B *COMPASS*™ Model

COMPASS™ Model Calibration

The *COMPASS*™ Model System is a flexible multimodal demand-forecasting tool that provides comparative evaluations of alternative socioeconomic and network scenarios. It also allows input variables to be modified to test the sensitivity of demand to various parameters such as elasticities, values of time, and values of frequency. This section describes in detail the model methodology and process used in the study.

B.1 Description of the COMPASS™ Model System

The *COMPASS*™ model is structured on two principal models: Total Demand Model and Hierarchical Modal Split Model. For this study, these two models were calibrated separately for four trip purposes, i.e., Business, Commuter, Tourist, and Social. Moreover, since the behavior of short-distance trip making is significantly different from long-distance trip making, the database was segmented by distance, and independent models were calibrated for both long and short-distance trips, thus provide separate elasticities for trips over and under 80 miles. For each market segment, the models were calibrated on origin-destination trip data, network characteristics and base year socioeconomic data.

The models were calibrated on the base year data. In applying the models for forecasting, an incremental approach known as the "pivot point" method is used. By applying model growth rates to the base data observations, the "pivot point" method is able to preserve the unique travel flows present in the base data that are not captured by the model variables. Details on how this method is implemented are described below.

B.2 Total Demand Model

The Total Demand Model, shown in Equation 1, provides a mechanism for assessing overall growth in the travel market.

Equation 1:

$$T_{ijp} = e^{\beta_{0p}} (SE_{ijp})^{\beta_{1p}} e^{\beta_{2p}\, U_{ijp}}$$

Where,

T_{ijp} = Number of trips between zones *i* and *j* for trip purpose *p*
SE_{ijp} = Socioeconomic variables for zones *i* and *j* for trip purpose *p*
U_{ijp} = Total utility of the transportation system for zones *i* to *j* for trip purpose *p*
$\beta_{0p}, \beta_{1p}, \beta_{2p}$ = Coefficients for trip purpose *p*

As shown in Equation 1, the total number of trips between any two zones for all modes of travel, segmented by trip purpose, is a function of the socioeconomic characteristics of the zones and the total utility of the transportation system that exists between the two zones. For this study, trip purposes include Business, Commuter, Tourist, and Social, and socioeconomic characteristics consist of population, employment and per household income. The utility function provides a measure of the quality of the transportation system in terms of the times, costs, reliability and level of service provided by all modes for a given trip purpose. The Total Demand Model equation may be interpreted as meaning that travel between zones will increase as socioeconomic factors such as population and income rise or as the utility (or quality) of the transportation system is improved by providing new facilities and services that reduce travel times and costs. The Total Demand Model can therefore be used to evaluate the effect of changes in both socioeconomic and travel characteristics on the total demand for travel.

B.2.1 Socioeconomic Variables

The socioeconomic variables in the Total Demand Model show the impact of economic growth on travel demand. The *COMPASS*™ Model System, in line with most intercity modeling systems, uses three variables (population, employment and per household income) to represent the socioeconomic characteristics of a zone. Different combinations were tested in the calibration process and it was found, as is typically found elsewhere, that the most reasonable and stable relationships consists of the following formulations:

Trip Purpose	***Socioeconomic Variable***
Business	$E_i E_j (I_i + I_j) / 2$
Commuter	$(P_iE_j+P_jE_i) / 2 (I_i+I_j) / 2$
Tourist and Social	$P_i P_j (I_i + I_j) / 2$

The Business formulation consists of a product of employment in the origin zone, employment in the destination zone, and the average per household income of the two zones. Since business trips are usually made between places of work, the presence of employment in the formulation is reasonable. The Commuter formulation consists of all socioeconomic factors, this is because commuter trips are between homes and places of work, which are closely related to population and employment. The formulation for Tourist and Social consists of a product of population in the origin zone, population in the destination zone and the average per household income of the two zones. Tourist and Social trips encompass many types of trips, but the majority is home-based and thus, greater volumes of trips are expected from zones from higher population and income.

B.2.2 Travel Utility

Estimates of travel utility for a transportation network are generated as a function of generalized cost (GC), as shown in Equation 2:

Equation 2:

$$U_{ijp} = f(GC_{ijp})$$

Where,

GC_{ijp} = Generalized Cost of travel between zones *i* and *j* for trip purpose *p*

Because the generalized cost variable is used to estimate the impact of improvements in the transportation system on the overall level of trip making, it needs to incorporate all the key attributes that affect an individual's decision to make trips. For the public modes (i.e., rail, bus and air), the generalized cost of travel includes all aspects of travel time (access, egress, in-vehicle times), travel cost (fares, tolls, parking charges), schedule convenience (frequency of service, convenience of arrival/departure times) and reliability.

