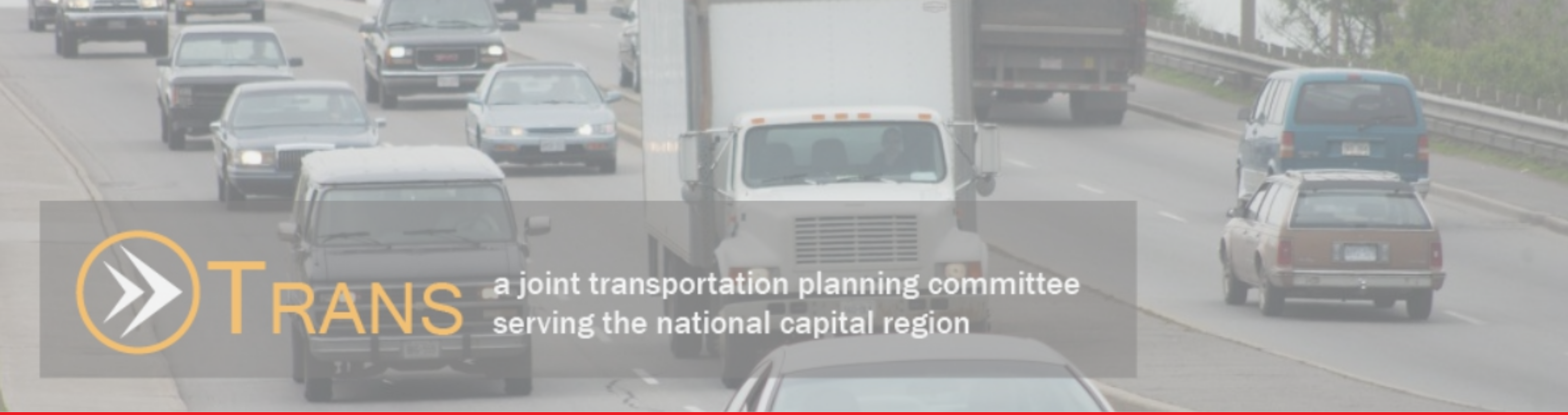
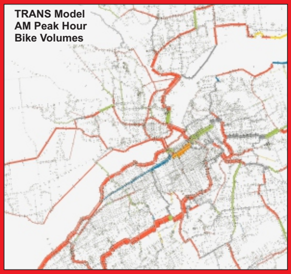
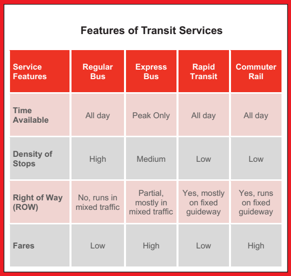
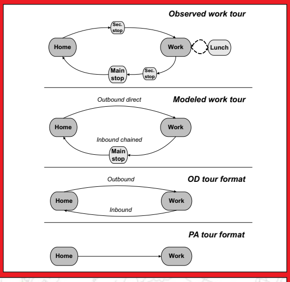
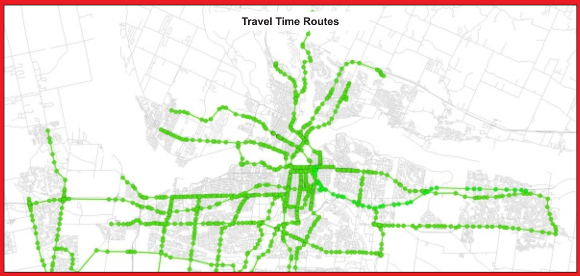





Features of Transit Services

Service Features	Regular Bus	Express Bus	Rapid Transit	Commuter Rail
Time Available	All day	Peak Only	All day	All day
Density of Stops	High	Medium	Low	Low
Right of Way (ROW)	No, runs in mixed traffic	Partial, mostly in mixed traffic	Yes, mostly on fixed guideway	Yes, runs on fixed guideway
Fares	Low	High	Low	High





MMM Group Limited

TRANS Model

Evolution of the TRANS Regional Travel Demand Forecasting Model

TECHNICAL REPORT

COMMUNITIES

TRANSPORTATION

BUILDINGS

INFRASTRUCTURE

MMM GROUP

PB 125 YEARS

June 2014

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1.0 INTRODUCTION

MMM Group Limited in association with Parsons Brinckerhoff, was retained in May 2012 to undertake the update of regional travel demand forecasting model on behalf of TRANS, a joint technical committee on transportation system planning in the National Capital Region (NCR). The City of Ottawa was acting as the contracting agency on behalf of all TRANS Agencies – including the cities of Ottawa and Gatineau, STO, and the Provinces of Ontario and Quebec.

1.1 Study Objectives

TRANS has a long standing commitment to transportation model development, having been involved in joint model development programs during the late 1970's. During the intervening years, various forms of a transportation planning model were updated as part of the ongoing mandate of the TRANS Committee. The existing model is a tour-based aggregate model developed in 2008 was based on the regional origin destination survey administered during the Fall of 2005, as well as a number of other related transportation data collection activities undertaken. The TRANS Agencies determined it was appropriate to initiate a comprehensive review and update of the model including it's techniques, practices and input data. In 2011, TRANS Agencies conducted a new regional origin destination survey to serve as a basis for this model update and to enhance the current modelling framework.

The key objectives of the model review and update were:

- To recalibrate the existing model based on recent data collection efforts including the TRANS 2011 O-D Travel Survey, with a view of establishing a forecasting model framework with an increased level of accuracy in carrying out both short-term and long-term forecasts;
- To develop a more comprehensive and robust model reflective of recent improvements in the transportation modelling field, integrating advanced modelling techniques where appropriate, leading to more a more advanced modelling framework with an increased level of reliability of the modelling results as well as their sensitivity to various socio-economic scenarios, land-use development, and transportation improvements;
- To outline a vision for the next generation of the model i.e. Activity-Based Model.

The TRANS Model is almost entirely implemented in the EMME/4 software that is developed and distributed through INRO based in Montreal, Canada. Overall, travel demand is generated as a function of a number of independent demographic and land-use variables to explain the regional travel behaviour. Ultimately the travel demand, in terms of person and vehicular travel is organized within the EMME/4 framework in the form of origin-destination trip tables (matrices) constructed for each travel mode and time-of-day period. These matrices, representing trips between various traffic zones, are assigned onto the appropriate transportation networks to obtain auto person, auto vehicle, bicycle, as well as transit travel on the road, bicycle and transit networks respectively. The update of the TRANS Model therefore involved a full updating of the key demographic, land-use variables, as well as auto, bicycle and transit networks to reflect 2011 current conditions. In addition, a large part of the work included estimating statistical models based on the reported travel demand, trip patterns, and characteristics so that local observed travel behaviour are well captured and predicted within the model framework. A number of new features were added to the assignment procedures – accessibilities, auto assignment by vehicle occupancy type, bicycle assignment and transit assignment with crowding function and capacity constraining.

1.2 Study Participants

The TRANS Committee is comprised of the following member agencies: the National Capital Commission (NCC), the Ministry of Transportation of Ontario (MTO), the City of Ottawa (including OC Transpo), Ministère des Transports du Québec (MTQ), Ville de Gatineau and Société de transport de l'Outaouais (STO). The NCC did not participate in the study.

The study was conducted under the direction of a TRANS Steering Committee including representation from the following agencies:

- **City of Ottawa**: Transportation – Strategic Planning, Transit Service Planning (OC Transpo)
- **Ministère des Transports du Québec** : Direction de l'Outaouais and Modélisation des systèmes de transport ;
- **Ministry of Transportation of Ontario**:System Analysis and Forecasting Office;
- **Société de transport de l'Outaouais**: Stratégies et développement;
- **Ville de Gatineau** : Section Transport.

The study progress was supervised by a Model Development Sub-Committee led by Mr. Ahmad Subhani, Senior Project Manager in the Transportation – Strategic Planning Unit at the City of Ottawa. The Sub-Committee also included Mr. Tim Wei, Transportation Planner (City of Ottawa) as well as Mr. Pierre Tremblay, Planning Director and Mr. Adham Badran, Transportation Analyst, both working in the Modélisation des systems de transport division (MTQ), and Sundar Damodaran, Senior Policy Advisor in the System Analysis and Forecasting Office (MTO). The Project Team appreciated their ongoing study review and input throughout the duration of the model update.

The practical guidance and assistance of the mentioned above organizations is gratefully acknowledged.

1.3 Report Overview

This report documents the model development process. It also provides technical background, detailed information on the data and networks used, as well as a description of each model component implemented to develop a comprehensive and robust model.

The report is structured as follows:

- Section 1 – Introduction,
- Section 2 – Model System Background,
- Section 3 – Demand Model Architecture,
- Section 4 – Zones and Network Adjustments,
- Section 5 – Model Estimation Results,
- Section 6 – Model Implementation in EMME/4 and User Manual,
- Section 7 – Suggested Future Model Enhancements.

