Analysis of New Starts Project by Using Tour-Based Model of San Francisco, California

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Activity-based models are increasingly attractive as alternatives to traditional trip-based travel demand forecasting models because of growing dissatisfaction with the internal consistency, aggregation bias, and lack of detail of trip-based approaches. New policy analysis requirements demand that forecasting models represent travel choices and the contexts in which these travel choices are made with ever-increasing geographic, temporal, and behavioral detail. Activity-based models can incorporate this detail and can provide decision makers with more precise insights into potential outcomes of transportation and land use investment and development strategies. The model of San Francisco, California, is a tour-based microsimulation model that forecasts daily activity patterns for individual San Francisco residents and has been used in transportation planning practice since 2000. The San Francisco model uses the daily activity pattern approach, first introduced by Bowman and Ben-Akiva, within a disaggregate microsimulation framework. This paper describes an application of the San Francisco model to the proposed new Central Subway project in downtown San Francisco. This is the first application of an activity-based travel demand model in the United States to a major infrastructure project in support of a submission to FTA for project funding through the New Starts program. To enable the submittal of a New Starts request, software was developed to collapse the microsimulation output of the tour and trip mode choice models into a format compatible with the FTA SUMMIT program. SUMMIT was then successfully used to summarize and analyze user benefits accruing to the project and to prepare an acceptable New Starts submittal.

Activity-based models are increasingly attractive as alternatives to traditional trip-based travel demand forecasting models due to growing dissatisfaction with the internal consistency, aggregation bias, and lack of detail of trip-based approaches. New policy analysis requirements demand that forecasting models represent travel choices and the contexts in which these travel choices are made with ever-increasing geographic, temporal, and behavioral detail. Activity-based models can incorporate this detail and can provide decision makers with more precise insights into potential outcomes of transportation and land use investment and development strategies.

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The model of San Francisco, California, is a tour-based microsimulation model that forecasts daily activity patterns for individual San Francisco residents and has been used in transportation planning practice since 2000. The San Francisco model uses the daily activity pattern approach first introduced by Bowman and Ben-Akiva (*1*) within a disaggregate microsimulation framework. From a model application perspective, disaggregate approaches promise improved policy sensitivity because policies are typically oriented toward influencing the choices of individual decision makers.

The San Francisco model and its application in the evaluation of the proposed new Central Subway project in downtown San Francisco are described. This is the first application of an activity-based travel demand model to a major transit infrastructure project in support of a submission to FTA for project funding through the New Starts program. The application involves a policy analysis of the change in consumer surplus through the use of FTA's "user benefit" methodology and software and the San Francisco model. A description is given of the challenges encountered in applying the user benefit methodology in the context of a tour-based model that incorporates individual-level attributes and significant backward linkages among model components within a stochastic microsimulation framework. In conclusion, the benefits accruing at both the tour and trip mode choice model components are briefly compared.

SAN FRANCISCO MODEL

One of the first activity-based microsimulation models to be used extensively in planning is the model system created by Cambridge Systematics and Parsons Brinckerhoff for the San Francisco County Transportation Authority, completed in 2000. The model system was designed to use the "full-day pattern" activity modeling approach, first introduced by Bowman and Ben-Akiva at Massachusetts Institute of Technology (*1*). The main feature of the full-day pattern approach is that it simultaneously predicts the main components of all of a person's travel across the day. A synthesized population of San Francisco residents is input to the component models of vehicle availability, day pattern choice (tour generation), tour time-of-day choice (*2*), destination choice, and mode choice (*3*). Destination and mode choice are predicted at both the tour and the trip level. The synthesized tours and trips are aggregated to represent flows between traffic analysis zones before traffic assignment. The model system predicts the choices for a full, representative sample of residents of San Francisco County, almost 800,000 simulated individual person-days of travel. Figure 1 illustrates the San Francisco model structure.

