MRM25v1.0 Development Documentation

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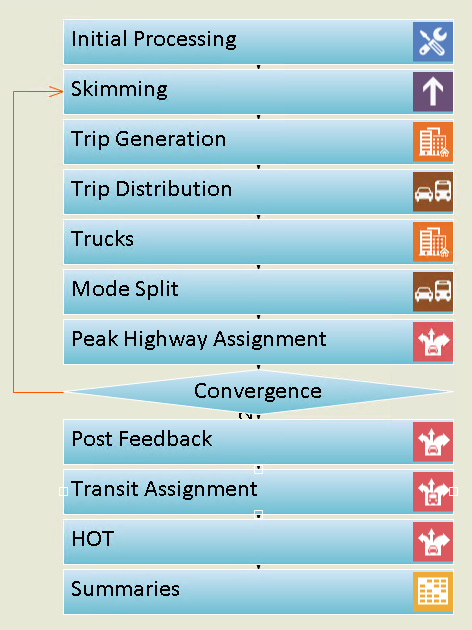
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# Introduction

This document covers the work performed by Caliper Corporation to update the Metrolina Regional Model (MRM) in 2024. The largest change to the model structure was the conversion to a fully-disaggregate model by converting trip mode choice from an aggregate, trip-based approach to a tour-based choice model. In addition, the latest household survey was used to update various other models including tour frequency, destination choice, intermediate stops, and time of day. Finally, the model’s approach to feedback was changed such that all resident trip purposes would run during feedback loops and adjust to congested travel times. Previously, only the work and at-work subtour purposes did so.

# Flowchart Interface

Caliper updated the MRM25 model to use the standard flowchart interface. This effort required a refactoring of the code to support the new interface, but makes the model easier to run and understand. More details on the flowchart and it’s usage can be found in the user’s guide wiki here: <https://github.com/Metrolina-Regional-Model-Team/MRM/wiki>



# Survey Processing

The household survey was conducted by RSG in 2023. Full survey documentation is available from the City of Charlotte. Caliper elected to use the weights developed by RSG after reviewing their weighting and expansion report. The survey was delivered largely pre-processed and identified tours, subtours, and other important variables that usually require post-processing. Still the model’s definition of some tours types (e.g. what qualified as an at-work subtour) were different and required custom processing. Caliper also performed various checks of the survey for things like logical trip consistency within tours, reasonability of behavior patterns, and other metrics and determined that the survey was high quality and able to be used for model estimation.

After creating the standard output tables like trips, tours, persons, and households, Caliper created estimation datasets for specific models. These were used internally, but for tour frequency and intermediate stop frequency, those tables were also provided to City of Charlotte staff who participated in the estimation.

# Tour Frequency Models

Tour frequency models predict how often members of a household will leave the home for various travel purposes like work, school, shopping, etc. Caliper updated the tour frequency models using the latest household travel survey collected by CRTPO. Estimation of the work model was completed by CRTPO staff while Caliper estimated the remaining models. The sections below provide the relevant statistics for each model.

Importantly, in the MRM, the choice of tour frequency is made at the household level rather than the individual.

### Work Tours

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variable** | **Coefficient** | **t-Statistic** | **Alternatives** | | |
| **0 Tours** | **1 Tour** | **2+ Tours** |
| Constant | -1.291 | -12.76 |  | X |  |
| Constant | -2.568 | -9.44 |  |  | X |
| workers | 0.387 | 7.16 |  | X |  |
| workers | 0.819 | 6.53 |  |  | X |
| school\_tours | 0.652 | 10.90 |  | X | X |
| life\_cycle | -0.385 | -5.60 |  | X | X |
| income1 | -1.008 | -3.30 |  |  | X |
| workers1 | -0.768 | -4.35 |  |  | X |
| atype5 | 0.209 | 2.57 |  | X |  |
| atype5 | 0.398 | 3.79 |  |  | X |
| size1 | 0.158 | 2.18 |  | X |  |
| size1 | 0.565 | 4.39 |  |  | X |
| **Rho^2** | **0.165** |  |  |  |  |
|  |  |  |  |  |  |
| Calibration Constant | 0.540 |  |  | X |  |
| Calibration Constant | 1.190 |  |  |  | X |

The work model is sensitive to the number of workers in the household, life cycle and income variables, area type, and the number of school tours made by the household. The model also gives special consideration to one-person households (‘size1’).

