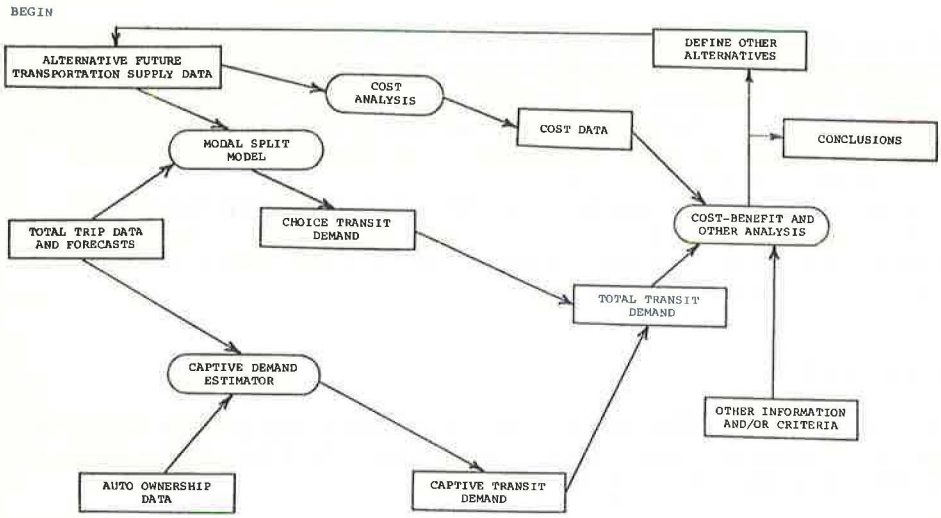


Figure 2. Diversion curve.

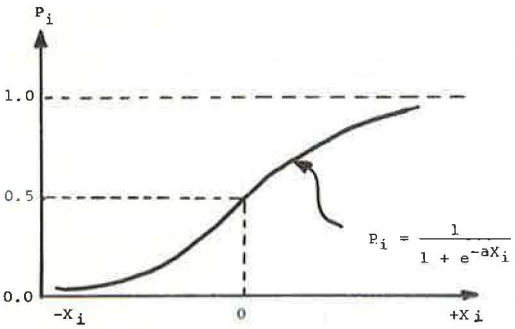


Figure 3. Diversion curve spread.

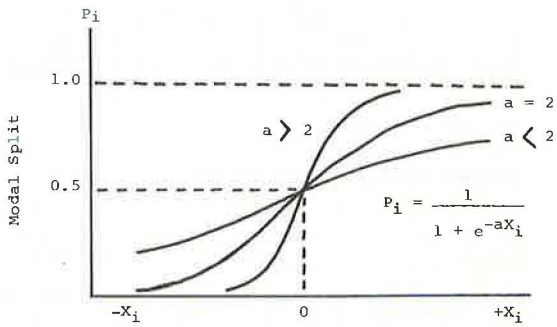
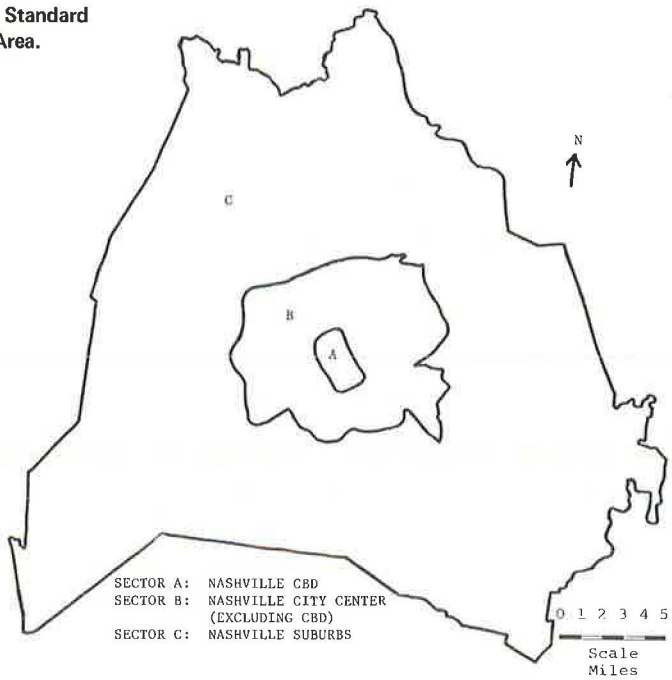