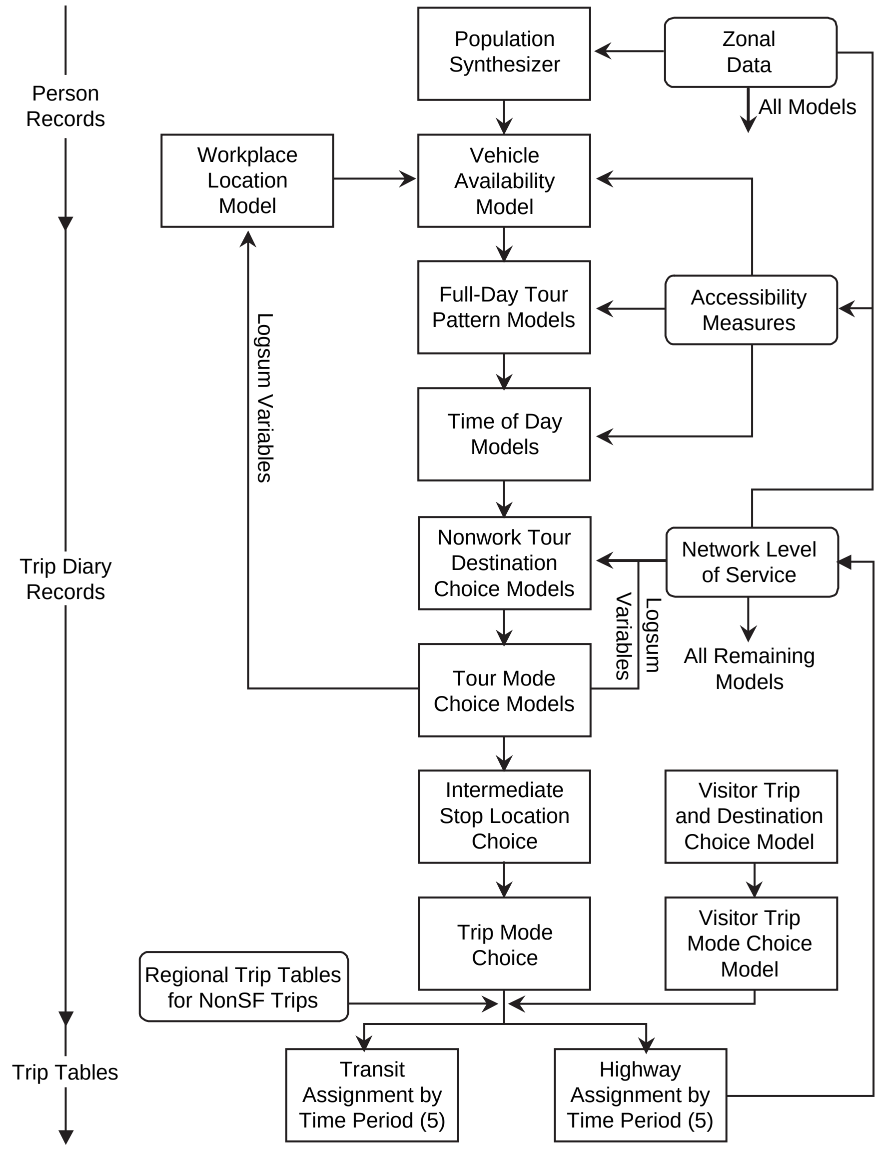

FIGURE 1 San Francisco model components.

Figure 2 shows the structure of the tour and trip mode choice models, which are particularly relevant to this paper.

In the San Francisco model, a microsimulation framework is applied to individuals and households making vehicle ownership, trip pattern, and trip destination and mode choices; many of these models are logit formulations. A Monte Carlo method is used to select outcomes according to these logit model probabilities on the basis of random number draws. Each time the sequence of random numbers used to simulate choices is varied, the model result, or end state of the model, may change.

The San Francisco model predicts demand for San Francisco County residents only. The model relies on the Bay Area regional travel demand model, developed and maintained by the Metropolitan Transportation Commission (MTC model), for nonresident travel demand, including non-home-based trips made entirely within San Francisco County by non-county residents. The MTC model is an aggregate trip-based model.

USER BENEFIT MEASURE

The user benefit measure was first included as part of the annual New Starts project evaluation criteria by FTA in 2001, although similar measures had been identified and used by FTA previously. The New Starts program is the U.S. government's "primary financial resource for supporting locally planned, implemented, and operated transit guideway capital investments" (*4*). The program funds a wide variety of projects, including commuter rail, light rail, and bus rapid transit systems.

FTA's process for evaluating projects pursuing New Starts funding incorporates a wide range of both quantitative measures and qualitative assessments. The criteria address areas such as mobility improvements, environmental benefits, operating efficiencies, and cost-effectiveness. These criteria are "intended to reflect the broad range of benefits and impacts that may be realized by the implementation of proposed investments" (*4*). The new "user benefit" measure

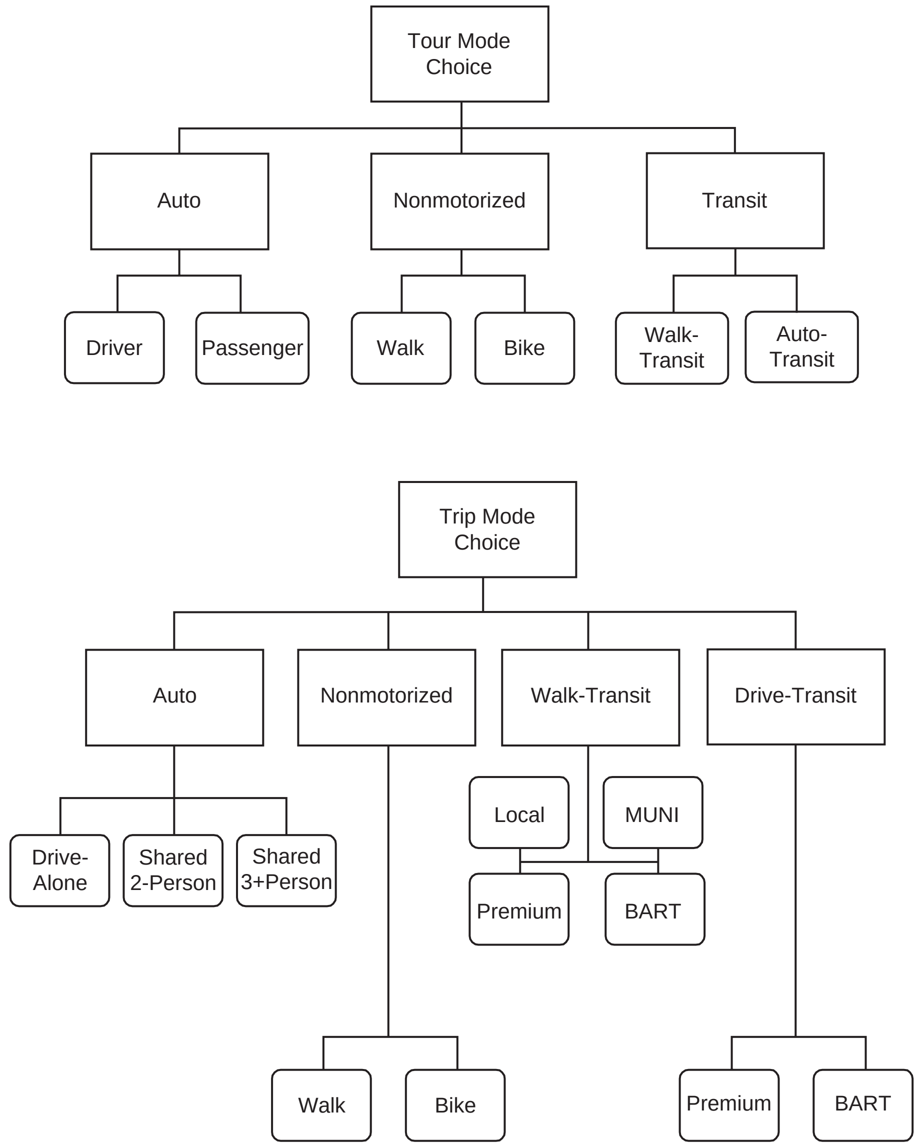

FIGURE 2 Tour and trip mode choice model nesting structures.