The generalized cost of travel is typically defined in travel time (i.e., minutes) rather than dollars. Costs are converted to time by applying appropriate conversion factors, as shown in Equation 3. The generalized cost (GC) of travel between zones *i* and *j* for mode m and trip purpose p is calculated as follows:

Equation 3:

$$GC_{ijmp} = TT_{ijm} + \frac{TC_{ijmp}}{VOT_{mp}} + \frac{VOF_{mp}\,OH}{VOT_{mp}\,F_{ijm}\,C_{ijm}} + \frac{VOR_{mp}\,\exp(-OTP_{ijm})}{VOT_{mp}}$$

Where,

TT_{ijm} = Travel Time between zones *i* and *j* for mode *m* (in-vehicle time + station wait time + connection wait time + access/egress time + interchange penalty), with waiting, connect and access/egress time multiplied by a factor (greater than 1) to account for the additional disutility felt by travelers for these activities

TC_{ijmp} = Travel Cost between zones *i* and *j* for mode *m* and trip purpose *p* (fare + access/egress cost for public modes, operating costs for auto)

VOT_{mp} = Value of Time for mode *m* and trip purpose *p*

VOF_{mp} = Value of Frequency for mode *m* and trip purpose *p*

VOR_{mp} = Value of Reliability for mode *m* and trip purpose *p*

F_{ijm} = Frequency in departures per week between zones *i* and *j* for mode *m*

C_{ijm} = Convenience factor of schedule times for travel between zones *i* and *j* for mode *m*

OTP_{ijm} = On-time performance for travel between zones *i* and *j* for mode *m*

OH = Operating hours per week

Station wait time is the time spent at the station before departure and after arrival. Air travel generally has higher wait times than other public modes because of security procedures at the airport, baggage checking, and the difficulties of loading a plane. On trips with connections, there would be additional wait times incurred at the connecting station. Wait times are weighted higher than in-vehicle time in the generalized cost formula to reflect their higher disutility as found from previous studies. Wait times are weighted 70 percent higher than in-vehicle time.

Similarly, access/egress time has a higher disutility than in-vehicle time. Access time tends to be more stressful for the traveler than in-vehicle time because of the uncertainty created by trying to catch the flight or train. Based on previous work, access time is weighted 30 percent higher than in-vehicle time for air travel and 80 percent higher for rail and bus travel.

The third term in the generalized cost function converts the frequency attribute into time units. Operating hours divided by frequency is a measure of the headway or time between departures. Tradeoffs are made in the stated preference surveys resulting in the value of frequencies on this measure. Although there may appear to some double counting because the station wait time in the first term of the generalized cost function is included in this headway measure, it is not the headway time itself that is being added to the generalized cost. The third term represents the impact of perceived frequency valuations on generalized cost. TEMS has found it very convenient to measure this impact as a function of the headway.

The fourth term of the generalized cost function is a measure of the value placed on reliability of the mode. Reliability statistics in the form of on-time performance (i.e., the fraction of trips considered to be on time). One feature of the RMRA model is that auto travel on I-70 is frequently unreliable due to weather conditions. As such, the reliability of auto travel in the corridor was reduced by 10 percent in winter months. The negative exponential form of the reliability term implies that improvements from low levels of reliability have slightly higher impacts than similar improvements from higher levels of reliability.

B.2.3 Calibration of the Total Demand Model

In order to calibrate the Total Demand Model, the coefficients are estimated using linear regression techniques. Equation 1, the equation for the Total Demand Model, is transformed by taking the natural logarithm of both sides, as shown in Equation 4:

Equation 4:

$$\log(T_{ijp}) = \beta_{0p} + \beta_{1p}\log(SE_{ijp}) + \beta_{2p}(U_{ijp})$$

Equation 4 provides the linear specification of the model necessary for regression analysis.

The segmentation of the database by trip purpose and trip length resulted in eight sets of models. Trips that would cover a distance more than 80 miles are considered long-distance trips. Shorter trips that are less than 80 miles are considered short-distance trips. This segmentation by trip length was chosen because by analyzing the trip data, we found that traveler behaviors differ in the two categories, and usually, air service is generally an unavailable or unreasonable mode for short-distance travelers. Although the calibrated models without distance segmentation were satisfactory, we decided to develop long-distance and short-distance models separately to better simulate travelers' decision-making. The results of the calibration for the Total Demand Models are displayed in Exhibit B-1.

Exhibit B-1: Total Demand Model Coefficients [1]