Figure 4. 1960 Nashville Standard Metropolitan Statistical Area.



rider trips from observed total transit trips. Unfortunately, adequate survey data on captive ridership are not generally available. But, it is widely acknowledged that captive ridership is, in many instances, a significant proportion of total transit patronage, especially when transit service is unattractive. An estimate of captive ridership, however compromised by the lack of reliable data, is superior to no estimate at all. No estimate is implicitly an estimate of no captive ridership. A 0 estimate would likely bias the calibration of the modal-split model in low-income trip corridors.

The number of captive transit travelers making a work trip in each sector was estimated by analyzing automobile ownership and work-force data. The excess number of work-trip origins over automobile seats available for the work trip was determined by using estimates of the automobile occupancy rate and the proportion of automobiles used for the work trip.

Having determined the number of captive transit trip origins in each sector, we distributed the trip destinations by using information regarding the commuting patterns in Nashville by socioeconomic class in the base year. This information was not quantitative but rather was based on the predominance of domestic workers traveling between certain sectors. The resulting captive transit demand trip table is given in column 4 of Table 1.

The model variables for each of the 9 trip interchanges were aggregated from base-year highway and transit "networks" for the Nashville area. Each model variable was averaged over all zone pairs in each sector-to-sector interchange. The model inputs for Nashville are given in Table 2.

Aggregation Bias

Typically, modal-split models are used in the urban transportation planning process to determine the percentage of transit use between pairs of zones. The zone is a very small area compared to the sectors used in this sketch-planning process.

It is desirable for the modal-split model to be accurate regardless of the level of areal aggregation. Consequently, the modal-split model was calibrated by using both zone-to-zone travel characteristics and sector-to-sector travel characteristics. However, because of the nonlinear nature of the modal-split model, the forecasted sector-to-sector modal split tends to be biased downward relative to the modal splits calculated at the zone-to-zone level.

This effect is especially large for suburban trips because the degree of variation of suburban transit service is very high, and many areas have no transit service at all.

Fortunately, accurate estimation of the degree of bias from available Nashville transit data was possible. Each input variable in Table 2 was aggregated from zone-to-zone travel characteristics. For example, in sector A to sector C, the average transit line-haul time was 24 min. Of the zone pair interchanges that comprise the sector A to sector C interchange, the transit line-haul times could vary substantially. The degree of variation can be measured by the standard deviation σ. The σ of each input variable therefore was determined.

Calculating the amount of aggregation bias in any particular instance by using modal-split model calibrations at both the zone-to-zone and sector-to-sector level is also possible. The calculated bias (expressed as a ratio) was regressed with the σ of all model variables. The ratio was calculated for individual observations of the regression by performing a number of individual zone-to-zone modal-split estimates and an aggregate estimate based on the average zone-to-zone characteristics in Nashville. Because of the relatively large variance of the variable for transit access (wait and egress time), explaining 96 percent of the variance of the bias ratio by using only the standard deviation of that variable was possible.

$$\frac{\hat{\hat{P}}}{\hat{P}} = 0.41656 + 0.09530(\sigma_{A_{tr}}) \qquad (3)$$

for all $\sigma_{A_{tr}}$ such that $6.12214\ \sigma_{A_{tr}} < 30$ and the coefficient of determination $r^2 = 0.962$ where

$\hat{\hat{P}}$ = average of zone-to-zone modal-split estimates selected at random (observation i),

$\hat{P}$ = aggregated zone-group-to-zone-group modal-split estimate—all independent variables used to estimate P_i were averaged to a single set of independent variables, and

$\sigma_{A_{tr}}$ = standard deviation of the independent variable $\sigma_{A_{tr}}$ used in the modal-split model that produced both $\hat{\hat{P}}$ and $\hat{P}$.