2.0 MODEL BACKGROUND

2.1 Previous TRANS Model Development

Previous transportation forecasting models were based on well-established traditional four stage travel demand procedures consisting of trip generation, distribution, modal split and trip assignment algorithms which were replaced with a tour-based aggregate model in 2008. The older versions of the models focused on the PM peak and therefore included trip purposes such as: Work to home; School to home; Other to home; Leave home; and non-home based travel. As such the trip generation equations developed and defined PM Peak period only and represented a 2 ½ hour time frame (3:30 PM and 5:59 PM) coincident with the afternoon peak commuter travel demands. The tour-based model operated at daily level and generated tours for work, university, school, maintenance and discretionary purposes. For assignment purposes, the tours were divided into trips and only peak hour auto and bicycle volumes within AM (6:30 AM to 8:59 AM) and PM (3:30 PM to 6:29 PM) periods were assigned. Transit volumes were assigned for the AM and PM peak periods. TRANS maintained comprehensive demographic datasets and also undertook roadside traffic counts as a means of keeping the model current, however more comprehensive origin destination (OD) surveys for the region tended to be carried out on a less frequent basis, an approximate ten year cycle (1986, 1995, and 2005) except for the most recent survey (2011) which was carried out in 6 years. The existing tour-based model went through model update in 2012 based on the recent OD survey.

As part of the 1995 model update, the existing EMME/4 network was converted to the NAD 27 coordinate system; road networks were expanded with increased definition into the rural areas; the number and location of centroid connectors were modified to allow traffic to spread more uniformly throughout the network; turn penalties for existing 1995 and future 2021 networks were reviewed; updated volume delay functions for the auto and transit modes were developed; and transit route descriptions were revised (e.g. transit time functions based on congested roadway speeds when operating in mixed traffic).

More recently additional work was completed in support of model maintenance to redefine the traffic zone system as well as to update the base road/transit networks to reflect current 2011 conditions. The zone system was adjusted to better align with census and other planning area boundaries, specifically in Quebec. Traffic zone were also divided in some areas where growth has been or is expected to increase significantly. The model also was updated to include the existing and planned bicycle network.

2.2 TRANS Model Update

2.2.1 Input Data

In response to the objective of increasing the model's sensitivity to demographic and policy changes, a substantial number of new variables not included in previous model were identified and evaluated in the new model in order to better define and describe travel behaviour. They included land-use variables and densities, socio-economics, more employment/business categories etc. The Consultant team, together with the Model Development Sub-Committee, coordinated the definition and preparation of these variables; in many cases these variables were prepared and tested as part of the model estimation procedures at several levels of aggregation: 672 traffic zones, 94 superzones, 26 districts (CBD being one of them), 2 provinces and/or as region-wide control targets. In general, the selection of specific variables was based on the results of the rigorous statistical testing and analysis performed as part of the model estimation procedure.

Ultimately the retention of specific variables within the new model was based on their ability to better explain and reproduce observed phenomena balanced against the level of effort/ability for various agencies to forecast these variables into the future for longer term planning horizons.

2.2.2 Primary Data - 2011 OD Survey

The regional OD Survey completed during the Fall of 2011 serves as a major source of trip patterns and trip characteristics for the redevelopment of the TRANS Model. The TRANS OD Survey represents a 5% sample of households in each of 42 urban and rural sampling districts and reports all trips made by persons of 5 years old or more, on an average weekday for each of the sampled households. Its aim is to provide a detailed picture of current trip patterns and travel choices made by residents of the NCR as well as to provide a strong foundation to establish and calibrate mathematical models to estimate and explain local travel behaviour. It also serves as a means to measure trends in regional travel.

The survey collected four categories of data:

- **Household data**: location, size, number of vehicles, income and dwelling type, etc;
- **Person data**: age, gender, driver's license, transit pass, worker/student status, occupation, place of work/school and parking arrangement, telecommute practice, etc;
- **Trip data**: origin, destination, purpose, mode of travel, departure time, arrival time, transit details (access mode, line used, transfer points, fare payment), car occupancy, etc.
- **Transfer points data**: location data for points of transfer between modes.

The survey results were then statistically expanded and validated based on other traffic, demographic and employment datasets obtained and validated by area agencies. For the advanced modelling purposes trips were combined into Tours (closed chains of trips starting from and ending at home) since several of the sub-models (generation and distribution) are essentially tour-based.

2.2.3 Secondary Traffic/Trip Related Data

Traffic counts conducted annually at major arterial intersections represent a major source of observed traffic flows along on most municipal roads. In addition, the City of Ottawa and the City of Gatineau conduct **screenline counts** to obtain more detailed information regarding various vehicle types and estimates of person flows across each of the major travel corridors in Ottawa-Gatineau. The series of data collected as part of these ongoing counts provide valuable observed information that can be used to validate the model estimates and results.

On-board transit ridership counts are also conducted separately by each transit operating agency. OC Transpo uses an Automated Passenger Counting (APC) system which is typically operated on about 10 percent of the vehicle fleet. These buses are consequently rotated through the scheduled service on various days of the week so that a representative sample of service is collected. APC buses are fitted with components that count all passenger activity through each door. For STO, manual counts are undertaken once a year, and cover every bus trip once during the period of January/February.

Transit Travel Speed (GPS) are obtained from the transit agencies based on the Automated Vehicle location systems (AVL) which are GPS based and provide a detailed log of transit speeds and travel times on specific routes and/or corridors.

Region-Wide Travel Time Surveys are resource extensive data collection efforts and consequently not normally undertaken frequently. However, to complement the regional origin-destination data collection efforts, travel time data was captured on approximately 22 travel itineraries through the use of the floating car approach. The travel time information was collected using GPS technology with time space information being recorded for both directions of travel in predefined corridors, which represented a sizeable amount of data.

External Travel Survey was undertaken using intercept surveys and license plate capture at 23 entrance points into the National Capital Region. This survey recorded the locations of both the internal trip end, by NCR traffic zone, and external trip end, by a system of external zones. The results of this survey formed the basis for the external trip table used in the current model redevelopment. As the external travel survey was performed in 2009, 2011 traffic counts and occupancy data were used to update the volumes on key connections to and from external zones for the model. It is notable that Quebec Autoroute 50 was fully completed in 2012 to provide a connection between the NCR and Montreal area on the north side of the Ottawa River. The availability of this link was not reflected in the results of the 2009 external travel survey or 2011 OD survey. As this link provides an alternative to Ontario Highway 417 to and from Montreal, it will be important in future data collection to assess the split of traffic between the two facilities.

Interprovincial Truck Survey was conducted in the summer of 2007, to establish a comprehensive database on interprovincial heavy truck travel patterns in the National Capital Region. The study included the volume and type of vehicles crossing each of the bridges and based on point of origin and destination, three trip types were identified: local trips, interregional trips, and through trips. The survey found daily heavy truck volumes crossing the Ottawa River were 3,760 in 2007 – 9% higher than in a similar survey conducted in 1999-2000. The MacDonald-Cartier Bridge carried 2,630 trucks per day (70% of total truck traffic), while the Chaudière Bridge carried 1,130 trucks per day (30% of total truck traffic).

While the interprovincial truck survey findings and O-D patterns are relevant, they do only place a focus on a small portion of the overall in-scope truck trips within, to/from the National Capital Region. They effectively provide detailed information regarding trips which cross the Ottawa River and as such a more comprehensive O-D data set drawn from a region-wide survey of truck movements would form the basis from which to establish and develop a framework for modeling truck movements for the Nation Capital Region

2.2.4 Population and Employment Data

2.2.4.1 Household distribution

Population data by various age groups were defined for each traffic zone, as specific household compositions and travel behaviour patterns are often linked to various age cohorts. In addition, population and household characteristics were used in defining key elements such as household distribution by size, dwelling type, number of workers in the household and household income group. Finally, total employed labour force (number of workers) was defined for each zone. Age cohorts were defined as follows: 0-4 years, 5-14 years, 15-24 years, 25-44 years, 45-64 years, >64 years. The household sizes were defined into six groupings (1, 2, 3, 4 or 5, 6+). The household income is defined into four groups - less than $30,000, 30,000 to $59,999, $60,000 to $89,999 and $90,000+. Two basic dwelling types were used: apartments and detached houses (include single detached, semi-detached and rowhouse / townhouse). The number of workers in each household is defined in categories of 0, 1, 2, or 3+. These marginal zonal controls, in combination with the seed distribution of households from the OD survey, allowed for construction of a detailed synthetic population in each traffic zone including a joint distribution of households by size, dwelling type, income group and number of workers (168 joint categories).

The socio-economic and socio demographic variables such as the household distribution by size were estimated by the Ministry of Transportation Quebec based on the 2011 census data produced by Statistics Canada. For some variables, the information for the year 2011 was still to be produced, in these cases, estimates were based on the 2006 census.

The City of Ottawa population estimates were based on 2011 post-census estimates and prepared and updated by City Staff based on their ongoing monitoring efforts of residential building permit issuances and observed housing occupancy rates for various regions of the City.

2.2.4.2 Employed labour force

A number of sources with respect to the employed labour force were available to the study team. In general, some adjustments were necessary to balance the information obtained indirectly from StatsCan with the information inputted from the OD survey results. The resident employed labour force is almost equal to the total employment in the region. This would means that there will not be any net significant inflow of labour force from outside of the region (i.e more persons commuting into the region from outside the region than those leaving the region for employment).

