

TECHNICAL APPENDICES

Appendix A: COMPASS™ Model

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.

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 two trip purposes, which are Business and Non-Business. For each market segment, the models were calibrated on base year origin-destination trip data, existing network characteristics and base year socioeconomic data.

Since the models were calibrated on the base year data, when 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.

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

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 and Non-Business. The socioeconomic characteristics consist of population, employment and average 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/or 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.

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 average 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 statistically stable relationships consist of the following formulations:

Trip Purpose	Socioeconomic Variable
Business	$E_i E_j (I_i + I_j) / 2$
Non-Business	$(P_i E_j + P_j E_i) / 2 (I_i + I_j) / 2$

The Business formulation consists of a product of employment in the origin zone, employment in the destination zone, and the average income of the two zones. Since business trips are usually made between places of work, the presence of employment in the formulation is reasonable. While the income factor is correlated to the type of employment, higher income levels generate more Business trips. The Non-Business 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, and income factor is related to the wealth of the origin zone and the type of employment in the destination zone, leisure and social trip are correlated to population in the origin zone and destination zone and the average income of the two zones.

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,

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

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 and bus), the generalized cost of travel includes all aspects of travel time (access, egress, in-vehicle times), travel cost (fares), and schedule convenience (frequency of service, convenience of arrival/departure times). For auto travel, full average cost of operating a car is used for Business, while only the marginal cost is used for Commuter and Other trips. In addition, tolls and parking charges are used where appropriate.

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:

$$GC_{ijmp} = TT_{ijm} + \frac{TC_{ijmp}}{VOT_{mp}} + \frac{VOF_{mp} * OH}{VOT_{mp} * F_{ijm}}$$

Where,

TT_{ijm} = Travel Time between zones i and j for mode m (in-vehicle time + station wait time + connection time + access/egress time), with waiting, connect and access/egress time multiplied by a factor (waiting and

connect time factors is 1.8, access/egress factors were determined by VOA/VOT ratios from the SP survey) 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

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

OH =Operating hours per week (sum of daily operating hours between the first and last service of the day)

Station wait time is the time spent at the station before departure and after arrival. 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 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 be 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 effective to measure this impact as a function of the headway.

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 resulted in two sets of models. The results of the calibration for the Total Demand Models are displayed in Exhibit 1.

Exhibit 1: Total Demand Model Coefficients ⁽¹⁾

Business	$\log(T_{ij}) = -7.4655 + 0.5298 \log(SE_{ij}) + 0.6236 U_{ij} \quad R^2=0.87$ <p style="text-align: center;">(21) (613)</p> <p>where $U_{ij} = \log[\exp(-9.8691+0.9976U_{Public}) + \exp(-0.0046 GC_{Auto})]$</p>
Other	$\log(T_{ij}) = -4.1441 + 0.4466 \log(SE_{ij}) + 0.7103 U_{ij} \quad R^2=0.92$ <p style="text-align: center;">(252) (725)</p> <p>where $U_{ij} = \log[\exp(-4.7022+0.9711U_{Public}) + \exp(-0.0056 GC_{Auto})]$</p>

(1) *t*-statistics are given in parentheses.

In evaluating the validity of a statistical calibration, there are two key statistical measures: *t*-statistics and R². 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. R² 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 R² values imply good fits of the equations to the data.

As shown in Exhibit 1, the socioeconomic elasticity values for the Total Demand Model are 0.53 and 0.36 for business and non-business trips, meaning that each one percent growth in the socioeconomic term generates approximately a 0.53 and 0.36 percent growth in the total business and non-business travel market respectively.

The coefficient on the utility term is not strictly elasticity, but it can be considered an approximation. The utility term 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 transportation systems are built. In these cases, a 20 percent improvement in utility is not unusual and may impact more heavily on longer origin-destination pairs than shorter origin-destination pairs.

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:

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

Where,

T_{ijp}^f = Number of Trips between zones *i* and *j* for trip purpose *p* in forecast year *f*

T_{ijp}^b = Number of Trips between zones *i* and *j* for trip purpose *p* in base year *b*

SE_{ijp}^f = Socioeconomic variables for zones *i* and *j* for trip purpose *p* in forecast year *f*

SE_{ijp}^b = Socioeconomic variables for zones *i* and *j* for trip purpose *p* in base year *b*

U_{ijp}^f = Total utility of the transportation system for zones *i* to *j* for trip purpose *p* in forecast year *f*