An alternate aggregation correction equation, also based on the variance of the logit model variables, is:

$$\hat{\hat{P}}_i = \hat{P}_i + [\mathrm{Var}(X_{iz})]P_i(P_i - 1)(P_i - 0.5) \tag{4}$$

where

$\hat{\hat{P}}_i$ = expected value of P_i aggregated from zone-to-zone modal-choice estimates;

$\hat{P}_i$ = value of P_i evaluated at the average sector-to-sector travel characteristics for automobile and transit—the mean values of all model variables are used to calculate X_i, which is used to determine P_i; and

$\mathrm{Var}(X_{iz})$ = variance of X_i for each zone-to-zone interchange—the function X_{iz} would be used to calculate an individual modal choice for zone pair z.

This formulation is an approximation based on a Taylor expansion of the logit estimator of P_i about the mean of X_{iz} provided by Talvitie (18). It requires estimating a more complex variance than does the regression approach, but the estimates can be used over any range of P_i, and the regression relationship can be applied only over a range of P_i within that used to estimate parameters. The variance of X_{iz} can be more easily calculated by assuming that the model variables are uncorrelated (18) so that

$$\mathrm{Var}(X_{iz}) = \mathrm{Var}(C_{hwy}) - \mathrm{Var}(C_{tr}) - \{(W_{Ai})^2[\mathrm{Var}(A_{tr})]\} + \{(W_{Li})^2[\mathrm{Var}(L_{tr})]\} \tag{5}$$

Nashville Modeling Results

After several trial-and-error iterations to account for the aggregation bias and several estimates for time values, the modal-split model was calibrated to produce base-year choice transit ridership within acceptable limits. The estimates of modal split and choice transit demand are given in columns 5 and 6 of Table 1. The estimated choice transit demand plus the estimated captive transit riders (column 4 in Table 1) produces a total transit demand estimate that can be compared with observed transit demand in the base year and in column 7 in Table 1. The error of the estimated versus the observed transit demand is best expressed as a percentage and an absolute number because either may be misleading unless total trips are taken into account. These errors are given in column 8 and column 9 in Table 1.

SELECTING TEST ALTERNATIVES

Ridership tests of alternative systems are a relatively simple and quick procedure.

Therefore, depending on the scope and the time limitations of the transit planning project, a great many alternatives can be analyzed at least for their impact on ridership. However, because of constraints on time and personnel to develop cost estimates, the number of test plans subjected to the complete analysis should be limited to those that are likely to show discernible differences in either ridership or cost effectiveness.

In designing alternative test systems, the number of changes to transit service variables should be limited. Ideally, only 1 variable at a time should be changed in each test to fully assess the effects of the change. Both significant reductions in fares and increases in line-haul speed will enhance ridership, but taking both into account in 1 test will make it difficult to assess the cost effectiveness of either service change.

A likely candidate for the initial test of the future of transit is the extension of current or base-year service levels (accessibility, speed, and fares) to target-year populations and land areas. This initial test serves as a base for comparing ridership, costs, and benefits of service improvements in other alternative plans. This was identified as alternative A for forecasts that were based on the Nashville application of this sketch-planning method.

Because improved accessibility (the average time to get to the rail station or bus stop plus the average wait time for a transit vehicle) has been found by transit planners and researchers to be the most important factor in enhancing ridership, a basic test alternative is one that improves accessibility. In physical terms, improved accessibility means either increased route miles (kilometers) or decreased headways or both.

Cutting transit-vehicle headways in half will cut the average wait time for patrons. Wait time, because of its problem in inclement weather and its general uncertainty, has a significant influence on transit ridership. This improvement means a doubling of transit vehicles in service. This was identified as alternative D; a more modest reduction of headways by a third was identified as alternative B.