2.2.4.3 Number of workers per household

The 2011 OD dataset was used to establish the seed distribution of household by number of workers at the traffic zone level of disaggregation. In general, workers per household were categorized as follows; Households with no worker, 1 worker, 2 workers and 3 or more workers. The control targets for households by number of workers for the region came from census data. A population synthesizer developed outside the EMME/4 model framework using JAVA was used for generating the joint household distribution by size, number of workers, income group and dwelling type.

2.2.4.4 Household income and percentage of Low-income Population

Household income was deemed to be a valuable factor in assessing travel behaviour and consequently it was retained as a variable for consideration in the modelling framework. The population synthesizer was updated to include household income in the joint household distributions. Household income was explicitly used in car ownership and tour generation models. In the later models, the impact of income was retained for work tours only. The work tours were segmented by low (less than $30,000), medium ($30,000 -$89,999) and high income ($90,000 or more) groups. The percentage of low income population per zone was used as an (aggregate) means to capture the impact of household income on trip making characteristics (such as time-of-day choice and pre-mode choice).

2.2.4.5 Employment by place of work

Employment levels for various classifications was to be retained in the modelling framework as it provided a strong relationship in the identification of stop attraction as well as overall trip activity levels for individual categories of employment types. The following categories were established for the region:

- Public Offices (25%)
- Private Offices (14%)
- Retail (11%)
- Service (24%)
- Education (7%)
- Health (10%)
- Industrial (9%)

The percentage in parenthesis indicates the regional share of the jobs in each of the categories noted. For Ottawa region, some of the employment types were available by more disaggregate categories:

- Major Shopping (6%)
- Street Shopping (4%)
- Restaurants (6%)
- Banks and Post office (2%)
- Theatres (0.3%)
- Other Services (16%)
- Hotels (0.8%)
- Major Hospitals (3%)
- Warehouses (0.1%)
- Other Industrial (9%)
- High Tech Employment (6%)

2.2.5 Land-use and Density Information

Land-use characteristics proved to be important determinants of travel behaviour and were significant in such sub-models as tour generation, share of walk trips, as well as in mode choice. Land use variables were calculated and statistically tested at different levels of geography: traffic zone, superzone, and district, for each of the following variables:

- Share of single detached, semi-detached, and ground oriented households vs. apartments and condominiums,
- Residential density (population per area unit),
- Employment density (total employment per area unit),
- Retail density (retail and service employment per area unit),
- Gross Leasable Area (GLA) for major shopping facilities, museums, theatres, warehouses, sport facilities and parks.

2.2.6 Average Income at Place of Work

The average income by place of work proved to be important determinant of tour attraction for work tours. The variable was statistically tested for the tour attraction model and was found to be significant.

2.2.7 School & University Related Variables

School trips as a trip purpose were defined in the OD dataset and could be further disaggregated into post-secondary (including Colleges and University) and elementary/secondary school trip categories based on the student’s age. In general this was carried out as follows:

- **5 to 17 years**: Elementary/Middle/Secondary schools
- **18 years and more**: while referred to as university trips do include all post-secondary institutions.

In addition to enrollments, university dorm student population was also provided to account for university students who are not part of regular households. Also, rental stock in the zone was used to identify population of students living in rentals close to the university areas.

2.2.8 Parking Related Data

The location of large parking supplies as well as the cost of parking was identified particularly for the core areas. Also, the specific supply of parking at Park and Ride lots on both sides of the Ottawa River was identified as these was used as controls for the development of the P&R mode choice model. In general the information developed and used within the modelling framework included the following:

- Existing park and ride lots capacity, provided by TRANS Agencies (OC Transpo / STO),
- City Owned / Leased Parking Lots (location, rates, capacity), as provided by various planning agencies.

These various data sources were combined to develop the parking-related zonal inputs for the mode choice sub-model in the following form:

- Auto parking cost:
  - Long-term (daily) parking used for work, school, and university tours,
  - Short-term (2 hours) parking for maintenance and discretionary tours.
- Park-and-Ride locations coded as separate traffic zones / centroids in EMME/4:
  - Park-and-Ride lots for rail and/ or bus

3.0 DEMAND MODEL ARCHITECTURE

3.1 Main Model Features and Sub-Models

3.1.1 Summary of Model Features

The proposed model architecture was developed to ensure increased behavioural realism and to permit further future enhancement of the model system over time. It includes several advanced features associated with the new generation of activity-based models, combined with more traditional 4-step model components. In addition, the proposed framework was cognizant of data availability to ensure feasibility of the model estimation, implementation constraints, and calibration efforts while at the same time recognizing both the project schedule and budget.

The main features of the core model are summarized here:

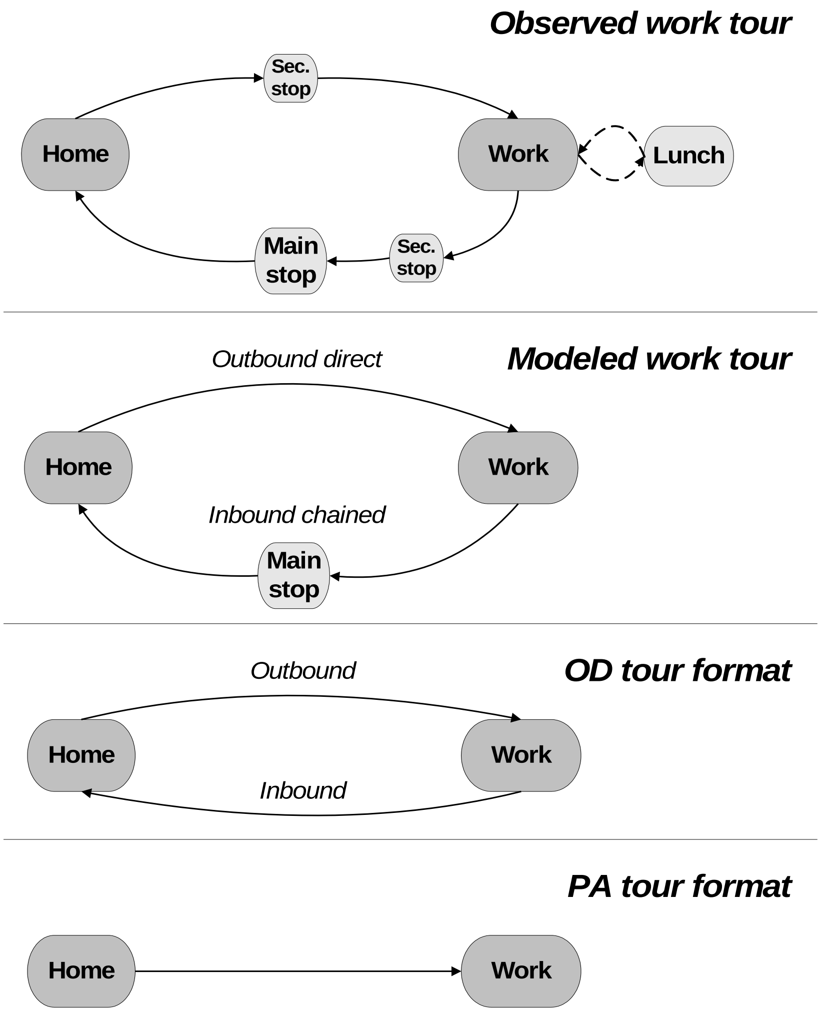
- **Enhance population synthesizer**. In the previous version of the population synthesizer, the households were generated by 42 joint household size, dwelling type and number of workers distributions. The population synthesizer was significantly enhanced to add household income in the generation of the households and generating 168 distributions. Also, in the previous version of the model, the number of workers in the household was identified based on total worker population in the zone. It was replaced with household distribution by number of workers in the zone. The algorithm for the population synthesizer was changed from simple iterative balancing approach to Newton Raphson method. It fastens the convergence and also allows specifying different priorities to different control variables.