of project performance intends to quantify the benefits resulting from the project accruing to all transportation system users by using a common unit of travel-time savings. This new measure supports two of the project justification factors: mobility improvements and cost-effectiveness.

The user benefit measure is based on basic economic theory; it measures the change in consumer surplus attributable to a new transportation investment (Figure 3). The measure takes into account the change in mobility for all travelers, across all modes of travel, and is expressed as hours of time savings. Because the user benefits measure applies to all travelers, not simply transit users, the true increase in consumer surplus is measured. In addition, the new measure captures a broader set of benefits, including reductions in walk times, wait times, ride times, and number of transfers.

The user benefit measure is based on two key inputs. The first is derived from the denominator of the logit mode choice model. The natural log of the denominator of the mode choice model, often referred to as the logsum, is a measure of the composite utility of all modes of travel considered by the model. An increase in the mobility attributable to the introduction of transportation infrastructure (highway or transit) will increase the utility of that mode and will be reflected as an increase in composite utility of all modes. When divided by the in-vehicle time coefficient (a negative value), the logsum term is converted to a composite price of travel for all modes, measured in equivalent minutes of in-vehicle time (Figure 4). This analysis can be applied to any transport improvement captured by the mode choice model and is not strictly limited to providing information on transit investment in general or fixed guideway infrastructure in particular.

The second key input is the incremental cost of the project. The incremental cost is defined as the estimated annualized capital cost (not including financing costs) plus annual operating and maintenance costs. The transportation system user benefit is defined as the incremental annual cost of the project divided by all annual travel-related benefits in terms of hours saved by all users of the transit system (both existing riders and new riders).

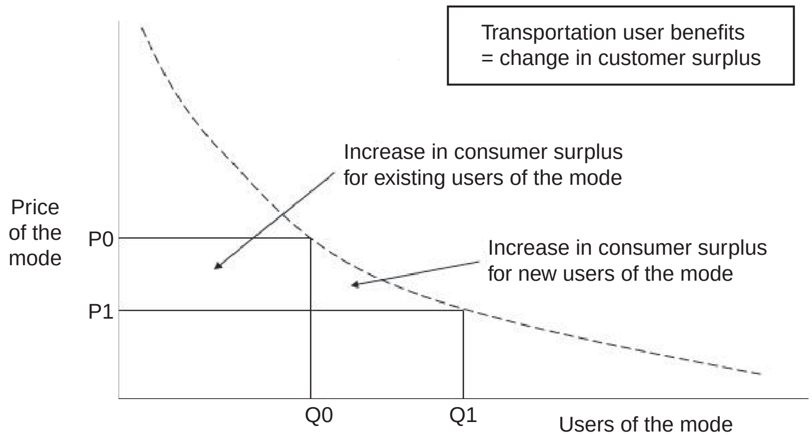

FIGURE 3 User benefit principles.

This new measure replaces two measures previously used: (*a*) hours of travel time savings for existing transit trips in the calculation of mobility benefits and (*b*) the number of new transit trips in the calculation of cost-effectiveness. The new measure deemphasizes new riders and not only reports the benefits to people who change modes but also accounts for benefits within modes (i.e., benefits to existing transit riders and highway users).

Calculation of the new measure is supported through software distributed by FTA called SUMMIT. Until the work described here, all implementations of user benefits calculations were within standard four-step mode choice models. Equations 1, 2, and 3 show how the total price of travel is computed by SUMMIT. Equation 1 shows a simple multinomial logit model formulation with only two alternatives, auto and transit. The probability of transit is computed by dividing the exponentiated utility of transit by the sum of the exponentiated utilities of both auto and transit. The natural log of the denominator of Equation 1 is the mode choice logsum, or composite utility of travel that takes into account both auto and transit accessibility:

$$P_{\text{trn}} = \frac{e^{U_{\text{trn}}}}{e^{U_{\text{trn}}} + e^{U_{\text{auto}}}} \tag{1}$$

where

P_{trn} = probability of transit,
$e^{U_{\text{trn}}}$ = exponentiated utility of transit, and
$e^{U_{\text{auto}}}$ = exponentiated utility of auto.

$$e^{U_{\text{trn}}} = \frac{P_{\text{trn}}}{1 - P_{\text{trn}}} \times e^{U_{\text{auto}}} \tag{2}$$

$$\text{cost}_{(\text{auto+trn})} = \frac{\ln\left(e^{U_{\text{auto}}} + e^{U_{\text{trn}}}\right)}{\beta_{\text{ivt}}} \tag{3}$$

where β_{ivt} is the in-vehicle time parameter and $\text{cost}_{(\text{auto+trn})}$ is the composite cost of travel by auto and transit, in equivalent minutes of in-vehicle time.