Long-Distance Trips *(longer than 80 miles)*

Business $\log(T_{ij}) = -15.759 + \underset{(23)}{0.670 \log(SE_{ij})} + \underset{(21)}{1.789\, U_{ij}}$ $R^2=0.48$

where $U_{ij} = \log[\exp(5.406 + 0.898 U_{Pub}) + \exp(-0.009\, GC_{Car})]$

Commuter $\log(T_{ij}) = -7.243 + \underset{(19)}{0.407 \log(SE_{ij})} + \underset{(31)}{1.493\, U_{ij}}$ $R^2=0.42$

where $U_{ij} = \log[\exp(3.554 + 0.682\, U_{Pub}) + \exp(-0.016 GC_{Car})]$

Tourist $\log(T_{ij}) = -8.580 + \underset{(30)}{0.405 \log(SE_{ij})} + \underset{(40)}{1.267\, U_{ij}}$ $R^2=0.33$

where $U_{ij} = \log[\exp(4.154 + 0.809\, U_{Pub}) + \exp(-0.007 GC_{Car})]$

Social $\log(T_{ij}) = -13.905 + \underset{(24)}{0.634 \log(SE_{ij})} + \underset{(25)}{2.001\, U_{ij}}$ $R^2=0.48$

where $U_{ij} = \log[\exp(3.682 + 0.745\, U_{Pub}) + \exp(-0.012 GC_{Car})]$

Short-Distance Trips *(shorter than 80 miles)*

Business $\log(T_{ij}) = -6.580 + \underset{(25)}{0.367 \log(SE_{ij})} + \underset{(40)}{0.680\, U_{ij}}$ $R^2=0.42$

where $U_{ij} = \log[\exp(-5.325 + 1.321\, U_{Pub}) + \exp(-0.032 GC_{Car})]$

Commuter $\log(T_{ij}) = -8.134 + \underset{(28)}{0.458 \log(SE_{ij})} + \underset{(47)}{1.038\, U_{ij}}$ $R^2=0.48$

where $U_{ij} = \log[\exp(-4.049 + 1.258\, U_{Pub}) + \exp(-0.035 GC_{Car})]$

Tourist $\log(T_{ij}) = -0.391 + \underset{(11)}{0.197 \log(SE_{ij})} + \underset{(46)}{1.324\, U_{ij}}$ $R^2=0.38$

where $U_{ij} = \log[\exp(-3.200 + 1.010\, U_{Pub}) + \exp(-0.026 GC_{Car})]$

Social $\log(T_{ij}) = 0.870 + \underset{(10)}{0.164 \log(SE_{ij})} + \underset{(45)}{0.706\, U_{ij}}$ $R^2=0.34$

where $U_{ij} = \log[\exp(-3.334 + 0.928\, U_{Pub}) + \exp(-0.062 GC_{Car})]$

[1] t-statistics are given in parentheses.

In evaluating the validity of a statistical calibration, there are two key statistical measures: t-statistics and R^2. The *t*-statistics are a measure of the significance of the model's coefficients; values of 1.95 and above are considered "good" and imply that the variable has significant explanatory power in estimating the level of trips. The R^2 is a statistical measure of the "goodness of fit" of the model to the data; any data point that deviates from the model will reduce this measure. It has a range from 0 to a perfect 1, with 0.3 and above considered "good" for large data sets.

Based on these two measures, the total demand calibrations are good. The *t*-statistics are high, aided by the large size of the data set. The R^2 values imply good fits of the equations to the data.

As shown in Exhibit B-1, the socioeconomic elasticity values for the Total Demand Model are in the range of 0.16 to 0.45 for short distance trips and 0.4 to 0.74 for long distance trips, meaning that each one percent growth in the socioeconomic term generates approximately a 0.16 to 0.4 percent growth in short distance trips and a 0.4 to 0.74 percent growth in long distance trips.

The coefficient on the utility term is not elasticity, but it can be used as an approximation. The utility elasticity is related to the scale of the generalized costs, for example, utility elasticity can be high if the absolute value of transportation utility improvement is significant. This is not untypical when new highways or rail system are built. In these cases, a 20 percent reduction in utility is not unusual and may impact more heavily on longer origin-destination pairs than shorter origin-destination pairs.

B.2.4 Incremental Form of the Total Demand Model

The calibrated Total Demand Models could be used to estimate the total travel market for any zone pair using the population, employment, per household income, and the total utility of all the modes. However, there would be significant differences between estimated and observed levels of trip making for many zone pairs despite the good fit of the models to the data. To preserve the unique travel patterns contained in the base data, the incremental approach or "pivot point" method is used for forecasting. In the incremental approach, the base travel data assembled in the database are used as pivot points, and forecasts are made by applying trends to the base data. The total demand equation as described in Equation 1 can be rewritten into the following incremental form that can be used for forecasting (Equation 5):

Equation 5:

$$\frac{T_{ijp}^{\,f}}{T_{ijp}^{\,b}} = \left(\frac{SE_{ijp}^{\,f}}{SE_{ijp}^{\,b}}\right)^{\beta_{1p}} \exp(\beta_{2p}\,(U_{ijp}^{\,f} - U_{ijp}^{\,b}))$$

Where,

T^f_{ijp} = Number of Trips between zones *i* and *j* for trip purpose *p* in forecast year *f*
T^f_{ijp} = Number of Trips between zones *i* and *j* for trip purpose *p* in base year *b*
SE^f_{ijp} = Socioeconomic variables for zones *i* and *j* for trip purpose *p* in forecast year *f*
SE^b_{ijp} = Socioeconomic variables for zones *i* and *j* for trip purpose *p* in base year *b*
U^f_{ijp} = Total utility of the transportation system for zones *i* to *j* for trip purpose *p* in forecast year *f*
U^b_{ijp} = Total utility of the transportation system for zones *i* to *j* for trip purpose *p* in base year *b*

In the incremental form, the constant term disappears and only the elasticities are important.