New freeway express-service corridors were selected in appropriate Nashville corridors from sector C to sector A. On the basis of the available freeway corridors, 30 percent of the suburban market was assumed to be served by the express bus service. Alternatives C and E were then defined to be alternatives B and D respectively with express bus service added.

In general, the current bus or rail transit systems in the large urban areas provide regularly scheduled service to all parts of the city center but relatively little service in suburbs. The density of city center development makes scheduled service efficient in the city center but inefficient in the lower density suburbs. To narrow the suburb and city center difference in transit service levels, demand-responsive, small-bus service was added in the suburbs of each test plan. The dial-a-ride service included in the test plans closely approximates existing systems in the United States and Canada. Some of the dial-a-ride trips generated are merely a short link in a longer trip in which line-haul bus or rail service is the principal service mode. These are accounted for in the ridership estimates for the principal mode. Other dial-a-ride trips were principally nonwork, suburb-to-suburb trips and were estimated to attract 2 percent of the total suburb-to-suburb trips. The modal-choice model was not used to estimate these trips because the wait time characteristics of this type of service cannot be compared with scheduled, fixed-route service.

Fare policy also could be tested by using additional alternatives. However, for the purposes of this exercise in applying the sketch planning procedure, fares were not changed. Many studies (2, 5, 10, 11, 12, 13, 14, 17, 19, 20) have shown that reducing fares has less significant influence on transit ridership than other service improvements have. The resulting fiscal deficit from fare reduction (caused by a relatively low demand elasticity of transit fare) requires additional funding that might better be spent on further service improvements to gain ridership. Consequently, fares were held at the calibration-year level, but we emphasize that the sketch planning method we have described can quite easily account for different future-year fare policies.

The 5 test alternatives can be summarized as follows:

1. Service for alternative A is the same as 1959 service but with routes extended

to serve the expanded urban area and population;

2. Service for alternative B is the same as for alternative A but with a $33\frac{1}{3}$ percent decrease in bus headways, a 50 percent increase in buses, and dial-a-ride service added throughout most of the suburbs;

3. Service for alternative C is the same as for alternative B but with freeway express bus service;

4. Service for alternative D is the same as for alternative A but with a 50 percent decrease in bus headways, 100 percent increase in buses, and dial-a-ride service added throughout most of the suburbs; and

5. Service for alternative E is the same as for alternative D but with freeway express bus service.

Transit fares for all 1990 alternatives equal 1959 levels adjusted to 1970 dollars.

NASHVILLE STUDY RESULTS

The results of the travel demand analysis for the 5 alternative plans are given in Table 3. The largest increases of ridership result from wait time reductions provided by alternatives B and D. The express bus service provided in alternatives C and E does not change the overall ridership estimates as significantly, but the proportion of suburb-to-center-city riders does increase quite significantly (Table 4).

In Table 4, ridership by each sector-to-sector interchange by available mode of travel is given for each forecast alternative. Because work trips and nonwork trips were estimated separately (peak and off-peak travel characteristics were different in the base year), the impact of each alternative on peak-hour CBD-oriented travel can be identified as follows:

	Average Daily Work Trips to and From CBD		
Alternative	Transit	Automobile	Percent Transit
A	21,713	98,287	19
B	25,073	94,927	21
C	28,877	91,123	24
D	27,599	92,401	23
E	30,977	69,023	26

No attempt is made here to analyze the competing alternatives and make any recommendations. The numbers produced show the kind of planning data yielded by the sketch planning process. Other considerations, including cost and income and, ultimately, detailed network-level testing, should be taken into account before specific public transit programs are implemented.

The sketch-planning process does not account for various qualitative changes in transit service that should be evaluated (air conditioning, carpeting, and reduced noise). Also any directly related financial analysis would not necessarily account for possible improvements in operating efficiency of transit operators. Similarly, proposals to deregulate the urban transit industry to allow paratransit competition (jitneys) with current scheduled bus and regulated taxicab service must be evaluated outside the context of the described procedures.

Table 1. Actual and estimated trip demand.