- **Incorporation of household income and more tour purposes**. The household distributions are now also generated by household income group. The model was significantly restructured and re-estimated to accommodate income group in the model chain. The tour purposes were redefined to split work tours by three income groups - low (less than $30,000), medium ($30,000 -$89,999) and high income ($90,000 or more).
- **Incorporation of accessibility effect**. Accessibility measures were included in car ownership, tour generation, pre-mode choice, time-of-day choice and tour distribution. This will account for TDM policies, including road tolling and parking fares. These accessibility measures include time and cost for different modes and different time periods. They are technically implemented as a set of time-of-day specific mode & destination choice logsums.
- **Incorporation of Trip Chaining.** This feature was retained from the previous version of the TRANS Model. It considers individual's trips as part of the trip chain in which they are made, constitutes the most advanced practice in travel modelling today. Accounting for trip linkages within the chain brings several important benefits. First of all, it allows for better and more consistent modelling of non-home-based trips (that account for approximately 20% of the total daily trips). Secondly, it ensures a logical consistency across trips included in the same tour in terms of their destinations, time-of-day, and mode choice. The model architecture explained below includes many entire-tour-based and half-tour-based procedures. The introduction of these procedures is restricted to the trip generation and trip distribution stages, where they can be effectively implemented. Thus, the new model is not a full tour-based model since the mode choice model is still essentially trip-based. A tour-based mode choice model would require a full micro-simulation approach. The opportunity for this extension of the TRANS Model in a future generation is, however opened.
- The **tour construction** technique (retained from the previous TRANS Model version) is illustrated in Exhibit 3-1 below under example of a typical work tour including 7 trips. It includes the following four major steps:
    1. **Identification of the primary tour destination and ranking of the intermediate stops.** All trip destinations on the tour are ranked based on activity type and duration. In the given case, the primary destination is work. The primary destination naturally breaks the tour into two directional half-tours – outbound and inbound. Then, all other destinations are treated as stops and ranked to identify the main and secondary stops. This process serves to eliminate insignificant stops (typically less than 10 min and route deviations of less than 5%), thus simplifying the tour structure. In the given example, two intermediate stops proved to be insignificant. Also, this tour included a work-based sub-tour for lunch. Statistical analysis has shown that the share of work-based sub-tours in the AM and PM periods is negligible, thus this component was not modelled in the current version of the model. It should be added if the Midday period is also modelled explicitly.
    2. **Identification of the simplified modelled tour.** After elimination of insignificant stops by linking the corresponding trips, we obtain a simplified tour structure that is actually modelled. This structure always includes the primary destination and may include up to one additional stop in each direction. Although this is a simplification of the reality, it covers

almost 95% of the observed trips and 90% of the observed VKT in the modelled time-of-day periods (AM and PM).

3. **Origin-Destination (OD) tour format.** This is a further aggregation that essentially reduces the tour to round trip by elimination of intermediate stops. In the modelling process, the OD tour format is applied at the second stage of the trip distribution (after which, at the third stage, intermediate stops are inserted).
4. **Production-Attraction (PA) tour format.** This is the most aggregate tour representation that essentially considers the locations of home and primary-destination of the tour with no distinction by travel directions. In the modelling process, the PA tour format is applied at the very first stage of trip distribution. In general, it should be noted, that for the clarity sake, the levels of aggregation 1-4 are presented in the order of simplification. This order also corresponds to the steps of data processing of the OD Survey. However, in the model application stream the order is reversed. It starts with the most aggregate PA format, then converts it into OD format with directional half-tours, and finally inserts stops into chained half-tours.

Exhibit 3-1 | Tour Construction Steps



- **Daily Tour Generation.** The production and attraction sub-models are operate with tours and provide daily trip numbers of which time-of-day-specific numbers are derived in a consistent way based on the time-of-day choice model. The tour production model does not focus on the individual person rates but rather on the household as a whole and on its composition (number of workers, number of non-workers, etc.), dwelling type, income group and car ownership. The tour (primary destination) attraction model is also daily (with subsequent time-of-day choice). It is formulated as a zonal model and is based on the socio-economic and land-use variables. This model was updated based on new zonal data.
- **Daily tour distribution of which TOD-specific trip matrices are derived in a consistent way.** The distribution of tours is first modelled for the entire day in a PA format that provides an aggregate regional picture of major traffic flows (commuting to work being the most important of them). Further on, tours and half-tours are broken by time-of-day periods. At the final stage, half-tours are converted into trips, by types of half-tours. Direct half-tours represent a single trip each. Chained half-tours are converted into two successive trips each by insertion of an intermediate stop. It should be noted that the proposed technique is principally different from just having independent time-of-day-specific

models. In the proposed structure, TOD-specific trip matrices are consistently derived from the same source and dependent on the same input variables. This model was re-estimated using the new OD survey, but the same structure was retained as the existing model.

- **Detailed mode choice procedures to support TRANS planning needs.** As an additional improvement to the existing TRANS Model, the proposed mode choice sub-model explicitly incorporates a non-labeled approach for transit modes (local transit vs. premium transit) and access options (walk, park & ride, kiss & ride, bike & ride), distinguishes between auto driver and passenger modes by vehicle occupancy and explicitly models bicycle trips.
- **Enhanced auto assignment with high-occupancy vehicles and tolls.** The auto assignment by class now includes network prohibitions and tolls by single occupancy, high occupancy (2) and high occupancy (3+) vehicles. The level-of-service variables (time, cost) are generated by occupancy type of the vehicle and used accordingly in the mode choice model.
- **Iterative auto and bike assignments with feedback of volumes**. The designed model framework addresses specifics of bicycling Level-of-Service (LOS) and the associated cross-modal impacts which cyclists and motorized traffic have upon each other. The bicycle route choice model is designed to be sensitive to a wide range of LOS measures including time, speed, pavement condition, vehicular traffic etc. This is a substantial improvement and quite innovative feature that has not been yet incorporated even in the most advanced travel models in practice. This is an iterative procedure where the network assignment of autos and bicycles is applied iteratively with a 2-way linkage between them. Auto assignment includes multiple classes of vehicles reflecting there differential network prohibitions and PCEs (Passenger Car Equivalents). This assignment produces traffic volumes on network links by vehicle classes that are carried over to the bicycle assignment. Traffic volumes are used as one of the important components in calculation of the bicycle level of service. Bicycle volumes generated by the bicycle assignment are carried over to the (next iteration) auto assignment as part of the background volumes that affect auto impedance functions.
- **Improved transit assignment with capacity constraints, crowding functions, and equilibration.** A number of important improvements have been made to the transit assignment procedures. The following new features will help better portray the complex transit systems within the Ottawa-Gatineau Region:
    - Improve loading patterns of individual transit lines by taking into account individual line capacities. Transit capacity restraint assignment is essential for the base year when all line frequencies are known. Transit vehicle load factor and crowding level are calculated accounting for probability of having a seat in transit assignment and mode choice.
    - Consider frequency adjustment (optimization) procedures for future years when line frequencies are unknown and can be changed by the transit operators in response to the changing demand. The procedure starts with maximum feasible frequencies for each line under maximum capacity constraints of the infrastructure (bus lanes and rail). Then, demand and supply are gradually equilibrated by adjusting frequencies downward for lines that are under-utilized.

- Non-linear piece-wise wait time function (instead of half-headway with maximum). This function reflects on the way how transit users arrive at the station in reality. They arrive at random for frequent services (headway of 10 min or less) but in general arrive based on the schedule for infrequent services.
- Dwelling time at stop as a function of the number of boarding and alighting passengers to account for impact of crowding on transit in-vehicle time and reliability.
- Park and Ride lot capacity constrain using shadow pricing.

- **Current focus on the AM and PM periods.** The effort required for the development of the much more advanced and thorough approach described above translates in the implementation and calibration of the subsequent mode choice and trip assignment stages to be restricted to the AM and PM periods for the current model version. In practical terms, modelling these key periods suffices for an effective supporting of most planning decisions. The new model framework allows for a comparatively straightforward extension of the model system to include some other or even all periods of a day if needed in future.
- **Taking maximum advantage of the available land-use and socio-economic data** in combination with the OD-Survey micro-sample. The model design and particularly, the population synthesizer, was subject to the availability, texture, and quality of the zonal population and employment data. It is however flexible and can incorporate practically any set of available zonal data items that can be provided for and used as control targets – both for the base and forecast years. These targets are applied in combination with the household/person distributions extracted from the OD Survey in order to build a synthetic distribution of households / persons needed to support the demand model.
- **EMME based system.** The entire model system was implemented as a 3-level nested macro script compatible with the last version of EMME/4 software. The TRANS Population Synthesizer (calculation of household distributions for each zone) is the only external procedure programmed in JAVA. The nested macro structure is extremely modular with all main procedures encapsulated as parametric sub-routines called from the meaningful shells. This allows for an easy modification of the model system in future including extensions to the other periods of a day.