### School Tours (K12)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variable** | **Coefficient** | **t-Statistic** | **Alternatives** | | |
| **0 Tours** | **1 Tour** | **2+ Tours** |
| Constant | -1.54 | -2.91 |  | X |  |
| Constant | -0.917 | -1.84 |  |  | X |
| life\_cycle = 2 | 0.817 | 1.12 |  | X |  |
| workers = 3 | 0.557 | 3.19 |  | X |  |
| size34 | 0.284 | 3.15 |  | X |  |
| income = 1 | 0.225 | 1.48 |  | X |  |
| CBD | -1.122 | -3.6 |  | X |  |
| life\_cycle = 1 | -2.358 | -3.98 |  | X |  |
| life\_cycle = 2 | 0.502 | 0.54 |  |  | X |
| workers = 3 | -0.486 | -1.67 |  |  | X |
| size34 | -1.831 | -9.47 |  |  | X |
| income = 1 | -0.516 | -1.2 |  |  | X |
| CBD | -1.163 | -2.18 |  |  | X |
| life\_cycle = 1 | -1.419 | -2.31 |  |  | X |
| size = 2 | -3.935 | -7.42 |  |  | X |
| size = 5 | 0.633 | 5.04 |  |  | X |
| **Rho^2** | **0.5** |  |  |  |  |
|  |  |  |  |  |  |
| Calibration Constant | -0.030 |  |  | X |  |
| Calibration Constant | 1.180 |  |  |  | X |

The school tour model is sensitive life cycle variables (presence of kids), size, income, and other variables that are expected to influence school making behavior. Most t-stats are strong, but the life\_cycle = 2 dummy variable in the 2+ utility equation is low. Still, the model maintains separate coefficients for 1 and 2+ tours because the relative sizes of the coefficients are intuitive.

### University Tours

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Variable** | **Coefficient** | **t-Statistic** | **Alternatives** | |
| **0 Tours** | **1+ Tours** |
| Constant | -5.492 | -28.140 |  | X |
| size | 0.567 | 8.012 |  | X |
| school\_tours | -0.247 | -0.757 |  | X |
| income = 2 | 0.987 | 4.645 |  | X |
| areatype = 2 | 0.859 | 4.384 |  | X |
| size = 3 | 0.335 | 1.828 |  | X |
| worker = 3 | 0.701 | 3.364 |  | X |
| **Rho^2** | **0.86** |  |  |  |
|  |  |  |  |  |
| Calibration Constant | 0.740 |  |  | X |

The university model is simple, but it does consider the number of K12/school tours made by the household. Making these tours makes it less likely to make university tours. Not only do these tours take up time in the day making other tours less likely, but it also means that at least some children in the house are not university age.

### Shopping Tours

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variable** | **Coefficient** | **t-Statistic** | **Alternatives** | | |
| **0 Tours** | **1 Tour** | **2+ Tours** |
| Constant | -0.395 | -4.79 |  | X |  |
| Constant | -2.059 | -22.94 |  |  | X |
| size | 0.069 | 2.39 |  | X |  |
| suburban | 0.098 | 1.5 |  | X | X |
| school+univ | -0.314 | -6.8 |  | X | X |
| work\_tours | -0.932 | -25.29 |  | X | X |
| CBD | -0.164 | -1.61 |  | X |  |
| workers = 1 | -0.284 | -4.37 |  | X |  |
| size | 0.588 | 17.66 |  |  | X |
| workers | -0.355 | -4.91 |  |  | X |
| CBD | -0.894 | -3.43 |  |  | X |
| workers = 1 | -0.384 | -5.13 |  |  | X |
| **Rho^2** | **0.23** |  |  |  |  |
|  |  |  |  |  |  |
| Calibration Constant | 0.590 |  |  | X |  |
| Calibration Constant | 0.460 |  |  |  | X |

School and work tours both detract from the propensity of a household to make shopping tours. It is more likely that these shopping needs are met as intermediate stops on those tours instead. Living in the most-dense areas lowers the number of shopping trips you make. This is an interesting result and may reflect the complex nature of outings with multiple stops in these areas.

### Other Tours

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Variable** | **Coefficient** | **t-Statistic** | **Alternatives** | |  |  |  |
| **0 Tours** | **1 Tour** | **2 Tours** | **3 Tours** | **4+ Tours** |
| Constant | -0.084 | 1.27 |  | X |  |  |  |
| Constant | -0.382 | -1.26 |  |  | X |  |  |
| Constant | -2.156 | -11.33 |  |  |  | X |  |
| Constant | -3.322 | -20.06 |  |  |  |  | X |
| size | 0.271 | 6.48 |  | X | X |  |  |
| life\_cycle = 2 | 0.44 | 4.48 |  | X | X |  |  |
| workers | 0.169 | 5.28 |  | X | X |  |  |
| MED\_INC | 0.00000142 | 1.97 |  | X | X | X | X |
| school+univ | -0.316 | -4.81 |  | X | X | X | X |
| work\_tours | -1.248 | -32.6 |  | X | X | X | X |
| shop\_tours | -0.798 | -25.1 |  | X | X | X | X |
| income = 4 | 0.29 | 5.72 |  | X | X |  |  |
| areatype = 5 | -0.34 | -4.62 |  | X | X | X | X |
| suburban | -0.148 | -3.15 |  | X | X | X | X |
| size = 1 | -1.034 | -14.8 |  |  | X |  |  |
| size | 0.646 | 11.02 |  |  |  | X |  |
| income = 4 | 0.606 | 8.44 |  |  |  | X | X |
| income = 1 | -0.579 | -3.71 |  |  |  | X | X |
| size = 1 | -0.561 | -6.09 |  |  |  | X |  |
| size | 1.125 | 23.29 |  |  |  |  | X |
| size = 1 | -1.194 | -6.44 |  |  |  |  | X |
| **Rho^2** | **0.21** |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
| Calibration Constant | 0.670 |  |  | X |  |  |  |
| Calibration Constant | 0.460 |  |  |  | X |  |  |
| Calibration Constant | 0.770 |  |  |  |  | X |  |
| Calibration Constant | 0.400 |  |  |  |  |  | X |