In the current form, user benefits are measured by zone pair for as many as eight market segments by multiplying the difference in price of travel (Equation 3) between the base and build alternatives by the number of trips in each market segment. The difference between the build alternative and the base alternative price measures consumer surplus, as shown in Figure 4 and algebraically in Equation 4.

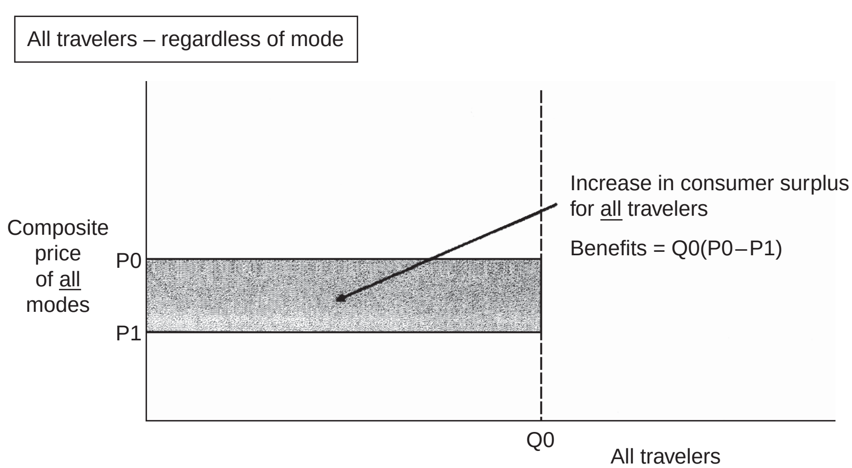

FIGURE 4 User benefits across all travelers.

The results can be aggregated to show total user benefits or user benefits by zone or district aggregation. This allows the output of user benefits for detailed spatial analysis and mapping.

$$\text{surplus}_{ijs} = T_{ijs}\left[C_{ijs(\text{base})} - C_{ijs(\text{build})}\right] \tag{4}$$

where

T_{ijs} = trips produced in zone i, attracted to zone j, in market segment s;
$C_{ijs(\text{base})}$ = baseline alternative composite cost of travel for trips produced in zone i, attracted to zone j, in market segment s;
$C_{ijs(\text{build})}$ = build alternative composite cost of travel for trips produced in zone i, attracted to zone j, in market segment s; and
surplus_{ijs} = consumer surplus.

One critical requirement imposed by FTA in the New Starts process, which is not imposed by the mathematical structure of the user benefit calculations, is that the trips in each zone pair (subscripts i, j) and market segment (subscript s) must be held constant between the base and build alternatives. This requirement ensures that user benefits are due strictly to "first-order" effects of transport accessibility (i.e., mode choice measures of benefits) and not land use changes between base and build alternatives or distributional changes induced by increased accessibility in modeling systems that consider composite utility of travel in trip distribution. This has distinct implications for tour-based models such as the San Francisco model.

USER BENEFITS AND ACTIVITY-BASED MICROSIMULATION

The calculation of user benefits as currently implemented in the SUMMIT software, within a tour-based microsimulation framework, presents some challenges. These stem from three related but distinct structural differences between trip-based travel demand forecasting models and tour-based microsimulation models. These differences make it difficult to observe the constraint that total trips by zone pair and market segment remain fixed between the baseline and build alternatives.

Market Segmentation

First, in trip-based models, each additional explanatory variable means an additional dimension in a multidimensional probability array. Since each probability array is also zone based (with n^2 cells where n equals the number of zones), the calculation time and storage of these arrays become cost prohibitive at a relatively small number of variables. The use of microsimulation in model application means that the inclusion of explanatory variables in each model component is virtually unconstrained by any consideration of computational burden. In the microsimulation modeling paradigm, each variable is stored as a column or field in a table in which each agent is a row. Each model is applied to each decision maker in turn, so the addition of explanatory variables adds virtually no overhead to the model application process. Tour-based models applied in a microsimulation framework often have many more individual or agent-level socioeconomic variables influencing choice outcomes than traditional trip-based models. For example, the tour mode choice model component of the San Francisco model considers household income (three segments), household size (three segments), age of traveler (two segments), whether the traveler pays for parking (two segments), and the number of intermediate stops on the tour (possibly eight stops total). This advantageous feature of microsimulation models has distinct implications for the consideration of market segments in the SUMMIT software. Within each market segment, there may be significantly different utilities at the individual level for many of the alternatives. The current implementation of SUMMIT limits the number of market segments to eight, so it is necessary to devise a scheme in which the range of agent-level utilities is collapsed into more generalized market segments. Note that there is nothing intrinsic to the user benefit measure that requires the use of generalized market segments. Rather, the market segmentation in SUMMIT is a reflection of the structure of the typical trip-based, four-step travel demand forecast model.

Backward Linkages

Second, in most trip-based modeling systems, there are weak or altogether no backward linkages between trip generation, distribution, and mode choice. Typically, the only linkage is provided by running the entire model stream iteratively until the model reaches convergence, although some trip-based model systems incorporate accessibility measures that may affect trip generation. Conversely, tour-based modeling systems often have strong linkages among the various model components. Most tour-based modeling systems use some version of simultaneous destination and mode choice models, in which mode choice logsums are used to select the tour primary location and intermediate stops. Some tour-based modeling systems predicate the number of intermediate stops on the chosen mode, while other models condition the tour mode on the required number of stops, placing the stop frequency model higher in the choice hierarchy than the mode choice model. This is the case in the San Francisco model. The San Francisco model also considers accessibility to destinations by mode of travel in the generation of tours and trips, allowing the accessibility to destinations to influence the number of tours and the number of stops on those tours. Finally, the San Francisco model bases the choice of when to travel (time-of-day choice) on the accessibility provided in each time period. These backward linkages have a profound impact on the ability to abide by the constraint that total trips by zone pair and market segment remain fixed between the baseline and build alternatives, given that transportation system changes affect accessibility measures used in virtually all components of the San Francisco model.