B.3 Hierarchical Modal Split Model

The role of the Hierarchical Modal Split Model is to estimate relative modal shares, given the Total Demand Model estimate of the total market that consists of different travel modes available to travelers. The relative modal shares are derived by comparing the relative levels of service offered by each of the travel modes. The *COMPASS™* Hierarchical Modal Split Model uses a nested logit structure, which has been adapted to model the intercity modal choices available in the study area. A three-level hierarchical modal split model is shown in Exhibit B-2 and a two-level hierarchical modal split model is shown in Exhibit B-3, where Air mode is not available to travelers.

Exhibit B-2: Hierarchical Structure of the Three-Level Long Distance Modal Split Model

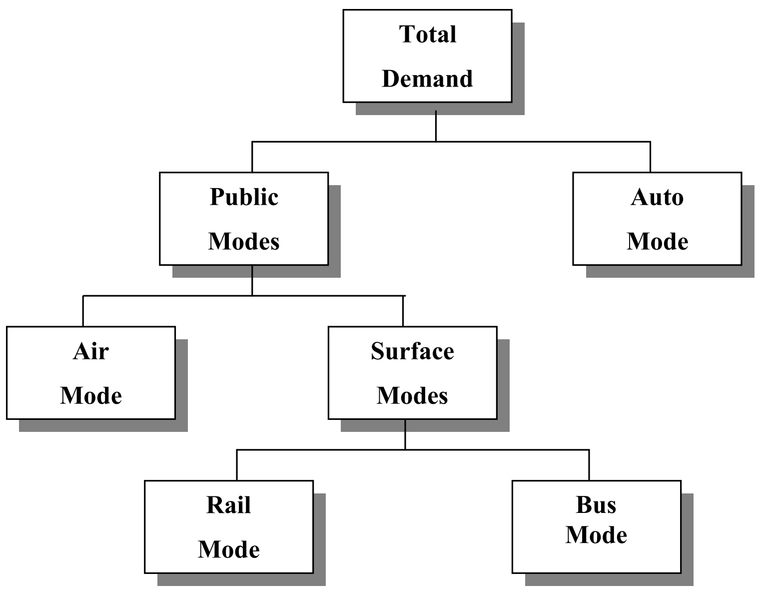
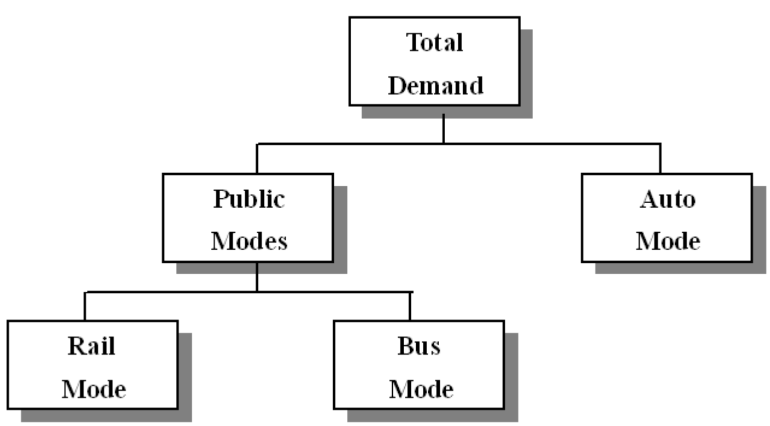


Exhibit B-3: Hierarchical Structure of the Two-Level Short Distance Modal Split Model