Sector-to-Sector Trip Interchange (1)	Total Demand[a] (2)	Observed Transit Demand[a] (3)	Captive Transit Demand Estimate (4)	Modal-Split Estimate (5)	Choice Transit Demand Estimate (6)	Choice + Captive Transit Demand Estimate (7)	Percentage Error of Estimated Versus Observed Transit Demand (8)	Absolute Overestimate or Underestimate of Observed Transit Demand (9)
A-A	1,205	232	0	0.325	392	392	+69.0	+160
A-B	1,337	232	34	0.150	201	235	+1.3	+3
A-C	473	162	137	0.054	26	163	+0.6	+1
B-A	25,898	6,095	313	0.225	5,827	6,140	+0.7	+45
B-B	29,953	3,707	1,251	0.083	2,486	3,737	+0.8	+30
B-C	10,547	1,861	1,564	0.016	167	1,731	-8.5	-166
C-A	13,256	1,144	0	0.085	1,127	1,127	-1.5	-17
C-B	12,621	266	0	0.016	202	202	-10.6	-24
C-C	13,677	80	0	0.005	68	68	-15.0	-12
Total	108,967	13,769	3,299		10,496	13,795	0	+26

[a]From 1959 Nashville home-interview survey, internal trip file.

Table 2. 1959 work-trip characteristics.

Sector-to-Sector Trip Interchange	Transit Fare (cents)	Transit Access[a] (min)	Transit Line-Haul Time (min)	Highway Time (min)	Parking Cost (cents)
A-A	15	8	8	4.4	24
A-B	15	15	15	9.3	0
A-C	20	32	24	17.0	0
B-A	15	15	15	9.3	24
B-B	15	20	24	11.6	0
B-C	20	41	34	19.0	0
C-A	20	32	24	17.0	24
C-B	20	41	34	19.0	0
C-C	15	45	25	14.0	0

[a]Wait and egress time.

Table 3. 1990 average daily work trips on transit.

Alternative	Freeway Bus	Bus	Demand Responsive	Total	Modal Split	Increase Over Plan A (percent)
A	—	57,587	—	57,587	5.2	—
B	—	75,627	6,920	82,547	7.5	43
C	5,352	74,079	6,920	86,351	7.9	51
D	—	92,038	6,920	98,958	9.0	72
E	5,352	90,070	6,920	102,342	9.7	77

Table 4. 1990 average daily passenger trips.

Sector-to-Sector Trip Interchange	Service	Alternative A	Alternative B	Alternative C	Alternative D	Alternative E
A-A	Bus	2,416	2,668	2,668	2,796	2,796
A-B	Bus	1,254	1,433	1,433	1,547	1,547
A-C	Bus	291	391	391	485	485
B-A	Bus	27,337	30,425	30,425	32,457	32,457
B-B	Bus	16,321	25,001	25,001	31,361	31,361
B-C	Bus	2,894	4,544	4,544	6,009	6,009
C-A	Bus	4,372	7,131	5,583	9,503	7,535
C-A	Express bus	0	0	5,352	0	5,352
C-B	Bus	1,248	2,848	2,848	4,272	4,272
C-C	Bus	1,454	1,186	1,186	3,608	3,608
C-C	Dial-a-ride	0	6,920	6,920	6,920	2,676
Total		57,587	82,547	86,351	98,958	102,342

SKETCH PLANNING PERSPECTIVE

The principal purpose of this transit sketch planning process is not to determine the future with precision but to compare the probable impact of alternative transit planning policies. We understand that relationships such as those used in the modal-split model may explain a given set of data for a particular time period but may not always hold true when used to forecast future activity. Even with the most sophisticated procedures, cause-and-effect relationships between current and future behavioral data cannot be determined. The future is always full of imponderables—and indefinitely numerous sets of possible courses of development—that never can be determined with certainty.

More sophisticated modeling procedures are certainly possible, and some are being advanced in many large, urban, regional transportation planning studies. However, the sketch planning process described here serves a different role, one in which alternative transit policies can be quickly evaluated, which is a task that no detailed urban modeling process has yet accomplished.

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