## Value of Time and Toll

Starting in NCSTMGen3, the model incorporates a path-based toll diversion model that makes use of different vehicle classes subdivided into distinct values of time. This section documents the data preparation and model specification steps used to estimate distributions of values of time (VOT) for travelers in North Carolina. Multinomial logit (MNL) and mixed multinomial logit (MMNL) models were estimated using data collected from three separate stated preference surveys conducted in North Carolina. A brief description of each project is provided below:

Triangle Expressway Stated Preference Travel Survey

The Triangle Expressway Stated Preference Survey was conducted by RSG in 2007 for CDM Smith and the North Carolina Turnpike Authority. The survey was conducted as part of an investment-grade traffic and revenue study of the Triangle Expressway, a proposed extension of I-540 from NC-55 near Research Triangle Park (RTP) south to the NC-55 Holly Springs Bypass, with a spur from I-540 to the intersection of I-40 and NC-147. Data was collected in the Research Triangle area in January and February of 2007. A total of 4,745 complete surveys were collected through laptop-based participation of respondents intercepted at activity centers, online completion by employees of local businesses, and online completion by participants in a previous origin-destination study who were willing to participate in any follow-up studies regarding the study route.

Metrolina Region Stated Preference Travel Study

In the spring of 2010, RSG conducted the Metrolina Region Travel Study for CDM Smith and the North Carolina Turnpike Authority. The Turnpike Authority was working to improve east-west mobility and connectivity within southern Gaston County and Western Mecklenburg County. As part of this work, The Turnpike Authority was considering the construction of a toll highway that would extend for roughly 22 miles from Interstate 85, west of Gastonia, NC to the I-485 Loop in Mecklenburg County, NC. RSG collected 1,151 completed surveys from residents throughout the Gastonia-Charlotte area in early 2010. The survey was made available to respondents via onsite intercepts using laptop computers, email invitation to the email addresses collected in an associated origin-destination survey, and via email invitation to members of the community who requested to participate in the study.

Monroe Connector/Bypass Stated Preference Travel Study

In the spring and summer of 2009, RSG teamed with CDM Smith to conduct the Monroe Connector/Bypass Stated Preference Travel Study. The North Carolina Turnpike Authority was working to improve mobility in the Mecklenburg / Union County Region. As part of this work, the Turnpike Authority was considering constructing a highway that would extend for approximately 20 miles from US 74/I-485 near Matthews and the Charlotte Outer Loop to US 74 east of Wingate. Data were collected in the early summer of 2009. Travelers who had traveled in or through the Monroe-Charlotte study area were recruited to participate in the study. Data were collected via laptops to respondents intercepted at activity sites, as well as online to targeted audiences who could benefit from the construction of the Monroe Connector/Bypass. A total of 878 completed surveys were used to estimate discrete choice models.

To assemble a single dataset suitable for the estimation of discrete choice models, the stated preference (SP) datasets from each of the three studies were carefully reviewed. Relevant categorical variables were recoded so that each dataset contained a matching number of identically coded fields.

Because several years have elapsed since the data were collected, the toll costs in each dataset were adjusted for inflation using consumer price index (CPI) data published by the Bureau of Labor Statistics (BLS). Study-specific CPI adjustment factors based on time elapsed and geographic area were applied to the original toll costs that were shown to respondents in the stated preference surveys. The adjustment factors applied to the Triangle Expressway, Monroe Connector, and Garden Parkway data were 1.21, 1.13, and 1.12, respectively.

After removing a small number of respondents with unrealistic reported trip distances, a total of 54,982 stated preference observations from 6,763 respondents were included in the final dataset. Due to the significant computational resources required to estimate mixed multinomial models, random samples of 2,000 peak and 2,000 off-peak travelers were selected from the merged dataset, resulting in 16,203 and 16,294 SP observations, for each segment respectively.

### Model Estimation

The primary objective of the SP studies was to estimate the VOT for passenger vehicle travelers who make trips on toll roads in North Carolina.

Statistical analysis and discrete choice model estimation were carried out using the sampled stated preference survey data. The statistical estimation and specification testing were completed using a conventional maximum likelihood procedure that estimates coefficients for a set of multinomial logit (MNL) and mixed multinomial logit (MMNL) models. The model coefficients provide information about the respondents’ sensitivities to the attributes that were tested in the tradeoff scenarios and can be used to calculate VOT for travelers in the study corridor.

The candidate multinomial logit (MNL) models were developed for specification testing and for use in comparing and scaling the results of the final distributions and to identify systematic differences in preference heterogeneity—for example the difference in value of time by trip purpose or time-of-day.