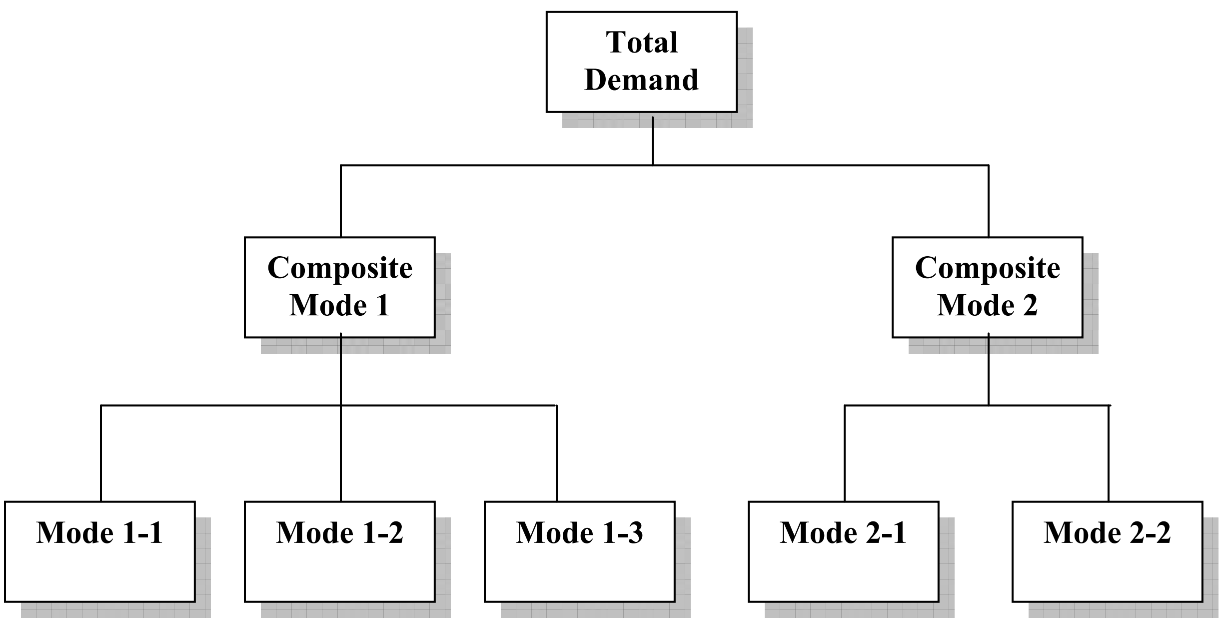


The main feature of the Hierarchical Modal Split Model structure is the increasing commonality of travel characteristics as the structure descends. The first level of the hierarchy separates private auto travel – with its spontaneous frequency, low access/egress times, low costs and highly personalized characteristics – from the public modes. The second level of the three–level structure separates air – the fastest, most expensive and perhaps most frequent public mode – from the rail and bus surface modes. The lowest level of the hierarchy separates rail, a potentially faster, more comfortable, and more reliable mode, from the bus.

B.3.1 Form of the Hierarchical Modal Split Model

The modal split models used by TEMS derived from the standard nested logit model. Exhibit B-4 shows a typical two-level standard nested model. In the nested model shown in Exhibit B-4, there are five travel modes that are grouped into two composite modes, namely, Composite Mode 1 and Composite Mode 2.

Exhibit B-4: A Typical Standard Nested Logit Model



Each travel mode in the above model has a utility function of U_j, j = 1, 2, 3, 4, 5. To assess modal split behavior, the logsum utility function, which is derived from travel utility theory, has been adopted for the composite modes in the model. As the modal split hierarchy ascends, the logsum utility values are derived by combining the utility of lower-level modes. The composite utility is calculated by

$$U_{N_k} = \alpha_{N_k} + \beta_{N_k} \log \sum_{i \in N_k} \exp(\rho U_i) \qquad (1)$$

where
N_k is composite mode k in the modal split model,
i is the travel mode in each nest,
U_i is the utility of each travel mode in the nest,
ρ is the nesting coefficient.

The probability that composite mode k is chosen by a traveler is given by

$$P(N_k) = \frac{\exp(U_{N_k} / \rho)}{\sum_{N_i \in N} \exp(U_{N_i} / \rho)} \qquad (2)$$

The probability of mode i in composite mode k being chosen is

$$P_{N_k}(i) = \frac{\exp(\rho U_i)}{\sum_{j \in N_k} \exp(\rho U_j)} \qquad (3)$$

A key feature of these models is a use of utility. Typically in transportation modeling, the utility of travel between zones i and j by mode m for purpose p is a function of all the components of travel time, travel cost, terminal wait time and cost, parking cost, etc. This is measured by generalized cost developed for each origin-destination zone pair on a mode and purpose basis. In the model application, the utility for each mode is estimated by calibrating a utility function against the revealed base year mode choice and generalized cost.

Using logsum functions, the generalized cost is then transformed into a composite utility for the composite mode (e.g. Surface and Public in Exhibit B-2). This is then used at the next level of the hierarchy to compare the next most similar mode choice (e.g. in Exhibit B-2, Surface is compared with Air mode).

B.3.2 Degenerate Modal Split Model

For the purpose of the Colorado High-Speed Rail Study (and other intercity high-speed rail projects) TEMS has adopted a special case of the standard logit model, the degenerate nested logit model [*Louviere, et.al., 2000*]. This is because in modeling travel choice, TEMS has followed a hierarchy in which like modes are compared first, and then with gradually more disparate modes as progress is made up the hierarchy, this method provides the most robust and statistically valid structure. This means however, that there are singles modes being introduced at each level of the hierarchy and that at each level the composite utility of two modes combined at the lower level (e.g. the utility of Surface mode combined from Rail and Bus modes) is compared with the generalized cost of a single mode (e.g. Air mode). It is the fact that the utilities of the two modes being compared are measured by different scales that creates the term degenerate model. The result of this process is that the nesting coefficient is subsumed into the hierarchy and effectively cancels out in the calculation. That is why TEMS set ρ to 1 when using this form of the model.