Other tours include all tours not captured in the other tour types. They are non-mandatory (meaning not for work or school) and they are not shopping. They do include activities like dining, entertainment, social, or general recreation. All other tour types negatively impact the ability to make other tours given the limited time during the day. Income and size also play important roles in predicting these tours.

### At Work Subtours

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Variable** | **Coefficient** | **t-Statistic** | **Alternatives** | |
| **0 Tours** | **1+ Tours** |
| Constant | -1.484 | 1.27 |  | X |
| MED\_INC | -0.0000012 | 2.62 |  | X |
| **Rho^2** | **0.33** |  |  |  |

The at-work subtour model is slightly different from the others above. Instead of predicting the number of subtours a household makes, this model predicts the probability that each work tour will generate an at-work subtour. This model is practically a constants model (asserting observed probabilities from the survey), does include an income effect that makes it slightly more likely for high-income workers to go out for lunch or do other things during the work day.

# Destination Choice

During the model update phase, the coefficients of the existing destination choice model specifications were re-estimated. Rather than develop an entire new framework for destination choice and use TransCAD’s in-built procedures for both Multinomial and Nested DC, the current specifications were updated owing to budgetary and time constraints.

Some salient features of the models and the update are:

* The models are multinomial choice (MNL)
* Many models have two sets of equations, one for income classes 1 to 3 and another for the highest income class 4.
* The size variable is reduced by 1 after each choice is made.
* During the estimation, any modifications to the intrazonal calculations (which was perhaps done during calibration of the previous model) were removed. The intrazonal variable in the updated model is now simply a binary variable.
* In general, the estimations were a decent fit given these are models with a lot of alternatives with few observations with inadequate coverage of chosen alternatives.
* The time co-efficient for a couple of the models were adjusted post estimation to match observed (weighted) trip lengths. These will be indicated along with the results.

Model Estimation Results

Work Tours

A table with numbers and text

Description automatically generated

School Tours

A table with numbers and a few black text

Description automatically generated with medium confidence

University Tours

A blue and yellow rectangular box with black text

Description automatically generated with medium confidence

Shop Tours

A table with numbers and text

Description automatically generated

Other Tours

A blue and orange calculator with black numbers

Description automatically generated

At-Work Tours

A screenshot of a computer

Description automatically generated

# Time of Day

For each tour, the Metrolina model predicts the choice of forward and return time periods with the choices being Peak (PK) or Off-peak (OP). Therefore, every tour falls under one of four categories depending on the forward and return period, namely PK\_PK, PK\_OP, OP\_PK, OP\_OP. The previous version of the model reverts to a trip-based approach after destination choice. PK and OP matrices were generated by purpose on which the mode choice models were evaluated. A TOD model then subsequently splits the PK and OP mode choice output matrices by using PA/AP factors to generate subperiod (AM, MD, PM and NT) matrices.

The updated Metrolina model deviates slightly from this approach. Like in the previous model, the forward and return period (PK/OP) is predicted for each tour. However, the mode choice is also tour-based, and the time-of-day model is applied just before the creation of the OD matrices. Therefore, there is a need to generate 4 sets of matrices (AM, MD, PM and NT) from the tour level output.

This is done by analyzing the survey to apportion the appropriate combination of PK\_PK, PK\_OP, OP\_PK and OP\_OP tours into sub-periods.

For example, the PK\_PK combination has three possibilities (AM\_AM, AM\_PM and PM\_PM). The survey was used to obtain percentages of tours in each subcategory by purpose. These are directly applied in the model. The tables containing these factors are shown below:

PK\_PK factors

A table with numbers and percentages

Description automatically generated

PK\_OP factors

A table with numbers and text

Description automatically generated

OP\_PK factors

A table with numbers and text

Description automatically generated

OP\_OP factors

A table of numbers and percentages

Description automatically generated

# Mode Choice

The mode choice model for Metrolina was estimated based on the household survey records for 6 tour purposes: Work, Other, Shop, University, Sub-Tour and School tours. These models are estimated as nested logit models. Note that the previous Metrolina model did not have a mode choice model for school tours since it was based on a fixed shares model.