In addition to systematic heterogeneity, there are also random differences in preference heterogeneity within a population. In other words, there are actual random variations of preference among the same set of individuals that cannot be accounted for in any systematic way. One of the key benefits of the MMNL model is that it allows for random variations among respondents by assuming their sensitivities to travel time and/or toll cost fall along a known distribution. The MMNL model provides a mean estimate for the value of time and the standard deviation of that estimate. This information can be used to simulate VOT distributions for the sample. This information is used to establish the proportion of traffic that will choose a toll route at any given combination of travel time savings and toll cost amounts. The model results are discussed in more detail below.

### Model Specification and Segmentation

In each stated preference scenario, the following two alternatives were presented for making a future trip in the area:

1. Current toll-free route with a travel time
2. Toll route with a shorter travel time and an associated toll
3. Toll route with a shorter travel time and an associated toll (Monroe Connector only)

The multinomial logit model estimates a choice probability for each alternative presented in the stated preference tradeoff exercises. The alternatives are represented in the model by observed utility equations of the form:

∪1=β1 X1+β2 X2…+βn Xn

Where each X represents a variable specified by the researcher and each β is a coefficient estimated by the model that represents the sensitivity of the respondents in the sample to the corresponding variable.

To achieve the best model outcomes, several utility equation structures were tested using different variables from the collected data. In addition to the travel times and toll costs presented in the stated preference experiments, tested variables included trip characteristics, attitudinal indicators, and demographic variables. These variables were introduced, one at a time, to test potential interactions with the toll cost and travel time coefficients and to determine whether respondents’ trip or personal characteristics significantly influenced their choices in the stated preference scenarios. Variables that were tested for interaction included:

* Time of day (peak or off-peak period)
* Day of week (weekends or weekdays)
* Trip purpose
* Trip start and end locations (home based or non-home based)
* Project opinion
* Household income
* Trip distance

After reviewing the significance of each variable, the final model specification was chosen based on model fit, the intuitiveness and reasonableness of the model coefficients, and the expected application of the model results. The final model specifications include variables for travel time and toll cost, with segmentation based on time of day and project opinion. To control for potential strategic bias (where a respondent may respond to the survey in a way that influences a specific outcome), respondents who indicated strong opposition to the project in the opinion question were separated from the peak and off-peak market segments. Table 11‑10 shows the segmentations used in the final MNL and MMNL models.

Table 11‑10: Final Model Segmentations

|  |  |  |  |
| --- | --- | --- | --- |
| Segment | Count | Percent | Definition |
| Peak Trips | 1,336 | 33% | Weekdays 6am-9am  Weekdays 4pm-7pm |
| Off-peak Trips | 1,312 | 33% | Weekends  Weekdays 7pm-6am  Weekdays 9am-4pm |
| Strongly Opposed | 1,352 | 34% | Strongly opposed to project |
| Total | 4,000 | 100% |  |

Additionally, the toll cost coefficient was interacted with household income and trip distance to identify the relationship of income and trip distance with sensitivity to toll prices. Log transformations were used to capture the non-linear, diminishing relationships of income and trip distance with VOT. The following transformation was used:

### MNL Model: Coefficient Estimates

The results of the final segmented peak and off-peak MNL models are presented below in Table 11‑11 and Table 11‑12, respectively, which contain coefficient values, robust standard errors, robust t-statistics, and general model statistics.

The coefficient values are the values estimated by the choice model that represent the relative importance of each of the variables. It should be noted that these values are unit-specific and the units must be accounted for when comparing coefficients. The sign of the coefficient indicates a positive or negative relationship between utility and the associated variable. For example, a negative travel time coefficient implies that utility for a given travel alternative will decrease as the travel time associated with that alternative increases.

The standard error is a measure of error around the mean coefficient estimate. The t-statistic is the coefficient estimate divided by the standard error, which can be used to evaluate statistical significance. A t-statistic greater/less than ±1.96 indicates that the coefficient is statistically significantly different from zero (unless otherwise reported) at the 95% level.

The model fit statistics presented below include the number of observations, the number of estimated parameters, the initial log-likelihood, the log-likelihood at convergence, rho-squared, and adjusted rho-squared. The log-likelihood is a model fit measure that indicates how well the model predicts the choices observed in the data. The null log-likelihood is the measure of the model fit with coefficient values of zero. The final log-likelihood is the measure of model fit with the final coefficient values at model convergence. A value closer to zero indicates better model fit. The log-likelihood cannot be evaluated independently, as it is a function of the number of observations, the number of alternatives, and the number of parameters in the choice model. The rho-square model fit measure accounts for this to some degree by evaluating the difference between the null log-likelihood and the final log-likelihood at convergence. The adjusted rho-square value accounts for the number of parameters estimated in the model.