Take the three-level hierarchy shown in Exhibit B-2 for example, the utilities for the modes of Rail and Bus in the composite Surface mode are

$$U_{Rail} = \alpha_{Rail} + \beta_{Rail} GC_{Rail} \tag{4}$$

$$U_{Bus} = \beta_{Bus} GC_{Bus} \tag{5}$$

The utility for the composite Surface mode is

$$U_{Surface} = \alpha_{Surface} + \beta_{Surface} \log[\exp(\rho U_{Rail}) + \exp(\rho U_{Bus})] \tag{6}$$

The utility for the Air mode is

$$U_{Air} = \beta_{Air} \log[\exp(\rho GC_{Air})] = \rho \beta_{Air} GC_{Air} \tag{7}$$

Then the mode choice model between Surface and Air modes are

$$P(Surface) = \frac{\exp(U_{Surface} / \rho)}{\exp(U_{Surface} / \rho) + \exp(U_{Air} / \rho)} \tag{8}$$

It can be seen in equation (7) that $U_{Air} = \rho \beta_{Air} GC_{Air}$, the term of $\exp(U_{Air} / \rho)$ in equation (8) reduces to $\exp(\beta_{Air} GC_{Air})$, thus that the nesting coefficient ρ is canceled out in the single mode nest of the hierarchy. As a result, ρ loses its statistical meaning in the nested logit hierarchy, and leads to the degenerate form of the nested logit model, where ρ is set to 1.

B.3.3 Calibration of the Hierarchical Modal Split Model

Working from the bottom of the hierarchy up to the top, the first analysis is that of the rail mode versus the bus mode. As shown in Exhibit B-5, the model was effectively calibrated for the four trip purposes and the two trip lengths (over and under 80 miles), with reasonable parameters and R^2 and *t* values. All the coefficients have the correct signs such that demand increases or decreases in the correct direction as travel times or costs are increased or decreased, and all the coefficients appear to be reasonable in terms of the size of their impact.

Exhibit B-5: Rail versus Bus Modal Split Model Coefficients [1]

Long-Distance Trips *(longer than 80 miles)*

Business	$\log(P_{Rail}/P_{Bus})$	=	1.163	- 0.009 GC_{Rail} (156)	+	0.013 GC_{Bus} (396)	R^2=0.97
Commuter	$\log(P_{Rail}/P_{Bus})$	=	0.012	- 0.017 GC_{Rail} (268)	+	0.019 GC_{Bus} (660)	R^2=0.98
Tourist	$\log(P_{Rail}/P_{Bus})$	=	2.655	- 0.012 GC_{Rail} (179)	+	0.012 GC_{Bus} (502)	R^2=0.96
Social	$\log(P_{Rail}/P_{Bus})$	=	-0.798	- 0.012 GC_{Rail} (220)	+	0.013 GC_{Bus} (479)	R^2=0.97

Short-Distance Trips (*shorter than 80 miles*)

Business	$\log(P_{Rail}/P_{Bus})$	=	-0.955	- 0.003 GC_{Rail} (25)	+	0.005 GC_{Bus} (88)	R^2=0.62
Commuter	$\log(P_{Rail}/P_{Bus})$	=	-0.168	- 0.012 GC_{Rail} (61)	+	0.009 GC_{Bus} (99)	R^2=0.60
Tourist	$\log(P_{Rail}/P_{Bus})$	=	0.518	- 0.008 GC_{Rail} (57)	+	0.007 GC_{Bus} (147)	R^2=0.76
Social	$\log(P_{Rail}/P_{Bus})$	=	-4.031	- 0.010 GC_{Rail} (50)	+	0.018 GC_{Bus} (172)	R^2=0.82

[1] *t-statistics are given in parentheses.*

The constant term in each equation indicates the degree of bias towards one mode or the other. For example, if the constant term is positive, there is a bias towards rail travel that is not explained by the variables (e.g., times, costs, frequencies, reliability) used to model the modes. In considering the bias it is important to recognize that small values indicate little or no bias, and that small values have error ranges that include both positive and negative values. However, large biases may well reflect strong feelings to a modal option due to its innate character or network structure. For example, the short distance social trip purpose includes many shoppers who are sensitive to the access/egress convenience of their modal choice. This frequently leads them to select bus over rail, and for the social purpose to have a negative constant when compared to rail. The reason why the R^2 value for short-distance model is lower than in the long-distance model is due to the fact that some local trips (under 55 miles) were not included as a result of the intercity feature of this study.

For the second level of the hierarchy, the analysis is of the surface modes (i.e., rail and bus) versus air for the three-level model hierarchy only. Accordingly, the utility of the surface modes is obtained by deriving the logsum of the utilities of rail and bus. The Air mode for long distance travel displays a very powerful bias against both rail and bus as it provides a much faster alternative if more expensive. As shown in Exhibit B-6, the model calibrations for both trip purposes are all statistically significant, with good R2 and t values and reasonable parameters.