In the context of application, the tour mode choice model is applied after the tour destinations and tour time of day are determined.

## Preliminary Analysis

The survey records were scanned for frequency of observations, shown in the table below:

A screenshot of a computer

Description automatically generated

The number of observations for each tour purpose determines the alternative set of modes that can be estimated. Some highlights from the above table are:

* Observations with chosen modes micromobility and LD passenger are ignored since there are very few records. Missing mode records are obviously dropped.
* Taxi is combined with TNC (Transport Network Company) during estimation and only estimated for the ‘Work’, ‘Other’ and ‘Shop’ purposes.
* School Bus is an alternative only for the ‘School’ purpose. Records with school bus choice for ‘Work’ and ‘Other’ purpose are ignored.
* The full set of transit modes (Walk Access to Bus, Walk Access to Rail, Drive Access to Bus, Drive Access to Rail) are alternatives only for the ‘Work’ and ‘Other’ tour purpose.
* Only Walk Access transit modes are considered as alternatives for the ‘Shop’ purpose. The drive access to bus is typically ignored for shopping trips as it is unlikely in practice, although very few respondents chose this mode.
* Walk Access to Bus is the only transit alternative for the school purpose.
* The Subtour mode choice set comprises only of the Auto modes and the Walk mode.

## General Estimation Notes

* Nested Logit (NL) models are estimated for various purposes, which have significant advantages over Multinomial (MNL) mode choice models, especially if there are similar alternatives (such as SOV, HOV2, HOV3).
* The nesting structure can vary by purpose and do have multiple levels. Each alternative in a higher nest has a nest coefficient or theta that is typically estimated if possible. However, for the Metrolina model, estimation was possible only if these nesting coefficients were fixed. Values of 0.7 for the upper nests and 0.5 for the lower nest alternative are typical values and yielded successful estimation of other parameters.
* Since the model is applied in a disaggregate fashion, household variables such as income can be directly used in the model utility specification. There is no need to split data/productions into market segments before applying the models.
* The utility terms and relationships between the various parameters are similar to the previous model.
* T-stats of estimated coefficients are shown.

## Estimation Results

For each of the purposes, the nesting structure, the utility table along with estimated model coefficients and expressions, values of parameters and nest coefficients are shown. The rho-sq is shown at the bottom of the utility table. In the utility table, an X in a particular column (each alternative is a column) indicates that the utility term (row) is active for that alternative. If a cell in any column does not have an X, then that term does not apply to that column (alternative).

## Work Tour Purpose

Tree Structure

A diagram of a company

Description automatically generated

Utility Table

A screenshot of a computer

Description automatically generated

Constants Table

The constants in the table below are common to all estimated models.

A table with numbers and a green background

Description automatically generated with medium confidence

### Features of the utility specification:

* The ‘Variable’ column in the above table indicates the utility variable. During application, the appropriate variable from the skims matrix or the TAZ layer will be used. A ‘Constant’ indicates that the term is an alternative specific constant typically applicable to one of the alternatives.
* The ‘Derived Coefficient Formula’ indicates any derived coefficients. For example, the ‘Fare (Income 1)’ variable has a derived coefficient of *IVTT*/*vot1*. The *IVTT* coefficient from an earlier row can be seen as -0.0210. The value of time for the first income class, i.e., *vot1* value from the constant’s parameter table is 6.7 c/min. Thus the ‘Fare (Income 1)’ has a coefficient of -0.0210/6.7 = -0.003134. Note that for certain derived coefficients, the values of the parameter will vary based on the alternative. For example, the *occ* parameter in the ‘Auto Distance (Income1)’ term is 1.0 for the SOV alternative, 2.0 for the HOV2 alternative and 3.3 for the HOV3 alternative.
* The estimated coefficient and the t-statistic are shown in the columns ‘Coefficient’ and ‘t-statistic’. Only estimated coefficients (and not derived ones) will have an associated t-statistic. Typically, an absolute t-statistic of over 1.96 indicates a 95% confidence in the estimate. Some coefficients such as alternate specific constants (ASCs) may be retained even though they have poor t-stats. Note that it is expected that these ASCs are adjusted during model calibration.
* The remainder of the columns form the alternatives and an X for any row indicates that the variable (row) is applicable to that alternative. The partial utility term in this case is the coefficient (or derived coefficient) multiplied by the variable value. For example, the utility equation for TNC is -0.0910\*’Auto Time TNC’. The utility specification for the ‘Walk’ alternative is -0.2190 + 0.5370\*’Low Income Dummy’ + 1.55\*’Intrazonal Dummy’ -0.0210\*’WalkTime’. Note that the ASC term is simply multiplied by 1 and added.