Table 11‑11: Peak Segment MNL Model Results

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Name | Alternatives | | | Coefficient Values | | |
| Current Route | Toll  Option 1 | Toll  Option 2 | Value | Robust Std. Error | Robust T-Test |
| Travel Time |  |  |  |  |  |  |
| Not strongly opposed | X | X | X | -0.147 | 0.0106 | -13.79 |
| Strongly opposed | X | X | X | 0.0254 | 0.0448 | 0.57 |
| Toll Cost\* |  |  |  |  |  |  |
| Not strongly opposed |  | X | X | -22.1 | 1.74 | -12.73 |
| Strongly opposed |  | X | X | -1.73 | 0.595 | -2.90 |
| Constant |  |  |  |  |  |  |
| Toll Constant |  | X | X | -1.26 | 0.118 | -10.75 |
| **Model Statistics** | | | | | | |
| Number of estimated parameters | | 5 | | | | |
| Number of observations | | 16203 | | | | |
| Number of individuals | | 2000 | | | | |
| Null log-likelihood | | -11971.849 | | | | |
| Final log-likelihood | | -6604.399 | | | | |
| Rho-square | | 0.448 | | | | |
| Adjusted rho-square | | 0.448 | | | | |
| \*The toll cost variable enters the model in the form: toll cost/[LN(household income/100)\*LN(10\*trip distance+5)]. | | | | | | |

Table 11‑12: Off-Peak Segment MNL Model Results

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Name | Alternatives | | | Coefficient Values | | |
| Current Route | Toll  Option 1 | Toll  Option 2 | Value | Robust Std. Error | Robust T-Test |
| Travel Time |  |  |  |  |  |  |
| Not strongly opposed | X | X | X | -0.162 | 0.0099 | -16.43 |
| Strongly opposed | X | X | X | -0.0101 | 0.0247 | -0.41 |
| Toll Cost\* |  |  |  |  |  |  |
| Not strongly opposed |  | X | X | -29.4 | 1.90 | -15.52 |
| Strongly opposed |  | X | X | -2.40 | 0.478 | -5.02 |
| Constant |  |  |  |  |  |  |
| Toll Constant |  | X | X | -1.15 | 0.0976 | -11.82 |
| **Model Statistics** | | | | | | |
| Number of estimated parameters | | 5 | | | | |
| Number of observations | | 16294 | | | | |
| Number of individuals | | 2000 | | | | |
| Null log-likelihood | | -12367.001 | | | | |
| Final log-likelihood | | -7032.505 | | | | |
| Rho-square | | 0.431 | | | | |
| Adjusted rho-square | | 0.431 | | | | |
| \*The toll cost variable enters the model in the form: toll cost/[LN(household income/100)\*LN(10\*trip distance+5)]. | | | | | | |

### MNL Model: Willingness to Pay for Travel Time Savings (Value of Time)

One way to evaluate the sensitivities that are estimated in the MNL models is to calculate the marginal rates of substitution for different attributes of interest. In economic theory, the marginal rate of substitution is the amount of one good (e.g., money) that a person would exchange for a second good (e.g., travel time), while maintaining the same level of utility, or satisfaction. In this analysis, the marginal rate of substitution of the travel time and toll cost coefficients provides the implied toll value that travelers would be willing to pay for a given amount of travel time savings offered by using a North Carolina toll road.

The willingness to pay for travel time savings, or value of time, can be calculated by simply dividing the travel time coefficient by the toll cost coefficient after accounting for the income and distance transformations that were applied in the model specification. The resulting value of time is in units of dollars per minute; multiplying by 60 will convert this into the more commonly cited units of dollars per hour:

Where βTime is the value of the travel time coefficient (with units of 1/min), βCost is the value of the toll cost coefficient (with units of 1/$), and the log transformation controls for non-linear income and trip distance effects.

The values of time for respondents who were not strongly opposed to the projects are shown in Table 11‑13 and Table 11‑14 at the different income and distance categories for peak and off-peak trips.