Variability

Third, in the trip-based modeling world, the variance that exists in the underlying statistical models does not affect model results because they are applied in an aggregate framework (probabilities are accumulated and multiplied across travel markets). However, the San Francisco tour-based microsimulation model is stochastic. It depends on random number seeds to choose among alternatives for individual agents in the modeling system. The forecast of travel demand is the result of these individual decisions, which can and will vary with respect to the sequence of random numbers used to select from alternatives. Recent research (*5*, *6*) suggests that microsimulation models should be run more than once, and the results averaged, to increase the reliability of the forecasts of these models. In addition, individual model components use these seeds not only to choose outcomes on the basis of the probability distributions associated with the available choices but also to set individual-level attribute values, such as whether an individual pays for parking.

EFFECTS OF INTRODUCING A TRANSPORT ALTERNATIVE

All the differences listed above create difficulties in observing FTA's constraint that total trips by zone pair and market segment remain fixed between the baseline and build alternatives. Introducing a significant transport alternative in a build alternative will affect the accessibilities in the mode choice model (primary effects) but also will affect every other model that considers mode choice model logsums or accessibility measures, or is lower in the choice hierarchy than mode choice (secondary and tertiary effects). In the San Francisco model, the introduction of a transport alternative would have a number of effects.

Tour mode choice logsums would reflect the increased accessibility associated with the alternative; zone pairs in the corridor affected by the transport alternative will show the most increase in accessibility (higher logsum). This would result in changes in the distribution of work commute patterns, as work tour mode choice logsums inform the work tour location choice model. The change in the distributional pattern of work commute may have tertiary effects on household vehicle availability (depending on parking prices in the corridor) and also influence tour generation.

In addition, the distribution of nonwork patterns would be affected. Destinations in the corridor will effectively be treated as if they were closer together in the build alternative than in the base, and therefore will have a higher selection probability in the build alternative, leading to some increase in nonwork travel in the corridor. A higher number of nonwork tours will be attracted to the corridor (choose their primary destination there) as a result.

The location of intermediate stops also would be affected, as these stops are conditional on the tour mode and primary destination chosen for each tour, and additional roadway travel time (between the tour origin and primary destination) imposed by the stop location. In the San Francisco model, if tour mode and destination change, the location of intermediate stops can be expected to change as well. There also would be some increase in intermediate stops in the corridor as a result of the increase in primary destinations chosen in the corridor.

Finally, the choice of mode for each trip is conditional on the tour mode choice and location of the origin and destination for each leg of the tour. Trips will choose the new transport alternative mode according to the improvement it offers in accessibility over the base alternative. The amount and direction of the change in all of these dimensions are dependent on the significance of the transport alternative compared with baseline modes. If the new transport alternative does not offer a significant improvement in accessibility, its impact will be rather small. The tour mode choice logsums in the San Francisco model are based on the "best" walk–transit and "best" drive–transit path available for every zonal interchange. So, for example, if the build alternative is transit and offers increased service only in a corridor, the only skims that are likely to be affected are wait time (due to a reduction in headway), which will have a negligible impact on the overall accessibility. The more significant the alternative, the more impact the alternative will have throughout the model chain.

As in many tour-based models, there are two related but separate mode choice models in the San Francisco model: one predicts the tour mode "preference" or primary mode for the tour and the other predicts the mode for each individual stop on the tour and is conditioned by the chosen tour mode. In the San Francisco model, the tour mode choice model characterizes transit choices only by access mode and not by transit submode, so the tour utilities are not affected by submode-level alternative-specific constants. This results in different tour mode and trip mode user benefit patterns.

IMPLEMENTATION OF USER BENEFITS

The most comprehensive approach to the measurement of user benefits would allow all the choices of travel—including tour generation, time of day, tour mode, destination, intermediate stop frequency and location, and trip mode—to vary according to the different utilities introduced by the policy investments being considered. However, this was not possible due to FTA's desire to create a "level playing field" with trip-based models, in which the distribution is fixed in order to capture primary effects only.

The principal challenge in implementing the user benefit measure in the San Francisco model involved addressing this fixed distribution constraint imposed by FTA. For the user benefit measure to be truly meaningful in the context of an activity-based, tour-based model such as the San Francisco model, the constraint on identical trips in each zone pair and market segment ideally would be relaxed because, at a minimum, a change in accessibility caused by the introduction of a transport policy will lead to some change in total tour–trips and destinations (primary destinations or intermediate stop locations) in the corridor. Holding the distribution fixed while varying mode leads to inconsistencies between the chosen tour mode and the location of intermediate stops, and a theoretically incorrect estimation of the user benefits associated with a transport policy.

One approach that was considered would have required the tour primary destination and the frequency of intermediate stops to be fixed between the baseline and the build alternative, while tour mode, intermediate stop location, and trip mode would have been allowed to vary with respect to the transport policies adopted in the build alternative. The advantage of this approach is that it would have ensured some, but not complete, consistency between build and baseline trip tables in the tour-based models. This approach presented potential complications for tour-based model applications in which the frequency of intermediate stops is based on the chosen tour mode. Not only would the distribution vary, but the total amount of trip-making could vary as well, although this issue is not relevant in the context of the San Francisco model, as the number of intermediate stops is predicted before mode and destination choice.

Ultimately a more conservative approach was identified and applied. In this approach, user benefits accruing at both the tour level and the trip level were captured separately. The tour and trip distributions were fixed between the base and the build, which provides greater comparability with the traditional four-step model-based approach but also leads to some theoretical inconsistencies in the model because the distributions of both tours and trips are insensitive to tour mode changes.