It may be easier to look at a particular column (alternative), find the rows marked X and determine the partial utility term by multiplying the variable with the coefficient.

### Work Tour mode choice model estimation notes:

* The model is Nested Logit with main nests for the Auto, Non-Motorized and Transit modes. The nest coefficient at this level is asserted to be 0.7. The HOV nest has children POOL2 and POOL3. The transit nest is further split based on access mode. The nest coefficients at all these levels are asserted to be 0.5. Note that similar alternatives (or alternatives that can be more easily substituted with each other) form a nesting group.
* The Auto modes are sensitive to travel time, travel distance (that affects the auto operation cost) and parking. The relationships between the coefficients of the parking terms, auto operation costs (AOC) and time are consistent with the previous Metrolina model including the values of the *vot*, *aoc* parameters.
* Transit alternatives included both walk and drive access to Bus and Premium modes. The relationships between various transit skims such as In-Vehicle Travel Time (IVTT) and Fare etc. were borrowed from the previous model. Note that the IVTT on any premium transit leg is discounted by 30%. The previous model had further discounts to the premium modes, which we eliminated.
* Intrazonal effects are strong for the non-motorized modes.
* Low Income has a positive effect on transit choice.
* CBD destination has a positive impact on choice of transit.
* Since the mode choice is now applied in a disaggregate fashion (as opposed to aggregate before), the income designation is available for each record. Thus, there is no need to split the data by income class and apply different models to each class. The appropriate utility term pertaining to the income class will be used directly.
* The model rho-sq is a very good 0.577 with small ASCs. This typically indicates an excellent fit.

## Other Tour Purpose

Tree Structure

A diagram of a company

Description automatically generated

Utility Table

A screenshot of a computer screen

Description automatically generated

### Other Tour mode choice model estimation notes:

* The model has a very similar structure to the Work model.
* Like the work model, Intrazonal effects are significant for non-motorized modes, low-income effect is associated with higher transit usage probability and CDB destinations have a positive effect on transit choice.
* The model rho-sq 0.384 and indicates a good fit.
* All values of constants such as *vot1*, *occ* etc. are unchanged from those used in the ‘Work’ model.

## Shop Tour Purpose

Tree Structure

A diagram of a flowchart

Description automatically generated

Utility Table

A screenshot of a computer

Description automatically generated

### Shop Tour mode choice model estimation notes:

* The Shop tour model noticeably does not have drive-access modes to transit for reasons explained earlier. There is thus no need for a second level of nesting for transit alternatives.
* Other model effects common to the work and other purpose persist.
* The model rho-sq 0.449 again indicates a good fit.

## University Tour Purpose

Tree Structure

A diagram of a structure

Description automatically generated

Utility Table

A screenshot of a computer

Description automatically generated

### University Tour mode choice model estimation notes:

* The drive access modes to transit and TNC were dropped, due to insufficient records. The drive access modes to transit can be added during application if desired.
* Other model effects common to the work and other purpose persist.
* The model rho-sq 0.267 again indicates a decent fit given the estimation record set size especially for non-frequent modes.

## School Tour Purpose

Tree Structure

A diagram of a computer flowchart

Description automatically generated

Utility Table

A screenshot of a spreadsheet

Description automatically generated

### School Tour mode choice model estimation notes:

* The school tour mode choice replaces the fixed shares model.
* Walk access to bus is the only transit alternative. There is no TNC alternative.
* School Bus is an added alternative.
* Low-income effect having a positive effect on bus utility persists.
* Intrazonal effects for non-motorized modes persist.
* Neither auto-operative nor parking costs are considered as utility terms.
* The model rho-sq 0.328 again indicates a good fit.

## Sub-Tour Purpose

Tree Structure

A diagram of a structure

Description automatically generated

Utility Table

A screenshot of a computer

Description automatically generated

### Sub-Tour mode choice model estimation notes:

* The sub-tour mode choices are limited to auto modes and the walk mode.
* Auto mode utility terms consist of travel time, auto operating cost and parking cost.
* Intrazonal effect has a positive impact on walk mode utility.
* The model rho-sq 0.452 indicates a good fit.

## Model calibration: Constant (ASC) adjustments

Typically, logit models are estimated without survey weights. Post estimation, alternate specific constants are adjusted to match weighted survey shares by mode. A similar procedure was adapted for the Charlotte model.

The one complication is that transit weighted shares from the survey are not reliable due to the small sample size and therefore cannot be taken at face value. Instead, transit mode choice calibration heavily depends on external data such as observed boardings by transit mode. The initial application of the mode choice model (with constants adjusted to match survey weighted shares) resulted in model boardings well above the observed boardings. The transit shares were therefore lowered significantly, and new constants were established. These constants are updated in the model specifications and used during application.