3.1.2 Demand Model System Design

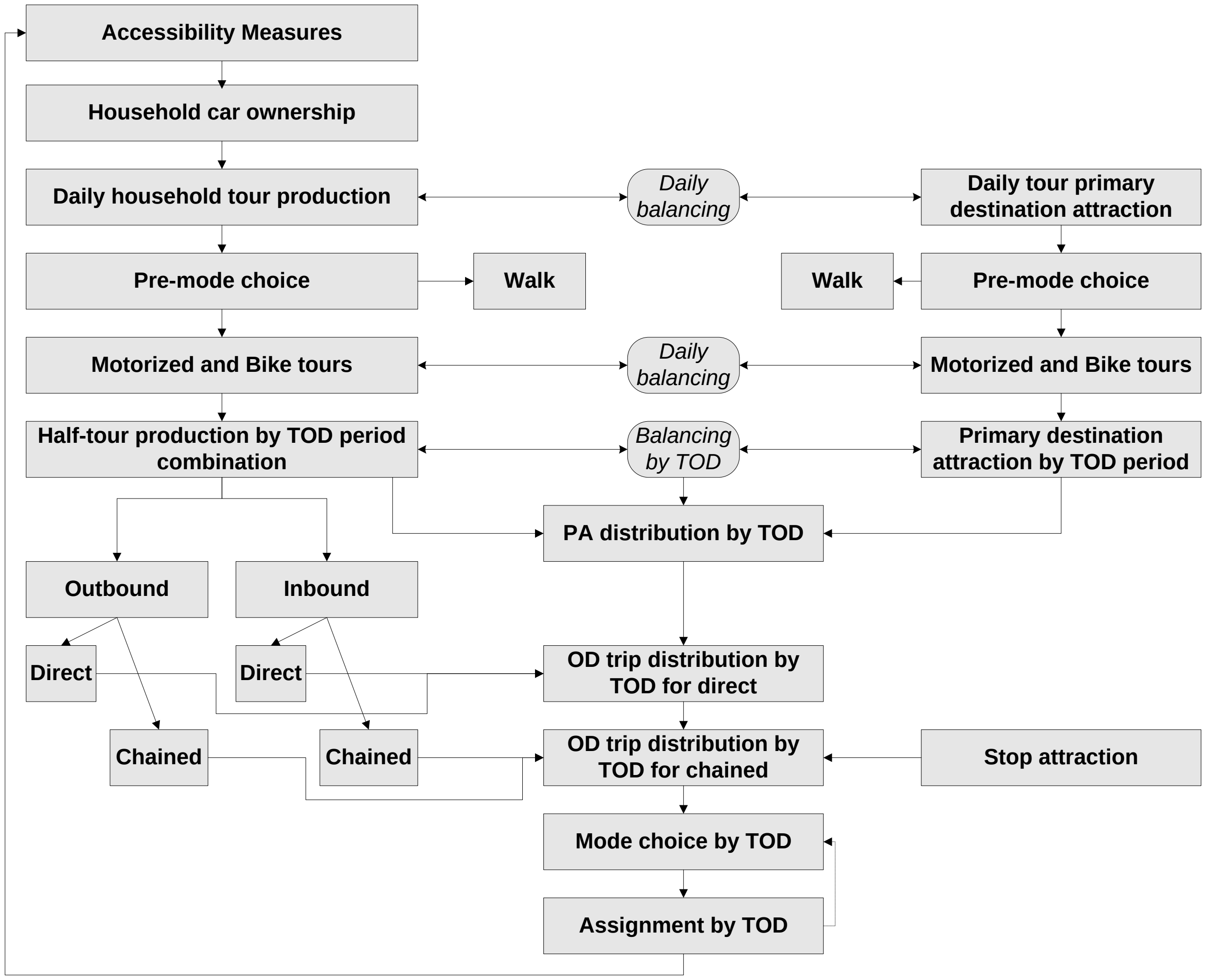
The demand model system design is presented in Exhibit 3-2 below. The main model stream can be divided into the following three major stages:

1. **Tour generation** sub-models and procedures implemented in parallel on the household production and zonal attraction sides with subsequent regional-wide balancing of production and attraction totals. These sub-models are implemented and the results are stored in a vector-based form (indexed by either production or attraction zone). The following components are included:
    - Accessibility measures
    - Household car-ownership sub-model,
    - Daily household tour-production model,

- Daily zonal tour (primary destination) attraction model,
- Daily tour balancing procedure design to ensure equal regional tour production and attraction totals,
- Pre-mode (walk vs. non-walk) binary choice sub-model on the household production side,
- Pre-mode (walk vs. non-walk) binary choice sub-model on the zonal attraction side,
- Daily motorized tour balancing procedure design to ensure equal regional motorized tour production and attraction totals (non-motorized travel is left out and not modelled from this point on),
- Half-tour production stratification by TOD periods and chaining (direct vs. chained half-tours),
- Primary destination attraction stratification by TOD periods,
- Non-Walk tour balancing procedure by TOD periods design to ensure equal regional motorized tour production and attraction totals for each TOD slice,
- Zonal stop attraction sub-model that provides stop-location size variables for the subsequent matrix chaining (stop insertion) sub-model.

2. **Tour and trip distribution** sub-models that use the outcome of the generation stage as marginal controls. These sub-models are implemented and the results are stored in a matrix-based form (indexed by OD zone pairs). The following components are included:
    - Tour distribution in PA format for each TOD period,
    - Trip distribution resulted from the direct half-tours in OD format for each TOD period,
    - Trip distribution resulted from the chained half-tours in OD format (with insertion of intermediate stops) for each TOD period.
3. **Integrated trip mode choice and assignment** procedure that uses time-of-day-specific trip matrices obtained at the distribution stage. These procedures are essentially network-based and the results are stored in both matrix-based and network-based forms. The following components are included:
    - Trip mode choice sub-models (currently implemented for AM and PM periods) fully integrates with multi-class traffic, bicycle and transit assignment procedures by the same TOD periods,

Exhibit 3-2 | TRANS Model System Design



3.1.3 Main Dimensions for Model Segmentation

The model system is segmented across several important dimensions. Some of them like travel purpose and time-of-day periods are applied across all sub-models and defined externally. Some other ones like car ownership are modelled in the process by the corresponding sub-model and then applied for the rest of the model chain. Several other segmentations are pertinent to the specific sub-models. The main dimensions for segmentation are defined in the following way:

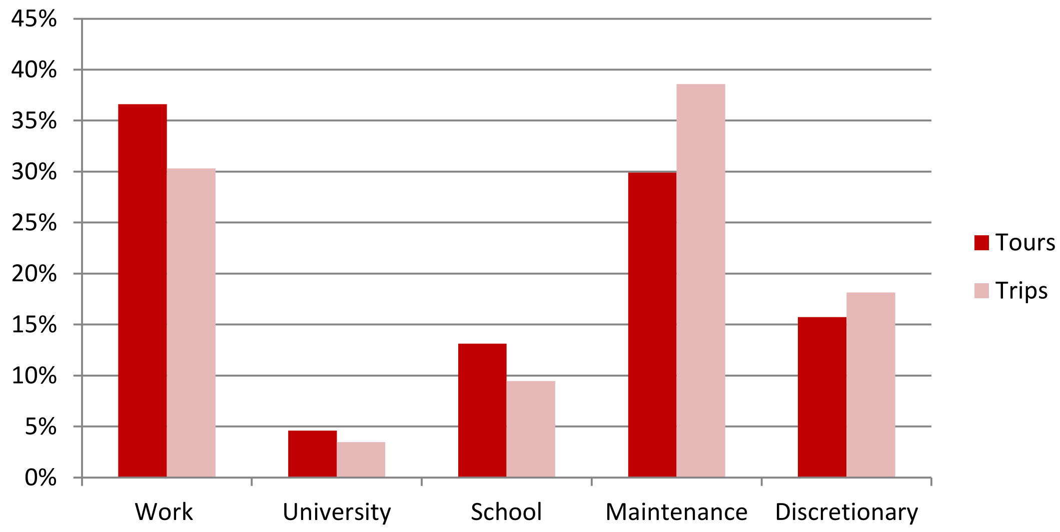
- **7 travel purposes** defined based on the original OD survey codes:
    1. **Work Low Income**, including original codes 1=usual place of work, 2=other work-related, and 3=work on the road / itinerant / not fixed workplace for a worker from low income group (less than $30,000).
    2. **Work Medium Income,** including original codes 1=usual place of work, 2=other work-related, and 3=work on the road / itinerant / not fixed workplace, for a worker from medium income group ($30,000 -$89,999).

3. **Work High Income,** including original codes 1=usual place of work, 2=other work-related, and 3=work on the road / itinerant / not fixed workplace, for a worker from high income group ($90,000+).
4. **University**, including original code 4=school for students of age 18 or older as well as those who reported any type of university, college, CEGEP, business school, etc.
5. **School**, including original code 4=school for students of age under 18 who reported either elementary or high school.
6. **Maintenance**, including original codes 5=shopping, 8=restaurant (take-out), 11=medical / dentist visit, 12=drive someone somewhere, 13=pick someone up.
7. **Discretionary**, including original codes 7=recreation, 9=restaurant (eat in), 10=visit friends / family.

- **5 time-of-day (TOD) periods** defined based on the mid points (between departure and arrival time) for each trip:
    1. **Early** than 6:30,
    2. **AM** (6:30 -8.59),
    3. **Midday** (9:00-15:29).
    4. **PM** (15:30-18:29),
    5. **Later** than 18:30.
- **4 car-sufficiency groups** (intentionally numbered from 0 through 3) defined based on the number of cars owned by the household relative to the number of workers:
    1. Zero cars (zero car sufficiency),
    2. At least one car, cars fewer than workers (low car sufficiency) ,
    3. At least one car, cars equal to workers (balanced car sufficiency),
    4. At least one car, cars greater than workers (high car sufficiency).