The first step in the adopted approach was to estimate the tour-level difference between the base and the build alternatives relative to total travel time expenditures. This was accomplished by first running the base through tour mode and destination choice. The base tour generation output and base tour destination output were input to the build alternative mode choice model input. This allowed the base alternative tour distribution to remain fixed, while the mode choice varied to reflect the new transportation improvement. The SUMMIT information required to calculate the total time expenditures derived from the mode choice denominator and other tour information was appended to both the base and build tour outputs. These outputs were then collapsed into a format readable by SUMMIT software (based on *i, j,* and market segment) and input to SUMMIT, which then provided an estimate of the hours of travel time savings at the tour level. Collapsing the transit probabilities was fairly straightforward, by simply aggregating the observations by any particular market segment. The auto exponentiated utilities for the market segment were computed by averaging the auto exponentiated utilities for all travelers in that market segment.

The format of the output SUMMIT file is given in Table 1. Note that the transit probabilities are given instead of percentage of transit trips in order to be consistent with four-step models and reduce (but not eliminate, see below) Monte Carlo variation. The auto sufficiency market segmentation (zero autos, autos less than persons, autos greater than or equal to persons) used for stratification of tour mode choice alternative-specific constants was used for reporting user benefits for San Francisco residents.

To calculate the hours of travel time savings at the trip level, which is lower in the model chain, the base alternative was run through trip mode choice; the SUMMIT-required information was appended to the base trip mode choice output; and this output subsequently was collapsed into a format readable by SUMMIT. The base intermediate stop choice output (which immediately precedes trip mode choice) was then used as input to the build alternative trip mode choice. The SUMMIT information required to calculate the total time expenditures was appended to the build trip mode choice output and then collapsed into a format readable by SUMMIT. SUMMIT then was used to calculate the difference between the base and the build, providing an estimate of the converted hours of travel time savings at the trip level for travelers who have not changed tour mode, tour destination, or tour intermediate stop, but changed trip mode due to the transportation system improvement.

A more desirable approach would have maintained the new tour mode chosen in the build alternative when intermediate stops and trip mode for the build alternative are predicted. However, it was not possible to implement this approach due to the significant effect that a change in tour mode can have on trip mode nontransit exponentiated utilities. For example, when a traveler changes tour mode from auto driver in the base alternative to walk–transit in the build alternative, the trip mode nontransit exponentiated utility goes from relatively large to very small; this results in a big and unreasonable change in price (as measured in converted minutes of travel time).

A further complication involves the random number generator (RNG) sequences that are used to select outcomes from the model-generated probability distributions. When choices higher up the model chain are allowed to vary, the RNG sequences between the base and build alternative can get out of sync; this results in illogical differences between the base and build at the individual record level. One of the most striking examples in the context of the San Francisco model involves the choice of whether to pay for parking or not. A change in the RNG sequence can result in a change in whether one pays for parking, which in turn has a significant effect on nontransit exponentiated utilities and user benefits. Differences in the RNG sequence also affect all subsequent records and choices. Ultimately, the San Francisco model code was modified to preserve the consistency of the RNG sequences provided that the number of tours and trips remains constant between the base and build. To keep tours and trips constant, however, necessarily implies not deriving the full measure of change expected to result from a given transportation system improvement.

NEW CENTRAL SUBWAY RESULTS

The user benefit analysis methodology described was developed and applied to evaluate the second phase of the Third Street light rail project in San Francisco, the new Central Subway. This project involves the extension of a new light rail line along the eastern bay shore of San Francisco into a subway segment running under downtown and extending to Chinatown. The purpose of the project is to improve service reliability and travel times, enhance transit connections, and help generate economic opportunities and jobs for local residents and business owners. See Figure 5 for a map of the Central Subway. The Central Subway will operate within a dense, transit-rich environment, with connections to existing San Francisco Municipal Railway (Muni) bus and light rail transit lines, Bay Area Rapid Transit (BART)

TABLE 1 SUMMIT Record Format for Tour and Trip Mode Choice Models

Field	Format	Bytes	Contents
1	Integer	2	Anchor–origin travel analysis zone (TAZ)
2	Integer	2	Primary destination–destination TAZ
3	Integer	2	Market segment
4	Real	4	Person trips in market segment and zone pair
5	Real	4	Person trips in market segment and zone pair
6	Real	4	Exponentiated utility for nonauto modes
7	Real	4	1 if zone pair has walk accessibility to transit, else 0
8	Real	4	Average transit probability for walk-access trips in zone pair and market segment
9	Real	4	1 if zone pair is drive-only to transit, else 0
10	Real	4	Average transit probability for drive-only trips in zone pair and market segment

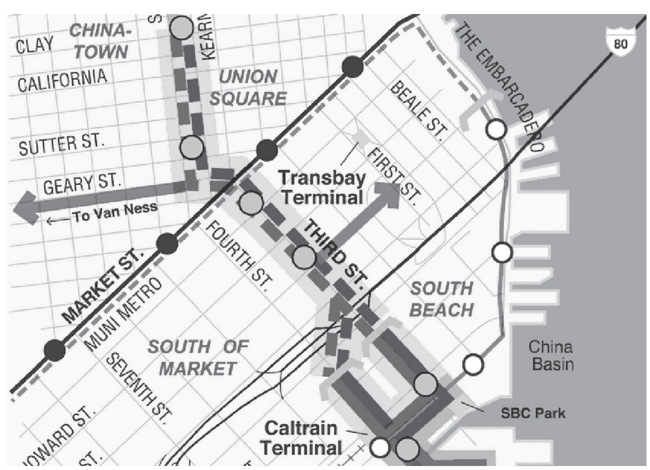

FIGURE 5 Central Subway and downtown San Francisco.