# Intermediate Stops

Once the destination and mode of each tour is known, these models predict the number of intermediate stops made along the tour. In other words, if a worker leaves to go to work, but stops to drop off a child, that drop off is an intermediate stop on their work tour. Based on the survey, transit tours were asserted to have no intermediate stops.

The MRM also predicts stops independently by direction: production-to-attraction (PA) or attraction-to-production (AP). In other words, stops on the way to work are predicted separately from stops on the way home. This allows several of the AP direction models to consider the number of stops already made in the PA direction.

## Work Stops

Work stops are sensitive to things like higher income (income = 4), the presence of kids (life cycle = 2), if the tour mode is HOV, and the amount of retail near the home. In the AP direction, making more work tours in a day reduces the likelihood of making an intermediate stop in the AP direction on each tour, which is an intuitive result.

### PA

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variable** | **Coefficient** | **t-Statistic** | **Alternatives** | | |
| **0 Stops** | **1 Stop** | **2+ Stops** |
| income = 4 | -0.55 | -3.59 |  | X | X |
| life cycle = 2 | 0.47 | 2.85 |  | X | X |
| retail within 1.5 miles of origin | 0.00005 | 2.57 |  | X | X |
| HOV | 1.24 | 6.68 |  | X |  |
| Constant | -3.55 | -22.45 |  | X |  |
| HOV | 1.60 | 5.44 |  |  | X |
| Constant | -4.81 | -19.99 |  |  | X |
| **Rho^2** | **0.79** |  |  |  |  |
|  |  |  |  |  |  |
| Calibration Constant | 0.74 |  |  | X |  |
| Calibration Constant | 0.95 |  |  |  | X |

### AP

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variable** | **Coefficient** | **t-Statistic** | **Alternatives** | | |
| **0 Stops** | **1 Stop** | **2+ Stops** |
| PA choice | 0.27 | 2.35 |  | X | X |
| life cycle = 2 | -0.33 | -3.79 |  | X | X |
| work tours | -0.18 | -2.18 |  | X |  |
| HOV | 1.18 | 11.04 |  | X |  |
| Constant | -0.96 | -7.44 |  | X |  |
| work tours | -0.28 | -2.71 |  |  | X |
| HOV | 1.70 | 14.36 |  |  | X |
| Constant | -1.55 | -9.68 |  |  | X |
| **Rho^2** | **0.23** |  |  |  |  |
|  |  |  |  |  |  |
| Calibration Constant | 0.00 |  |  | X |  |
| Calibration Constant | 0.14 |  |  |  | X |

## School Stops

Area type variables and tour mode dominate the school stops model. For school trips made by SOV (generally 17-18 year old high school students), they are less likely to make intermediate stops.

### PA

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variable** | **Coefficient** | **t-Statistic** | **Alternatives** | | |
| **0 Stops** | **1 Stop** | **2+ Stops** |
| retail within 3 miles of origin | 0.00 | 2.97 |  | X | X |
| HOV | 1.12 | 3.22 |  | X | X |
| Constant | -4.35880 | -12.22 |  | X |  |
| Constant | -5.78 | -13.57 |  |  | X |
| **Rho^2** | **0.8** |  |  |  |  |
|  |  |  |  |  |  |
| Calibration Constant | 0.63 |  |  | X |  |
| Calibration Constant | -0.12 |  |  |  | X |

### AP

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variable** | **Coefficient** | **t-Statistic** | **Alternatives** | | |
| **0 Stops** | **1 Stop** | **2+ Stops** |
| travel time | 0.05 | 4.34 |  | X |  |
| origin AT = 5 | 0.51 | 2.43 |  | X | X |
| HOV | 0.56660 | 3.27 |  | X | X |
| Constant | -3.12 | -13.36 |  | X |  |
| origin AT = 5 | 0.51 | 2.43 |  |  | X |
| Constant | -3.87 | -11.92 |  |  | X |
| **Rho^2** | **0.5** |  |  |  |  |
|  |  |  |  |  |  |
| Calibration Constant | -0.28 |  |  | X |  |
| Calibration Constant | 0.19 |  |  |  | X |

## University Stops

Income and area type are important for the university stop choice. The total number of tours made in a day also negatively impacts the likelihood of making a stop in the AP direction.