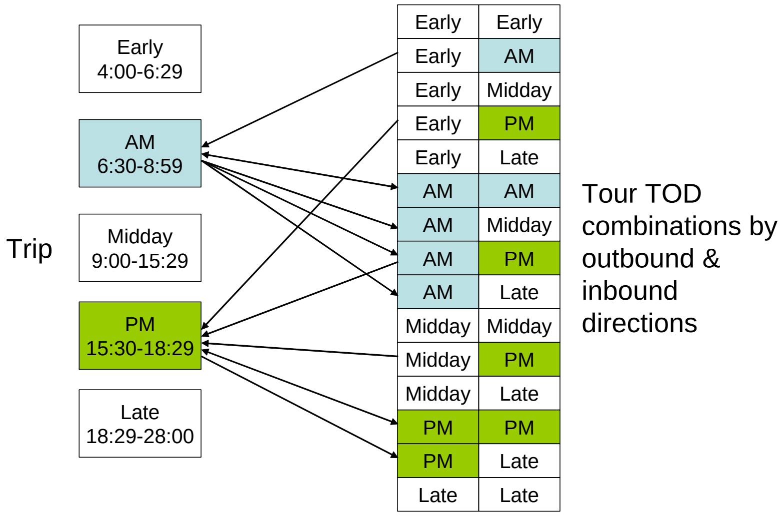
The observed frequency of trips and tours by travel purpose is compared in Exhibit 3-3. For tours, the purpose was defined based on the tour primary destination. For trips, purpose for each trip was defined by the trip destination and return trips home were not counted. The comparison of tour and trip distributions illustrates an additional advantage of linking trips into tours – a higher and more realistic share of work and university / school related travel. In particular, work commuting tours include many non-work stops (for maintenance and discretionary purposes) on the way to and from work. When being broken into elemental trips, these stops produce many non-work trips and reduce number of work trips. However, in reality and in terms of travel behaviour, these trips are parts of work commuting travel. For example, in terms of mode choice preferences they are closer to work trips than to trips from non-work tours (i.e. essential non-work travel).

Exhibit 3-3 | Observed Frequency of Trips and Tours by Purpose



Five TOD periods defined for each trip generate 15 feasible TOD period combinations for the tour measured by outbound and inbound time as shown in Exhibit 3-4. A feasible TOD period combination for a tour corresponds to any outbound-inbound TOD pair where the inbound TOD period is equal to or later than the outbound period. Only two (trip) TOD periods are currently modelled through the mode choice stage (AM and PM). However, to properly combine trip matrices for these two periods, 9 out of 15 tour TOD combinations should be considered. For example, a tour TOD combination with early outbound time and AM inbound time will contribute one direction (inbound) to the AM period. A combination of outbound AM and inbound PM periods (the most frequent work commuting pattern) would contribute one direction to each modelled period. A tour that starts and ends in the Midday period would be irrelevant for the modelled periods.

Exhibit 3-4 | Correspondence between Trip and Tour Time of Day



The following segmentation rules are applied through the main model chain – see Table 3-1.

Table 3-1 | Model Segmentation

Segments	Sub-model						
	Car ownership	**Tour generation**	**Walk share**	**Time of day**	**Tour/trip distribution**	**Mode choice**	**Assign-ment**
42 by household type	X	X					
4 by car sufficiency		X	X	X	X	X	
4 Income groups	X	X					
7 by travel purpose		X	X	X	X	X	
15 by tour TOD					9		
5 by trip TOD					2	2	**2**
Total	**168**	**4704**	**28**	**28**	**252/56**	**56**	**2**

Car ownership is applied for 168 different household types (by size, number of workers, household income group and dwelling type) produced by the population synthesizer. After car ownership choice probabilities have been calculated, additional 4 segments (by car sufficiency) are generated for each household type and used in the tour generation model. The tour generation model uses the resulted 168*4=672 household segments and is additionally segmented by 7 travel purposes. This creates 672*7=4,704 segments that are still feasible because of the vector-based calculations.

From this point on, all subsequent sub-models use only 4 car-sufficiency segments in combination with 7 purposes in order to avoid infeasible number of calculations, especially for matrix-based models (distribution and mode choice). The TOD choice model adds 5 trip and 15 tour segments of which 2 trip and 9 relevant tour TOD segments are stored for the subsequent calculations. The tour distribution model operates with 28*9=252 segments of which 56 trip matrices (by 7 purpose, 4 car sufficiency groups, and 2 TOD periods) are constructed and stored for mode choice. Mode choice is essentially fully segmented by these 56 segments. Assignments are implemented separately by trip TOD periods with no segmentation by either travel purpose or car sufficiency. Since mode choice is fully integrated with the assignments in one equilibration procedure, it is organized by two TOD periods – AM and PM, each period operating with 28 (4 car sufficiency by 7 purposes) segments.

3.1.4 Observed Stop Frequency by Tour Purpose

In order to eliminate unnecessary processing of infrequent cases and make the model structure simpler and operation more efficient, the modelled tour structure was simplified to take into account the most important specific features of the observed tours for each purpose (the entire-tour purpose associated with the primary destination). The observed tour structure in terms of stop-frequency for each purpose and also by half-tour direction is presented in the Table 3-2 below.

Table 3-2 | Observed stop-frequency, OD Survey, 2011

	Outbound Number of Stops						Inbound Number of Stops					
Tour Purpose	**0**	**1**	**2**	**3**	**4+**	**Total**	**0**	**1**	**2**	**3**	**4+**	**Total**
Number of Tours (un-weighted)												
1- Work Low	849	66	8	2	6	931	753	135	32	6	5	931
2- Work Med	7295	592	88	15	5	7995	6641	1047	212	71	24	7995
3- Work High	11997	1342	235	34	11	13619	10940	2008	497	114	60	13619
4- University	2676	125	23	5	1	2830	2478	293	45	13	1	2830
5- School	7978	99	10	1	1	8089	7479	497	90	16	7	8089
6- Maintenance	15383	2277	536	143	79	18418	14956	2586	614	179	83	18418
7- Discretionary	8874	681	100	25	16	9696	8697	813	139	38	9	9696
Percentage of Tours												
1- Work Low	91.2%	7.1%	0.9%	0.2%	0.6%	100.0%	80.9%	14.5%	3.4%	0.6%	0.5%	100.0%
2- Work Med	91.2%	7.4%	1.1%	0.2%	0.1%	100.0%	83.1%	13.1%	2.7%	0.9%	0.3%	100.0%
3- Work High	88.1%	9.9%	1.7%	0.2%	0.1%	100.0%	80.3%	14.7%	3.6%	0.8%	0.4%	100.0%
4- University	94.6%	4.4%	0.8%	0.2%	0.0%	100.0%	87.6%	10.4%	1.6%	0.5%	0.0%	100.0%
5- School	98.6%	1.2%	0.1%	0.0%	0.0%	100.0%	92.5%	6.1%	1.1%	0.2%	0.1%	100.0%
6- Maintenance	83.5%	12.4%	2.9%	0.8%	0.4%	100.0%	81.2%	14.0%	3.3%	1.0%	0.5%	100.0%
7- Discretionary	91.5%	7.0%	1.0%	0.3%	0.2%	100.0%	89.7%	8.4%	1.4%	0.4%	0.1%	100.0%

Tour and trip structure is defined after elimination (linking) of insignificant trips that are characterized by a short activity duration (less than 10 min in this preliminary analysis), and insignificant route deviation from the shortest path (less than 5%). Additionally all walk loop-trips (with destination zone equal to the origin) can be eliminated from motorized tours. However passenger dropping-off and picking-up trips were not eliminated because of their importance for mode choice. These infrequent cases are shadowed in the table where additional non-anchored non-home-based trips are made and could be linked to the corresponding modelled trips and therefore not explicitly modelled. This essentially reduces any complicated observed tour structure to the basic modelled type described above (one stop in each direction).

It was noted that two-stop half-tours and associated non-anchored NHB trips are relatively frequent only for the following half-tour segments: work inbound, maintenance outbound and inbound. For all other half-tour segments, one intermediate stop was sufficient to cover more than 95% of the observed cases. However, further analysis of the associated route deviations has shown that even for the half-tour segments with a relatively frequent second stop, the added route deviation compared to the route deviation to make the first (main) stop is negligible. Thus, in terms of VKT, modeling a single stop in each direction is acceptable in practical terms if the main stop is defined taking into account the route deviation.

3.2 Accessibility Measures and Model Equilibration

There are multiple accessibility measures used in the model system to reflect the impact of travel time and cost of different modes on different travel choices. In general, accessibility measures are calculated is composite utilities of the corresponding choices (mode choice, destination choice). Accessibility measures play two important and closely intertwined roles in the model system:

- Ensure that all sub-models are properly sensitive to the improvements of the transportation system. For example, it is expected that improvement of the transit system will not only affect mode choice but will also affect trip distribution, trip generation, and car ownership. These affects cannot be captured without accessibility measures.

- Ensure that the entire models system can be properly equilibrated and produce a consistent forecast across all travel dimensions. Accessibility measures are the only components of all upper level models that change from iteration to iteration in the equilibration process.