TABLE 2 Base-Year Transit Validation in Third Street Corridor

Route	Observed Boardings	Estimated Boardings	Difference	Percent Difference
N—Judah	45,621	45,883	262	1
K—Ingleside	25,304	27,116	1,812	7
9AX—San Bruno Express	2,538	2,320	(218)	–9
9BX—San Bruno Express	2,076	1,738	(338)	–16
9X—San Bruno Express	8,464	5,506	(2,958)	–35
12—Folsom	5,704	5,062	(642)	–11
15—Third Street	28,157	32,325	4,168	15
22—Fillmore	25,467	18,254	(7,213)	–28
30—Stockton	24,943	33,871	8,928	36
45—Union–Stockton	18,770	17,820	(950)	–5
Total corridor	187,044	189,895	2,851	2

heavy rail, Caltrain, and express bus services to the east bay and Marin County.

The Central Subway is expected to operate at 5-min headways in peak periods, 10-min headways in off-peak periods, and 12-min headways throughout the evening period. The analysis began with an investigation of the San Francisco model to ensure that it adequately modeled base-year ridership in the rail corridor. Table 2 shows the base-year validation summary. It demonstrates that at a corridor level the model performs well. There is some variation at the route level. The table indicates that it may be warranted to introduce transit capacity restraint into the model system in order to improve validation results since the 15–Third Street and 30–Stockton line are overestimated, and these are currently the most crowded transit routes in the corridor.

Table 3 illustrates the aggregate countywide results of the tour and trip user benefit analysis for this project. In the following table and figures, IOS refers to initial operating segment (baseline) and NCS refers to new Central Subway (build). The units of measure in Table 3 are daily hours of user benefit and are shown by tour purpose for both tour results and trip results. The difference between the tour and trip user benefits in both magnitude and distribution by purpose is immediately noticeable.

The difference is likely due primarily to the inclusion of submodal alternative-specific constants in the trip mode choice models. The tour mode choice models use a more generalized representation of transit, segmented only by mode of access, while the trip mode choice model contains much more transit submodal detail (see Figure 2). In the trip mode choice model, the presence of an alternative-specific constant associated with light rail allows the project to distinguish itself with much greater benefits over the existing high-frequency bus service, simply because the new service will be light rail. In contrast, in the tour mode choice model, in which transit is segmented only by mode of access, the project does not appear to provide much benefit simply on the basis of travel times, transfers, and access and egress.

TABLE 3 Tour and Trip User Benefits: IOS (Baseline) to NCS (Build)

	Tour	Trip	Tour+Trip
Work tour trips	388	2,098	2,486
School tour trips	187	483	670
Other tour trips	132	1,528	1,660
Work-based tour trips	–21	202	181
Total	686	4,311	4,997

A significant feature of the SUMMIT software is its ability to provide summaries of change in total travel time expenditures and trips by mode at any geographic level. These reports can then be imported easily into GIS software for thematic mapping of model results. User benefits are calculated separately for each tour and trip purpose, due to the fact that each of these purposes has different estimated values for the coefficient on in-vehicle travel time. Figures 6 and 7 illustrate the total tour and trip destination-based user benefits across all purposes. Figure 7 shows the much greater intensity of user benefits accruing at the trip level, due to the rail alternative-specific constant, while Figure 6 shows the more ambivalent pattern of benefits associated with the tour level, due to the fact that these benefits reflect only service changes such as frequency and alignment. As noted previously, the project involves replacing existing bus service with light rail, so while there are some improvements in travel times due to separate right-of-way, there also are declines in accessibility due to fewer stop locations, and reduction of level of service on the Embarcadero light rail transit line that exists in the baseline alternative.

CONCLUSIONS

Numerous challenges arise in the application of a tour-based microsimulation model such as the San Francisco model to evaluate changes in consumer surplus as defined with FTA's user benefit measure. These stem from three related but distinct structural differences between trip-based travel demand forecasting models and tour-based microsimulation models, including market segmentation, backward linkages among model components, and variability associated with the stochastic microsimulation framework. These structural differences make it difficult to observe FTA's requirement of a fixed distribution of trips in order to capture "primary" effects.

As part of this effort, to address the constraint of eight market segments in the context of a model system in which utilities vary at the level of the individual due to the inclusion of individual-level attributes in the mode choice models, a scheme was devised to collapse the microsimulation output into market segments for input into the SUMMIT software. The market segments were defined on the basis of household levels of auto availability and household size. This