### PA

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variable** | **Coefficient** | **t-Statistic** | **Alternatives** | | |
| **0 Stops** | **1 Stop** | **2+ Stops** |
| income = 4 | -1.26 | -2.05 |  | X | X |
| HOV | 1.17 | 1.98 |  | X | X |
| origin AT = 1 | 2.37020 | 2.22 |  | X | X |
| Constant | -3.08 | -5.61 |  | X |  |
| Constant | -3.49 | -5.85 |  |  | X |
| **Rho^2** | **0.7** |  |  |  |  |
|  |  |  |  |  |  |
| Calibration Constant | -0.31 |  |  | X |  |
| Calibration Constant | 1.62 |  |  |  | X |

### AP

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variable** | **Coefficient** | **t-Statistic** | **Alternatives** | | |
| **0 Stops** | **1 Stop** | **2+ Stops** |
| HOV | 1.49 | 4.08 |  | X | X |
| total tours | -0.28 | -2.42 |  | X | X |
| destination AT = 1 or AT = 2 | -1.04550 | -2.55 |  | X | X |
| Constant | -1.00 | -2.26 |  | X |  |
| Constant | -1.04 | -2.33 |  |  | X |
| **Rho^2** | **0.31** |  |  |  |  |
|  |  |  |  |  |  |
| Calibration Constant | 0.30 |  |  | X |  |
| Calibration Constant | 0.45 |  |  |  | X |

## Shopping Stops

For shopping trips, the longer the trip, the more likely it includes intermediate stops. Income, retail, number of tours made in a day, area type, and being an HOV tour all contribute to the likelihood of making stops.

### PA

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Variable** | **Coefficient** | **t-Statistic** | **Alternatives** | | | |
| **0 Stops** | **1 Stop** | **2 Stops** | **3+ Stops** |
| travel time | 0.03 | 6.05 |  | X | X | X |
| income = 1 or income = 2 | 0.51 | 4.60 |  | X | X | X |
| retail w/in 3 miles of origin | 0.00024 | 8.92 |  | X | X | X |
| total tours | -0.13 | -4.50 |  | X | X | X |
| HOV | 0.39 | 4.23 |  | X | X | X |
| origin AT = 3 or AT = 4 | 0.50 | 4.74 |  | X | X | X |
| Constant | -3.30 | -19.54 |  | X |  |  |
| Constant | -3.97 | -22.56 |  |  | X |  |
| Constant | -4.21 | -23.11 |  |  |  | X |
| **Rho^2** | **0.7** |  |  |  |  |  |
|  |  |  |  |  |  |  |
| Calibration Constant | -1.12 |  |  | X |  |  |
| Calibration Constant | -0.92 |  |  |  | X |  |
| Calibration Constant | -0.51 |  |  |  |  | X |

### AP

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Variable** | **Coefficient** | **t-Statistic** | **Alternatives** | | | |
| **0 Stops** | **1 Stop** | **2 Stops** | **3+ Stops** |
| PA choice | -0.24 | -4.21 |  | X |  |  |
| travel time | 0.06 | 10.52 |  | X |  |  |
| shop tours | -0.34 | -4.57 |  | X | X | X |
| total tours | -0.09 | -4.29 |  | X | X | X |
| life cycle = 1 | 0.17 | 2.49 |  | X | X | X |
| HOV | 0.55 | 7.67 |  | X | X | X |
| Constant | -0.83 | -5.92 |  | X |  |  |
| PA choice | -0.37 | -5.69 |  |  | X | X |
| travel time | 0.08 | 12.96 |  |  | X |  |
| Constant | -1.98 | -12.78 |  |  | X |  |
| travel time | 0.10 | 16.17 |  |  |  | X |
| Constant | -2.73 | -16.48 |  |  |  | X |
| **Rho^2** | **0.17** |  |  |  |  |  |
|  |  |  |  |  |  |  |
| Calibration Constant | 0.06 |  |  | X |  |  |
| Calibration Constant | -0.32 |  |  |  | X |  |
| Calibration Constant | 0.05 |  |  |  |  | X |

## Other Stops

Increasing travel time also increases the likelihood of stops on Other tours. Income, HOV, total tours, and area type variables also play a role.

### PA

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Variable** | **Coefficient** | **t-Statistic** | **Alternatives** | | | |
| **0 Stops** | **1 Stop** | **2 Stops** | **3+ Stops** |
| travel time | 0.03 | 5.88 |  | X | X | X |
| CBD destination | -1.17 | -3.07 |  | X | X | X |
| total tours | -0.20210 | -5.15 |  | X | X | X |
| income = 1 or income = 2 | 0.43 | 3.18 |  | X | X | X |
| origin AT = 1 or AT =2 | 0.30 | 2.42 |  | X | X | X |
| HOV | 0.69 | 6.27 |  | X | X | X |
| Constant | -3.70 | -20.52 |  | X |  |  |
| total tours | -0.26 | -3.76 |  |  | X |  |
| Constant | -4.71 | -17.32 |  |  | X |  |
| total tours | -0.37 | -4.92 |  |  |  | X |
| Constant | -4.41 | -16.09 |  |  |  | X |
| **Rho^2** | **0.84** |  |  |  |  |  |
|  |  |  |  |  |  |  |
| Calibration Constant | -0.44 |  |  | X |  |  |
| Calibration Constant | -0.06 |  |  |  | X |  |
| Calibration Constant | 0.18 |  |  |  |  | X |