Table 11‑13: Value of Time for Peak Trips

| Income Category Midpoint | Trip Distance (miles) | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| 10 | 20 | 30 | 40 | 50 | 60 |
| $12,500 | $8.97 | $10.26 | $11.02 | $11.57 | $11.99 | $12.34 |
| $37,500 | $11.01 | $12.59 | $13.53 | $14.20 | $14.72 | $15.15 |
| $62,500 | $11.96 | $13.68 | $14.70 | $15.43 | $15.99 | $16.46 |
| $87,500 | $12.58 | $14.39 | $15.47 | $16.23 | $16.83 | $17.32 |
| $125,000 | $13.24 | $15.15 | $16.28 | $17.09 | $17.71 | $18.23 |
| $175,000 | $13.87 | $15.86 | $17.05 | $17.89 | $18.55 | $19.09 |
| $250,000 | $14.53 | $16.62 | $17.86 | $18.75 | $19.44 | $20.00 |

Table 11‑14: Value of Time for Off-Peak Trips

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Income Category Midpoint | Trip Distance (miles) | | | | | |
| 10 | 20 | 30 | 40 | 50 | 60 |
| $12,500 | $7.43 | $8.50 | $9.13 | $9.58 | $9.94 | $10.22 |
| $37,500 | $9.12 | $10.43 | $11.21 | $11.76 | $12.20 | $12.55 |
| $62,500 | $9.91 | $11.33 | $12.18 | $12.78 | $13.25 | $13.63 |
| $87,500 | $10.42 | $11.92 | $12.81 | $13.45 | $13.94 | $14.35 |
| $125,000 | $10.97 | $12.55 | $13.49 | $14.15 | $14.67 | $15.10 |
| $175,000 | $11.49 | $13.14 | $14.12 | $14.82 | $15.37 | $15.81 |
| $250,000 | $12.04 | $13.77 | $14.80 | $15.53 | $16.10 | $16.57 |

### Mixed Multinomial Logit Models

The MNL models captured systematic preference heterogeneity in the data and produced a single, average value of time estimate for each segment. To capture random preference variations among individuals, mixed multinomial logit models were employed, using the final MNL specification. As with the MNL model, the final MMNL model specification includes variables for travel time and toll cost for peak trips, off-peak trips and strongly opposed travelers. The toll cost coefficient was interacted with household income and trip distance to determine the relationship between sensitivity to toll prices and household income. An alternative-specific constant is included on the toll road alternatives to capture the utility (or disutility) for the alternatives that cannot be attributed to any other variables in the model.

One of the key benefits of the MMNL model is that it captures actual random variation among respondents by assuming their preferences fall along a known distribution. In this analysis, the time coefficient and toll constant were specified as random parameters. The MMNL model produces two coefficient estimates for each random parameter—a mean (μ) and a standard deviation (σ)—that describe the center and spread of the distribution for that random parameter. The distribution of the random parameter represents the preference heterogeneity for that attribute across the survey population.

Different underlying distributions for the time and cost parameters and the toll constants were tested for each segment. Assuming a lognormal distribution for travel time sensitivity and a normal distribution for the constant on the toll alternatives produced the best model fit and the most intuitive and reasonable results for each segment. The lognormal distribution is one-sided and truncated at zero, eliminating the possibility of positive utility for travel time, which would be behaviorally inconsistent. The MMNL model was estimated using a maximum simulated likelihood estimation with 1,000 pseudo-random draws.

MMNL Model: Coefficient Estimates

The results of the final model specifications for the MMNL model are presented with robust standard errors, robust t-statistics, and general model statistics in Table 11‑15 and Table 11‑16. While the distribution for travel time was assumed lognormal, the parameters reported here are for the underlying normal distribution. A normal distribution can be transformed into a lognormal distribution by exponentiating the draws from the normal distribution.

Table 11‑15: MMNL Coefficients and Model Statistics for Peak Trips

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Name | Alternatives | | | Coefficient Values | | |
| Current Route | Toll Option 1 | Toll Option 2 | Value | Robust Std. Error | Robust T-Test |
| Travel Time |  |  |  |  |  |  |
| Not strongly opposed | X | X | X | -1.01 | 0.0813 | -12.46 |
| Not strongly opposed – Std. Deviation | X | X | X | 0.818 | 0.0326 | 25.06 |
| Strongly opposed | X | X | X | 0.0615 | 0.0572 | 1.08 |
| Toll Cost\* |  |  |  |  |  |  |
| Not strongly opposed |  | X | X | -111 | 6.97 | -15.91 |
| Strongly opposed |  | X | X | -3.52 | 1.14 | -3.1 |
| Constant |  |  |  |  |  |  |
| Toll Constant |  | X | X | -2.77 | 0.397 | -6.98 |
| Toll Constant – Std. Deviation |  | X | X | 5.66 | 0.427 | 13.26 |
| **Model Statistics** | | | | | | |
| Number of draws | | 1000 | | | | |
| Number of estimated parameters | | 7 | | | | |
| Number of observations | | 16203 | | | | |
| Number of individuals | | 2000 | | | | |
| Null log-likelihood | | -11971.849 | | | | |
| Final log-likelihood | | -4079.85 | | | | |
| Rho-square | | 0.659 | | | | |
| Adjusted rho-square | | 0.659 | | | | |
| \*The toll cost variable enters the model in the form: toll cost/[LN(household income/100)\*LN(10\*trip distance+5)]. | | | | | | |