Exhibit B-6: Surface versus Air Modal Split Model Coefficients [1]

Long-Distance Trips (*longer than 80 miles*)

Business $\log(P_{Surf}/P_{Air}) = -7.537 + 1.092\ V_{Surf} + 0.011\ GC_{Air}$ $R^2=0.98$
(282) (548)

where $V_{Surf} = \log[\exp(1.163 - 0.009\ GC_{Rail}) + \exp(-0.013\ GC_{Bus})]$

Commuter $\log(P_{Surf}/P_{Air}) = -5.068 + 1.045\ V_{Surf} + 0.019\ GC_{Air}$ $R^2=0.98$
(651) (1454)

where $V_{Surf} = \log[\exp(0.012 - 0.017\ GC_{Rail}) + \exp(-0.019\ GC_{Bus})]$

Tourist $\log(P_{Surf}/P_{Air}) = -6.458 + 1.080\ V_{Surf} + 0.012\ GC_{Air}$ $R^2=0.96$
(340) (950)

where $V_{Surf} = \log[\exp(2.655 - 0.012\ GC_{Rail}) + \exp(-0.012\ GC_{Bus})]$

Social $\log(P_{Surf}/P_{Air}) = -5.609 + 1.060\ V_{Surf} + 0.013\ GC_{Air}$ $R^2=0.98$
(992) (1854)

where $V_{Surf} = \log[\exp(-0.798 - 0.012\ GC_{Rail}) + \exp(-0.013\ GC_{Bus})]$

[1] *t-statistics are given in parentheses.*

The analysis for the top level of the hierarchy is of auto versus the public modes. The utility of the public modes is obtained by deriving the logsum of the utilities of the air, rail and bus modes in the three-level model hierarchy and the by deriving the logsum of the utilities of the rail and bus in the two-level model hierarchy. For Auto versus surface for long distance trips the bias is to air and potentially rail because of their travel time advantage, however, for short distance trips the bias is equally strong towards Auto reflecting the advantage of minimal access and egress times and cost.

As shown in Exhibit B-7, the model calibrations for both trip purposes are all statistically significant, with good R^2 and *t* values and reasonable parameters.

Exhibit B-7: Public versus Auto Hierarchical Modal Split Model Coefficients [(1)]

Long-Distance Trips (*longer than 80 miles*)

Business $\log(P_{Pub}/P_{Auto}) = 5.406 + \underset{(216)}{0.898}\, V_{Pub} + \underset{(128)}{0.009}\, GC_{Auto}$ $R^2=0.92$

where $V_{Pub} = \log[\exp(-7.537+1.092\, V_{Surf}) + \exp(-0.011\, GC_{Air})]$

Commuter $\log(P_{Pub}/P_{Auto}) = 3.554 + \underset{(188)}{0.682}\, V_{Pub} + \underset{(106)}{0.016}\, GC_{Auto}$ $R^2=0.88$

where $V_{Pub} = \log[\exp(-5.068+1.045\, V_{Surf}) + \exp(-0.019\, GC_{Air})]$

Tourist $\log(P_{Pub}/P_{Auto}) = 4.154 + \underset{(174)}{0.809}\, V_{Pub} + \underset{(58)}{0.007}\, GC_{Auto}$ $R^2=0.81$

where $V_{Pub} = \log[\exp(-6.458+1.080\, V_{Surf}) + \exp(-0.012\, GC_{Air})]$

Social $\log(P_{Pub}/P_{Auto}) = 3.682 + \underset{(315)}{0.745}\, V_{Pub} + \underset{(174)}{0.012}\, GC_{Auto}$ $R^2=0.96$

where $V_{Pub} = \log[\exp(-5.609 +1.060\, V_{Surf}) + \exp(-0.013\, GC_{Air})]$

Short-Distance Trips (*shorter than 80 miles*)

Business $\log(P_{Pub}/P_{Auto}) = -5.325 + \underset{(76)}{1.321}\, V_{Pub} + \underset{(190)}{0.032}\, GC_{Auto}$ $R^2=0.90$

where $V_{Pub} = \log[\exp(-0.955 - 0.003\, GC_{Rail}) + \exp(-0.005\, GC_{Bus})]$

Commuter $\log(P_{Pub}/P_{Auto}) = -4.049 + \underset{(99)}{1.258}\, V_{Pub} + \underset{(86)}{0.035}\, GC_{Auto}$ $R^2=0.60$

where $V_{Pub} = \log[\exp(-0.168 -0.012\, GC_{Rail}) + \exp(-0.009\, GC_{Bus})]$

Tourist $\log(P_{Pub}/P_{Auto}) = -3.199 + \underset{(310)}{1.010}\, V_{Pub} + \underset{(250)}{0.026}\, GC_{Auto}$ $R^2=0.94$

where $V_{Pub} = \log[\exp(0.518 -0.008\, GC_{Rail}) + \exp(-0.007\, GC_{Bus})]$

Social $\log(P_{Pub}/P_{Auto}) = -3.334 + \underset{(408)}{0.928}\, V_{Pub} + \underset{(375)}{0.062}\, GC_{Auto}$ $R^2=0.96$

where $V_{Pub} = \log[\exp(-4.031 -0.010\, GC_{Rail}) + \exp(-0.018\, GC_{Bus})]$

[(1)] t-statistics are given in parentheses.