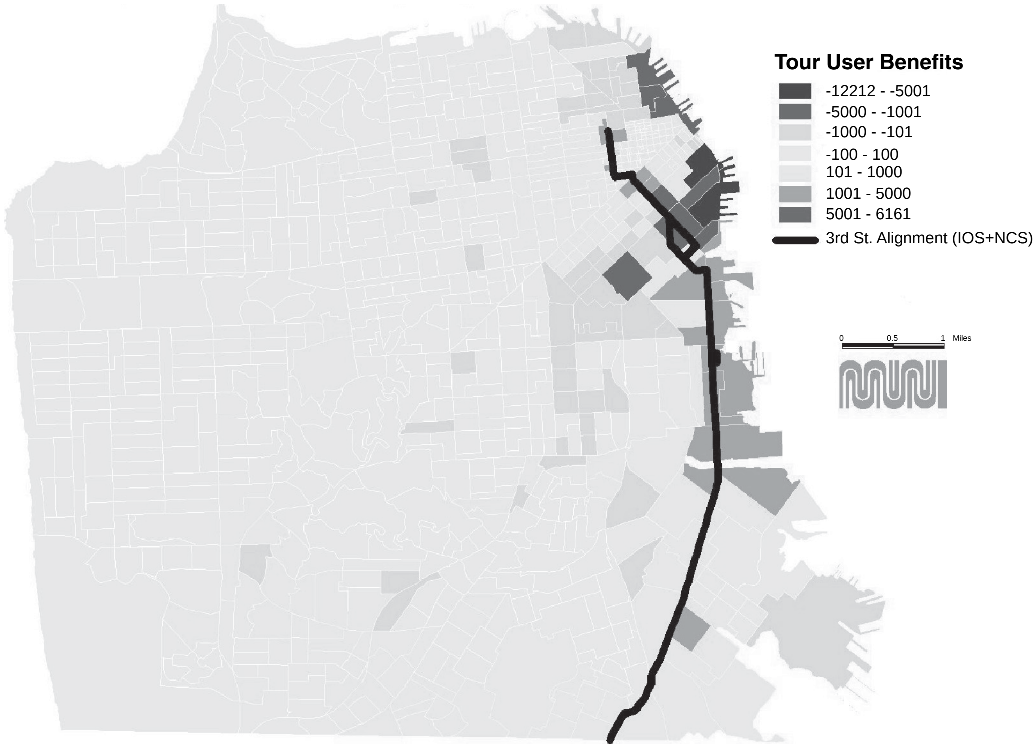

FIGURE 6 IOS-NCS destination-based user benefits (tour).

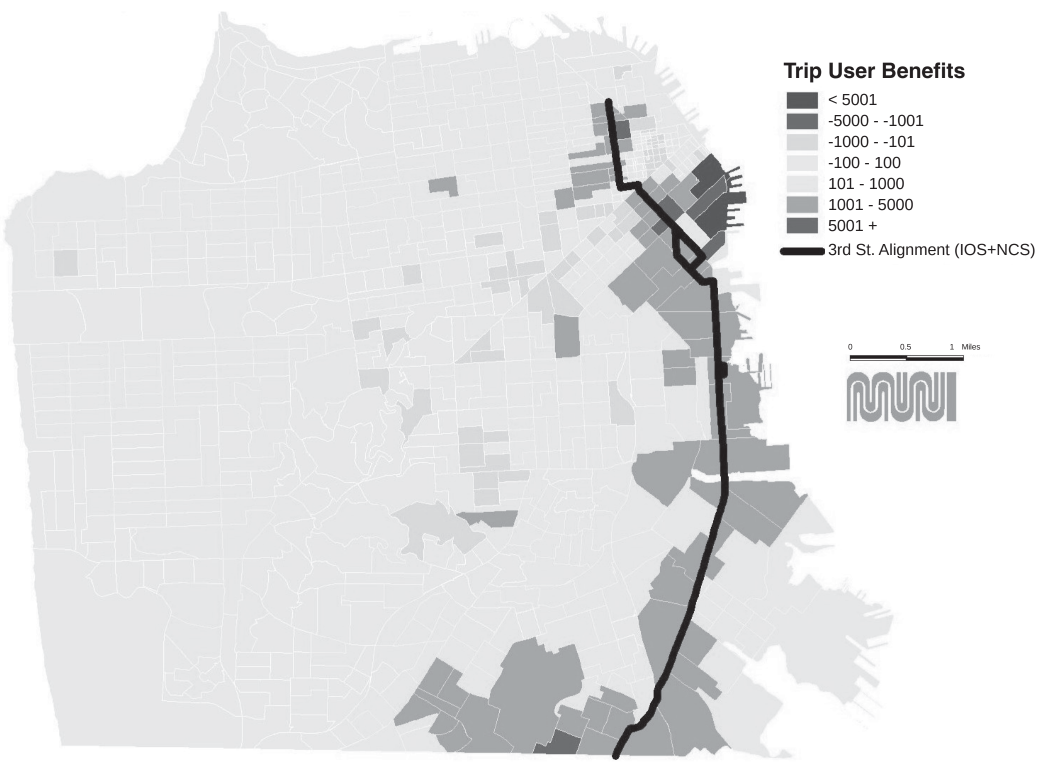

FIGURE 7 IOS-NCS total destination-based user benefits (trip).

collapsing is accomplished by calculating, at a travel analysis zone and market segment level, the total number of trips, the average non-transit exponentiated utility, the transit share of trips, and the indication of transit access required by SUMMIT (i.e., can walk to transit or must drive to transit). In the future it is anticipated that an updated version of SUMMIT will read individual trip records, although the market segment limit of eight will continue to be imposed, so the need to collapse individual-based results to market segments will persist.

The FTA requirement of a fixed distribution at both the tour and trip levels essentially thwarted any ability to achieve greater consistency with respect to backward linkages among components of the model system. In this application, the selection of tour and trip destinations is determined entirely by the base alternative and is fixed, despite backward linkages in the model in which changes in tour mode would affect subsequent intermediate stop (trip) destinations and trip mode of the build alternative. Until the fixed distribution requirement is relaxed, the user benefit measure will not be capturing the full range of transportation system user benefits accruing to travelers.

The issue of random simulation variation associated with the microsimulation-based context of the San Francisco model was not addressed in this effort, although it remains a critical issue. It is clear that the model should be run several times for both the baseline and the build alternatives to see how the results vary, and this issue will be revisited in updates to this New Starts project analysis. Future updates to this analysis will consider a number of options to address this issue, including running the model multiple times and selecting a "representative" baseline run and a "representative" build, calculating a priori the number of runs required to reach statistical reliability on some measure based on expected variance, or running the model multiple times and pooling the results, dividing to generate an average value.

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