### AP

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Variable** | **Coefficient** | **t-Statistic** | **Alternatives** | | | |
| **0 Stops** | **1 Stop** | **2 Stops** | **3+ Stops** |
| travel time | 0.04 | 10.98 |  | X |  |  |
| intrazonal = 1 | -0.33 | -3.27 |  | X | X | X |
| total tours | -0.08850 | -5.42 |  | X | X | X |
| retail w/in 3 miles of origin | 0.00 | -2.88 |  | X | X | X |
| life cycle = 1 | 0.16 | 2.71 |  | X | X | X |
| HOV | 0.50 | 8.50 |  | X | X |  |
| PA choice | 0.34 | 4.68 |  | X |  |  |
| Constant | -2.40 | -21.87 |  | X |  |  |
| travel time | 0.04 | 8.66 |  |  | X |  |
| PA choice | 0.36 | 3.41 |  |  | X |  |
| Constant | -3.53 | -26.53 |  |  | X |  |
| travel time | 0.05 | 9.08 |  |  |  | X |
| HOV | 0.67 | 4.95 |  |  |  | X |
| PA choice | 0.94180 | 11.51 |  |  |  | X |
| Constant | -4.48 | -25.35 |  |  |  | X |
| **Rho^2** | **0.55** |  |  |  |  |  |
|  |  |  |  |  |  |  |
| Calibration Constant | -0.37 |  |  | X |  |  |
| Calibration Constant | -0.33 |  |  |  | X |  |
| Calibration Constant | 0.07 |  |  |  |  | X |

## At Work Stops

As a rule, and due to the nature of at-work subtours, the model only predicts if a single stop is made in the PA direction or not. Travel time, tour mode, and retail near the origin are key variables.

### PA

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Variable** | **Coefficient** | **t-Statistic** | **Alternatives** | |
| **0 Stops** | **1 Stop** |
| travel time | 0.06 | 3.36 |  | X |
| retail w/in 3 miles of destination | 0.00 | -2.01 |  | X |
| SOV | 0.82 | 3.56 |  | X |
| Constant | -2.14 | -6.88 |  | X |
| **Rho^2** | **0.28** |  |  |  |

# Validation

In addition to the calibration checks performed for each submodel, where model performance is compared back to the survey used to estimate it, the final results are also compared to independent data sources not used in estimation. This is the validation set. Caliper used traffic counts and observed transit ridership to validate that the estimated models did a good job predicting conditions in 2022 (the base year).

The table below shows the model link volumes compared to traffic counts by volume group. Percent difference and percent root mean square error (%RMSE) all look great. While the percent difference for the 100000+ category looks low, there are only 2 counts and low volume. This means that even small differences look larger in percentage terms.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| VolumeGroup | N | TotalCount | TotalVolume | PctDiff | PRMSE |
| 10000 | 2063 | 9051500 | 9284533 | 2.57 | 56.19 |
| 25000 | 1161 | 18626300 | 17149797 | -7.93 | 29.98 |
| 50000 | 469 | 16041100 | 15547126 | -3.08 | 22.54 |
| 100000 | 146 | 9764300 | 9637426 | -1.3 | 14.66 |
| 100000+ | 2 | 205200 | 176706.3 | -13.89 | 13.89 |
| All | 3841 | 53688400 | 51795589 | -3.53 | 33 |

In the next table, link volumes are compared to counts by facility type. The model is predicting lower volumes on facility type C than observed. Given the strong performance by volume group, Caliper did not deem this a problem, but future enhancements could look into this facility type.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| FacType | N | TotalCount | TotalVolume | PctDiff | PRMSE |
| B | 304 | 8081500 | 8160430 | 0.98 | 26.83 |
| C | 304 | 5428200 | 4477111 | -17.52 | 34.93 |
| D | 48 | 1215100 | 1144579 | -5.8 | 28.38 |
| E | 19 | 486800 | 426668.5 | -12.35 | 20.15 |
| F | 306 | 14786100 | 14728504 | -0.39 | 15.81 |
| M | 49 | 997800 | 996694.7 | -0.11 | 25.55 |
| R | 2 | 36800 | 32253.92 | -12.35 | 12.38 |
| T | 271 | 5251800 | 5289483 | 0.72 | 28.63 |
| U | 2538 | 17404300 | 16539864 | -4.97 | 44.74 |
| All | 3841 | 53688400 | 51795589 | -3.53 | 33 |

In addition to these summary-level validation checks, Caliper also checked for link level differences using the maps shown below.

* Blue links: the model is lower than counts
* Red links: the model is higher than counts
* Green links: the model is close to counts

A map of a city

Description automatically generated

A map of a city

Description automatically generated

The table below shows observed unlinked transit boardings compared to the model. The model is matching the observed data well.

|  |  |  |
| --- | --- | --- |
| Mode | Observed | Model |
| Bus | 28,000 | 30,000 |
| Rail | 16,000 | 16,000 |