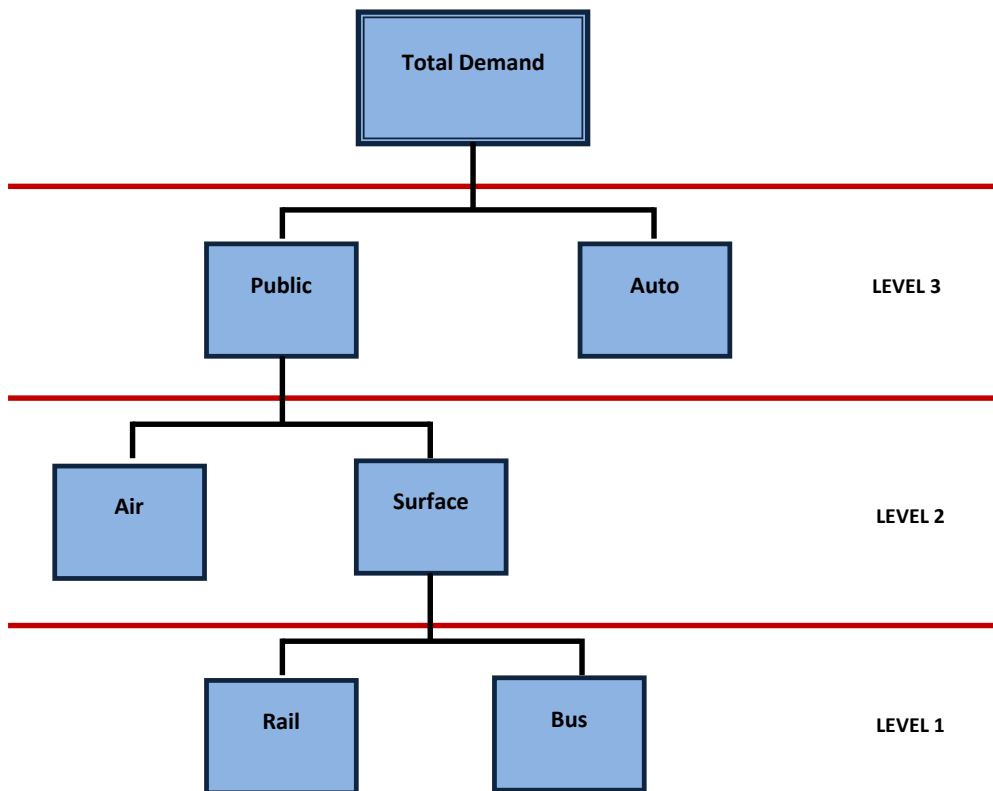
$$U_{ijp}^b = \text{Total utility of the transportation system for zones } i \text{ to } j \text{ for trip purpose } p \text{ in base year } b$$

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

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 interurban modal choices available in the study area. The hierarchical modal split model is shown in Exhibit 2.

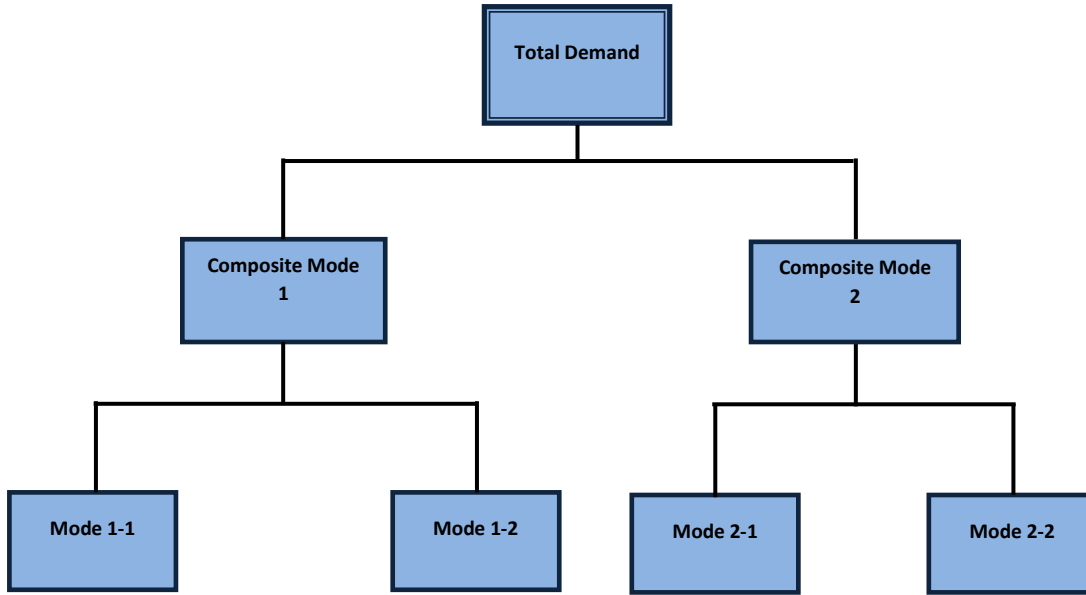
Exhibit 2: Hierarchical Structure of the Modal Split Model



The main feature of the Hierarchical Modal Split Model structure is the increasing commonality of travel characteristics as the structure descends. The upper 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 lower separates Maglev – a faster and more comfortable public mode – from Transit, which provides slower conventional rail and bus services within the corridor.