Mode choice based accessibilities are needed to ensure that tour distribution models reflect all modal opportunities between zone pairs. These accessibilities have an origin-destination matrix form of mode choice logsums. Destination choice based accessibilities are primarily needed to ensure that the upper-level models in the model hierarchy such as car ownership, tour generation, pre-mode choice and time-of-day choice are sensitive to improvements of transportation level-of-service across all modes and time periods, as well as changes in land use. These accessibilities have a form of either origin (or destination) vector of destination (or origin) choice logsums. Destination or origin choice logsums as accessibility indices are similar in nature to density measures and can be thought of as continuously buffered “fuzzy” densities; they reflect the opportunities to implement a travel tour for a certain purpose from a certain origin (residential or workplace) or two a certain destination. Simple density measures only ensure model sensitivity to changes in land use; however, accessibilities introduce sensitivity to both changes in land use and travel time. They are needed because it is infeasible to link all travel choices by full logsums due to the number of potential alternatives across all dimensions (purposes, modes, time periods, car sufficiency etc.). This feature of accessibilities has been adopted from the advanced Activity Based Models in practice. The TRANS Model is probably the only one or one of the few advanced aggregate travel models where accessibilities are not represented simply as “flat” area-type dummies or zone-based levels of service.

There are different types of accessibilities used in the TRANS Model:

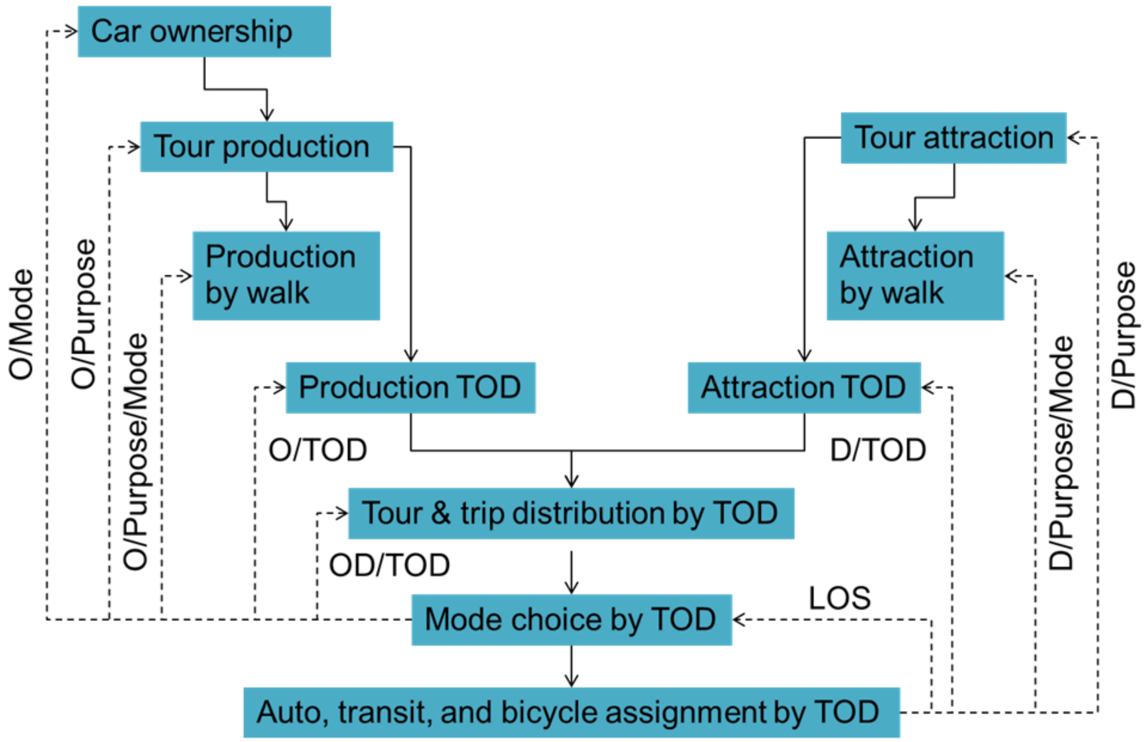
- Mode and time-of-day choice logsum, which is the composite utility of travel across all modes and all periods (peak and off-peak) from a given origin zone to a given destination zone
- Mode choice logsum for a specific time period, which is the composite utility of travel across all modes for a specific time period from a given origin zone to a given destination zone
- Destination choice logsum, which is the composite utility of travel across all modes and all time periods to all potential attractions from a production zone
- Origin choice logsum, which is the composite utility of travel across all modes and all time periods from all potential productions to an attraction zone to all production zones

Exhibit 3-5 shows the feedback of various accessibility measures in the TRANS Model. In a full model run all feedback are activated at each iteration ensure a full model sensitivity. A full run is recommended for the Base scenario for each year as well as for Build scenarios if they involve a substantial change in the regional network. If several alternative network scenarios are compared with only minor changes in the network it is possible to simplify the model run and equilibration by re-running only mode choice for each alternative keeping all other choices the same. It also possible to re-run only mode choice and tour/trip distribution with the corresponding feedbacks, another option is to re-run only mode choice, tour/trip distribution, and time-of-day choice. The model system and corresponding accessibility measures can support any equilibration schema that is suitable for the project.

It should be noted, that while from the theoretical standpoint it is always preferable to re-run a full model for each project, this might not be the best strategy in practical terms. First, small projects will have a negligible impact on the upper-level models such as car ownership and tour generation while the run time will increase substantially. Secondly, it is easier to compare and analyze different network scenarios when only several travel dimensions change at the same time while other dimensions are fixed. This way a useful practical common denominator is created across all scenarios. The choice of the equilibration schema depends on the expected impacts of the project on different travel dimensions. For example, congestion pricing is applied to shift auto users to transit in the peak period or shift them to off-peak period. In this case, equilibration must include both mode choice and time-of-day choice.

The feedback of accessibility measures allows for portraying peak spreading for future years where significant overall growth of congestion is expected. The model is applied in an iterative way of full equilibrating for a future year where travel impedance is different from the calibrated base year. Changes in travel impedances for policy analysis or future year will affect the car ownership, tour generation, walk mode choices, time-of-day choices and tour/trip distribution through accessibility measures.

Exhibit 3-5 | Accessibility Feedback in TRANS Model



3.2.1 Mode and Time-of-day Choice Logsums

A nested mode and time-of-day choice structure is assumed for creating the logsums. The TRANS mode choice model has very detailed segments (7 purposes x 4 car sufficiency) and detailed LOS variables (such as IVTT segmented by Transitway and stop density). Such level of detail is not required for accessibility measures since these are aggregate measures. A simplified mode choice model is defined to calculate the mode choice logsums for accessibility calculations. For this model, 5 modes are defined – SOV, HOV, Walk to transit, Drive to Transit and Walk, and 4 purposes (1-Work, 2-Univ, 3-School and 4- Other which includes maintenance and discretionary). The mode choice utilities are specified in the following parsimonious way:

$$V_{ijm}^{uch} = \Omega_m^{uch} + US_{ijm}^{uh},$$ Equation 1

where:

$i, j \in I$	=	origin and destination TAZs,
u	=	purpose from 1 through 4 (simplified purpose categories for accessibilities only),
c	=	household car sufficiency category (zero, low, high),
h	=	relevant TOD period (peak or off-peak),
m	=	modes from 1 through 5,
Ω_m^{uch}	=	purpose and car-sufficiency specific constants,
US_{ijm}^{uh}	=	LOS dependent utility component by OD-pairs.

The mode choice logsum for a specific time period is calculated by the following formula:

$$L_{ij}^{uh} = \mu_m \times Ln\left[\sum_{m \in M} \exp\left(\frac{V_{ijm}^{uh}}{\mu_m}\right)\right], \qquad \text{Equation 2}$$

where:

$m \in M$	=	all modes
μ_m	=	nesting coefficient for mode choice model

The time-of-day choice logsum is calculated by the following formula:

$$L_{ij}^{u} = \mu_h \times Ln\left[\sum_{h \in H} \exp\left(\frac{L_{ij}^{uh} + \beta^h}{\mu_h}\right)\right], \qquad \text{Equation 3}$$

where:

β^h	=	time period specific constant,
$h \in H$	=	all time periods considered
μ_h	=	nesting coefficient for time-of-day choice model

The mode choice utilities are computed for three time periods – Early (EA), AM peak and Midday (MD). A number of mode and time period choice logsums are computed during various combinations of modes and time periods. Table 3-3 shows the combinations used for various impedance terms. The column “Offpeak” shows additional constant added for off-peak period (Early and Midday) utilities. A value of 1 in the columns for modes (SOV, HOV, WT, DT, WK) and time periods (EA, AM, MD) shows that the mode utilities for these modes and time periods are used in creating the logsum. The 25 impedance terms or logsums are used in different models.