B.3.4 Incremental Form of the Modal Split Model

Using the same reasoning as previously described, the modal split models are applied incrementally to the base data rather than imposing the model estimated modal shares. Different regions of the corridor may have certain biases toward one form of travel over another and these differences cannot be captured with a single model for the entire system. Using the "pivot point" method, many of these differences can be retained. To apply the modal split models incrementally, the following reformulation of the hierarchical modal split models is used (Equation 7):

Equation 7:

$$\frac{\left(\frac{P_A^f}{P_B^f}\right)}{\left(\frac{P_A^b}{P_B^b}\right)} = e^{\beta (GC_A^f - GC_B^b) + \gamma (GC_B^f - GC_B^b)}$$

For hierarchical modal split models that involve composite utilities instead of generalized costs, the composite utilities would be used in the above formula in place of generalized costs. Once again, the constant term is not used and the drivers for modal shifts are changed in generalized cost from base conditions.

Another consequence of the pivot point method is that it prevents possible extreme modal changes from current trip-making levels as a result of the calibrated modal split model, thus that avoid over- or under- estimating future demand for each mode.

B.4 Induced Demand Model

Induced demand refers to changes in travel demand related to improvements in a transportation system, as opposed to changes in socioeconomic factors that contribute to growth in demand. The quality or utility of the transportation system is measured in terms of total travel time, travel cost, and worth of travel by all modes for a given trip purpose. The induced demand model used the increased utility resulting from system changes to estimate the amount of new (latent) demand that will result from the implementation of the new system adjustments. The model works simultaneously with the mode split model coefficients to determine the magnitude of the modal induced demand based on the total utility changes in the system.

B.5 References

- **[Ben-Akiva and Lerman, 1985],** M.E. Ben-Akiva and S.R. Lerman, *Discrete Choice Analysis: Theory and Application to Travel Demand,* MIT Press, 1985.
- **[Cascetta, 1996],** E. Cascetta, *Proceedings of the 13th International Symposium on the the Theory of Road Traffic Flow* (Lyon, France),1996.
- **[Daly, A, 1987],** A. Daly, *Estimating "tree" logit models*. Transportation Research B, 21(4):251-268, 1987.
- **[Daly, A., et.al., 2004],** A. Daly, J. Fox and J.G.Tuinenga, *Pivot-Point Procedures in Practical Travel Demand Forecasting*, RAND Europe, 2005
- **[Domenich and McFadden, 1975],** T.A. Domenich and D. McFadden, *Urban Travel Demand: A behavioral analysis,* North-Holland Publishing Company, 1975.
- **[Garling et.al., 1998],** T. Garling, T. Laitila, and K. Westin, *Theoretical Foundations of Travel Choice Modeling*, 1998.
- **[Hensher and Johnson, 1981],** D.A. Hensher and L.W. Johnson, *Applied discrete choice modelling.* Croom Helm, London, 1981
- **[Horowitz, et.al., 1986],** J.L. Horowitz, F.S. Koppelman, and S.R. Lerman, *A self-instructing course in disaggregate mode choice modeling,* Technology Sharing Program, USDOT, 1986.
- **[Koppelman, 1975],** F.S. Koppelman, *Travel Prediction with Models of Individual Choice Behavior*, PhD Submittal, Massachusetts Institute, 1975.
- **[Louviere, et.al., 2000],** *J.J.Louviere, D.A.Hensher, and J.D.Swait, Stated Choice Methods: Analysis and Application*, Cambridge, 2000
- **[Luce and Suppes, 1965],** R.D. Luce and P. Suppes, *Handbook of Mathematical Psychology*, 1965.
- **[Rogers et al., 1970],** K.G. Rogers, G.M. Townsend and A.E. Metcalf, *Planning for the work. Journey –a generalized explanation of modal choice*, Report C67, Reading, 1970.
- **[Wilson, 1967],** A.G. Wilson, *A Statistical Theory of Spatial Distribution models*, Transport Research, Vol. 1, 1967.
- **[Quarmby, 1967],** D. Quarmby, *Choice of Travel Mode for the Journey to Work: Some Findings*, Journal of Transport Economics and Policy, Vol. 1, No. 3, 1967.
- **[Yai, et.al., 1997],** T. Yai, S. Iwakura, and S. Morichi, *Multinominal probit with structured covariance for route choice behavior, Transportation Research B, 31(3):195-208, 1997.*

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