Background of the Hierarchical Modal Split Theory

The modal split models used by TEMS derived from the standard nested logit model. Exhibit 3 shows a typical two-level standard nested model. In the nested model shown in Exhibit 3, there are four travel modes that are grouped into two composite modes, namely, Composite Mode 1 and Composite Mode 2.

Exhibit 3: A Typical Standard Nested Logit Model


Each travel mode in the above model has a utility function of U_j , $j = 1, 2, 3, 4$. 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

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

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

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

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

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

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. Public modes in Exhibit 2). This is then used at the next level of the hierarchy to compare the next most similar mode choice (e.g. in Exhibit 2, Public mode is compared with Auto mode).

Calibration of the Hierarchical Modal Split Model

Working from the lower level of the hierarchy to the upper level, the first analysis is that of the Rail mode versus the Bus mode. As shown in Exhibit 4, the model was effectively calibrated for the two trip purposes, 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 4: Rail versus Bus Modal Split Model Coefficients ⁽¹⁾

Business	$\log(\text{PRail}/\text{PBus}) = -5.7562 - 0.0134 \text{ GCRail} + 0.0105 \text{ GCBus}$	$R^2=0.70$
	(-303) (322)	
Other	$\log(\text{PRail}/\text{PBus}) = 0.9312 - 0.0062 \text{ GCRail} + 0.0048 \text{ GCBus}$	$R^2=0.75$
	(-309) (377)	

(1) t -statistics are given in parentheses.

The coefficients for the upper levels of the hierarchy of Surface mode versus Air mode and Public versus Auto mode are given in Exhibits 5 and 6 respectively. The utility of the composite modes is obtained by deriving the logsum of the utilities of lower level modes from the model. The model calibrations for both trip purposes are statistically significant, with good R^2 and t values, and reasonable coefficients.

Exhibit 5: Surface versus Air Modal Split Model Coefficients ⁽¹⁾

Business	$\log(\text{PSurface}/\text{PAir}) = 5.6751 + 0.9795 \text{ USurf} + 0.0088 \text{ GCAir}$	$R^2=0.80$
	(425) (222)	
	where $\text{USurf} = \log[\exp(-5.7562-0.0134\text{GCRail}) + \exp(-0.0105 \text{ GCBus})]$	
Other	$\log(\text{PSurface}/\text{PAir}) = -0.2423 + 0.9815 \text{ USurf} + 0.0053 \text{ GCAir}$	$R^2=0.79$
	(137) (63)	
	where $\text{USurf} = \log[\exp(0.9312-0.0062\text{GCRail}) + \exp(-0.0048 \text{ GCBus})]$	

(1) t -statistics are given in parentheses.

Exhibit 6: Public versus Auto Modal Split Model Coefficients ⁽¹⁾

Business	$\log(P_{Public}/P_{Auto}) = -9.8691 + 0.9976 U_{Public} + 0.0046 G_{CAuto}$ $(384) \qquad (203)$	R ² =0.90
	<p>where $U_{Public} = \log[\exp(5.6751+0.9795U_{Surface}) + \exp(-0.0088 G_{CAir})]$</p>	
Other	$\log(P_{Public}/P_{Auto}) = -4.7022 + 0.9711 U_{Public} + 0.0056 G_{CAuto}$ $(266) \qquad (326)$	R ² =0.88
	<p>where $U_{Public} = \log[\exp(-0.2423+0.9815U_{Surface}) + \exp(-0.0053 G_{CAir})]$</p>	

(1) t-statistics are given in parentheses.

Incremental Form of the Modal Split Model

Using the same reasoning as previously described, the modal split models are applied incrementally to the base year 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 6):

Equation 6:

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

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 avoiding over or under estimating future demand for each mode.

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 uses 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. It should be noted that the model will also forecast a reduction in trips if the quality of travel falls due to increased congestions, higher car operating costs, or increased tolls. The utility function acts like a demand curve, increasing or decreasing travel based on changes in price (utility) for travel. It assumes travel is a normal good and subject to the laws of supply and demand.

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