Table 11‑16: MMNL Coefficients and Model Statistics for Off-Peak Trips

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Name | Alternatives | | | Coefficient Values | | |
| Current Route | Toll Option 1 | Toll Option 2 | Value | Robust Std. Error | Robust T-Test |
| Travel Time |  |  |  |  |  |  |
| Not strongly opposed | X | X | X | -0.883 | 0.0701 | -12.59 |
| Not strongly opposed – Std. Deviation | X | X | X | -0.781 | 0.053 | -14.73 |
| Strongly opposed | X | X | X | -0.0159 | 0.0393 | -0.4 |
| Toll Cost\* |  |  |  |  |  |  |
| Not strongly opposed |  | X | X | -131 | 7.52 | -17.38 |
| Strongly opposed |  | X | X | -4.63 | 0.498 | -9.3 |
| Constant |  |  |  |  |  |  |
| Toll Constant |  | X | X | -2.87 | 0.255 | -11.25 |
| Toll Constant – Std. Deviation |  | X | X | 5.25 | 0.299 | 17.55 |
| **Model Statistics** | | | | | | |
| Number of draws | | 1000 | | | | |
| Number of estimated parameters | | 7 | | | | |
| Number of observations | | 16294 | | | | |
| Number of individuals | | 2000 | | | | |
| Null log-likelihood | | -12367.001 | | | | |
| Final log-likelihood | | -4317.803 | | | | |
| Rho-square | | 0.651 | | | | |
| Adjusted rho-square | | 0.650 | | | | |
| \*The toll cost variable enters the model in the form: toll cost/[LN(household income/100)\*LN(10\*trip distance+5)]. | | | | | | |

### MMNL Model: Willingness to Pay for Travel Time Savings (Value of Time)

Given small differences between the MNL and mean MMNL values of time, the MMNL distributions were scaled to reflect the MNL values of time. Distributions of values of time were developed using the MMNL coefficients. The VOT distribution was simulated for a synthetic population using 10,000 independent draws from the lognormal distribution estimated for travel time sensitivity. The resulting draws were used to calculate 10,000 values of time.

The mean and median values of time for each segment are reported in Table 11‑17. Distributions of value of time, which show the percentage of respondents with a given value of time, are shown by market segment and evaluated at the segment median income and trip distance in Figure 11‑7. Toll choice curves for each of the traveler segments are shown in Figure 11‑8. The choice curves illustrate the percentage of not strongly opposed respondents with a value of time greater than or equal to a given value. For example, Figure 2 shows that 100% of all not strongly opposed respondents have a value of time greater than or equal to $0/hr., while 50% of peak trips have a value of time greater than or equal to $10.25/hr. and 50% of off-peak trips have a value of time greater than or equal to $8.79/hr.

Table 11‑17: Mean and Median MMNL VOT by Market Segment

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Segment | Segment Median Income Midpoint | Segment Median Distance (miles) | Mean | Median |
| Peak Trips | $87,500 | 18.3 | $14.16 | $10.25 |
| Off-peak Trips | $87,500 | 19.3 | $11.84 | $8.79 |

Figure 11‑7: VOT Distribution by Market Segment

Figure 11‑8: Toll Choice Curve by Market Segment

### Values of Time Implemented

The result of these analyses was a set of values of time for auto, single-unit trucks, and multi-unit trucks that could be implemented starting with the NCSTMGen3 toll model. These values of time are documented in Table 11-18 for autos and Table 11‑18 for trucks.

Table 11‑18: Automobile Values of Time

| Peak VOT | Off-Peak VOT | Average Auto VOT |
| --- | --- | --- |
| $3.28 | $3.22 | $3.24 |
| $7.15 | $7.08 | $7.11 |
| $12.29 | $12.21 | $12.24 |
| $19.53 | $19.41 | $19.46 |
| $38.58 | $36.37 | $37.28 |

Table 11‑19: Truck Values of Time

|  |  |
| --- | --- |
| Single-Unit Truck VOT | Multi-Unit Truck VOT |
| $20.52 | $12.57 |
| $38.79 | $31.12 |
| $56.75 | $49.54 |
| - | $67.95 |
| - | $88.34 |