Table 3-3 | Mode and Time Period Choice Logsums

Sl#	Description	Matrix Name	SOV	HOV	WT	DT	WK	Offpeak	EA LOS	AM LOS	MD LOS
1	Work Logsum	mf"Impe1"	1	1	1	1	1	-0.9		1	1
2	University Logsum	mf"Impe2"	1	1	1		1	-0.5		1	1
3	School Logsum	mf"Impe3"	1	1	1		1	-1.2		1	1
4	Other Logsum	mf"Impe4"	1	1	1		1	0.5		1	1
5	Other Logsum by WT	mf"Impe5"			1			0.5		1	1
6	Work auto dependency	mf"Impe6"	1	1		1		-0.9		1	1
7	Non Work auto dependency	mf"Impe7"	1	1		1		0.5		1	1
8	Work Non-motorized Logsum	mf"Impe8"					1	-0.9		1	1
9	Univ Non-motorized Logsum	mf"Impe9"					1	-0.5		1	1
10	School non-motorized Logsum	mf"Impe10"					1	-1.2		1	1
11	Other non-motorized Logsum	mf"Impe11"					1	0.5		1	1
12	Work non-auto dependency	mf"Impe12"			1		1	-0.9		1	1
13	Other non-auto dependency	mf"Impe13"			1		1	0.5		1	1
14	Early TOD OD Logsum for Work	mf"Impe14"	1	1	1	1		-0.9	1		
15	AM TOD OD Logsum for Work	mf"Impe15"	1	1	1	1				1	
16	Midday TOD OD Logsum for Work	mf"Impe16"	1	1	1	1		-0.9			1
17	Early TOD OD Logsum for Univ	mf"Impe17"	1	1	1	1		-0.5	1		
18	AM TOD OD Logsum for Univ	mf"Impe18"	1	1	1	1				1	
19	Midday TOD OD Logsum for Univ	mf"Impe19"	1	1	1	1		-0.5			1
20	Early TOD OD Logsum for School	mf"Impe20"	1	1	1	1		-1.2	1		
21	AM TOD OD Logsum for School	mf"Impe21"	1	1	1	1				1	
22	Midday TOD OD Logsum for School	mf"Impe22"	1	1	1	1		-1.2			1
23	Early TOD OD Logsum for Other	mf"Impe23"	1	1	1	1		0.5	1		
24	AM TOD OD Logsum for Other	mf"Impe24"	1	1	1	1				1	
25	Midday TOD OD Logsum for Other	mf"Impe25"	1	1	1	1		0.5			1

3.2.2 Destination Choice Logsums

Destination accessibility measures have the following general form:

$$A_i = \ln\left[\sum_{j=1}^{I} S_j \times \exp\left(-\gamma c_{ij}\right)\right], \quad \text{Equation 4}$$

where:

$i, j \in I$	=	origin and destination zones,
A_i	=	accessibility measure calculated for each origin zone,
S_j	=	size variable for each potential destination zone,
c_{ij}	=	cost of travel between origin zone and destination zone,
γ	=	dispersion coefficient.

The size variable (S_j) takes form of a linear regression without an intercept:

$$S_j = \sum_m a_m z_{jm} \quad \text{Equation 5}$$

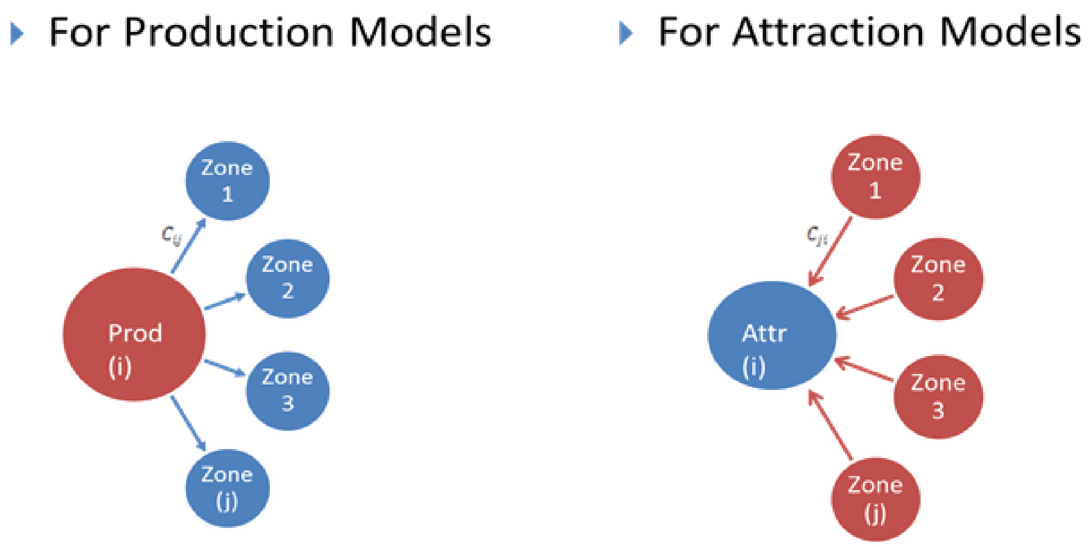
where:

j	=	traffic zone of the primary tour destination,
m	=	zonal variables,
a_m	=	attraction coefficient
z_{jm}	=	values of the zonal variables such as employment, total households etc,

In this form, the destination choice accessibility measure is essentially a sum of all attractions in the region discounted by the travel impedance. The dispersion coefficient expresses a sensitivity of the given type of activity to travel cost, i.e. travelers' tolerance to longer travel times in order to participate in the given activity. Larger dispersion coefficients reflect a greater sensitivity to travel times and costs, reflecting more localized activity types. In the TRANS Model, the impedance function $(\exp(-\gamma C_{ij}))$ is essentially a mode choice logsum and the size variable is tour productions/attractions.

Exhibit 3-6 shows how the accessibilities are calculated for production and attraction models. In case of accessibilities for production models (such as tour production, pre-mode choice production, time-of-day choice production), the size variable is the number of attractions in all the zones and the mode choice logsum is calculated from the production zone to the all attraction zones. For attraction model accessibilities (used in models such as tour attraction, pre-mode choice attraction, time-of-day choice attraction), the size variable is the number of productions in all the zones and the mode choice logsum is calculated from all production zones to the given attraction zone.

Exhibit 3-6 | Accessibility measures for production and attraction models



The set of accessibility measures created for TRANS Model are summarized in Table 3-4 below. The table shows the combination of size variable and impedance terms used for creating various accessibility measures and the models in which these measures were tested. There are 108 different accessibility measures that were created for testing and analysis. However, some of these measures did not prove to be significant in the estimation and were eventually dropped in the final model specification.

Table 3-4 | Accessibility Measures

No	Description	Model where it is used	Attraction size variable S_j	Impedance Function (Table 3-17)
1	Auto Dependency for Work (ADepWo)	Car ownership	Total attractions for Work Purpose (SizeA1)	Impe6
2	Non-Auto Dependency for Work (NDepWo)	Car ownership	Total attractions for Work Purpose (SizeA1)	Impe12
3	Auto Dependency for Non-Work (ADepNW)	Car ownership	Total attractions for Other Purposes (SizeA6)	Impe7
4	Non-Auto Dependency for Non-Work (NDepNW)	Car ownership	Total attractions for Other Purposes (SizeA6)	Impe13
5	Transit Accessibility for Other purposes (TraAcc)	Car Ownership	Total attractions for Other Purposes (SizeA6)	Impe5
13-19	Accessibility to Attractions by Purpose (AcceP1-7)	Tour Production	Total attractions by purpose (SizeA1-5)	Impe1-4
20-26	Accessibility toProductions by Purpose (AcceA1-7)	Tour Attraction	Tour Productions by purpose (SizeP1-5)	Impe1-4
27-34	Walk Accessibility to Attractions by Purpose (AcNmP1-7)	Pre-Mode Choice Production	Total attractions by purpose (SizeA1-5)	Impe8-11
35-41	Walk Accessibility to Productions by Purpose (AcNmA1-7)	Pre-Mode Choice Attraction	Tour Productions by purpose (SizeP1-5)	Impe8-11

No	Description	Model where it is used	Attraction size variable S_j	Impedance Function (Table 3-17)
41-47	Early TOD Accessibility to Attractions by Purpose (AcTP11-17)	TOD Production Model	Total attractions by purpose (SizeA1-5)	Impe14, 17, 20, 23
48-54	AM Peak TOD Accessibility to Attractions by Purpose (AcTP21-27)	TOD Production Model	Total attractions by purpose (SizeA1-5)	Impe15, 18, 21, 24
55-61	Midday TOD Accessibility to Attractions by Purpose (AcTP31-37)	TOD Production Model	Total attractions by purpose (SizeA1-5)	Impe16, 19, 22, 25
62-68	PM Peak TOD Accessibility to Attractions by Purpose (AcTP41-47)	TOD Production Model	Total attractions by purpose (SizeA1-5)	Transpose of AM Impedances (Impe15, 18, 21, 24)
69-75	Night TOD Accessibility to Attractions by Purpose (AcTP51-57)	TOD Production Model	Total attractions by purpose (SizeA1-5)	Transpose of Early Impedances (Impe14, 17, 20, 23)
76-82	Early TOD Accessibility to Productions by Purpose (AcTA11-17)	TOD Attraction Model	Total productions by purpose (SizeP1-5)	Impe14, 17, 20, 23
83-89	AM Peak TOD Accessibility to Productions by Purpose (AcTA21-27)	TOD Attraction Model	Total productions by purpose (SizeP1-5)	Impe15, 18, 21, 24
90-96	Midday TOD Accessibility to Productions by Purpose (AcTA31-37)	TOD Attraction Model	Total productions by purpose (SizeP1-5)	Impe16, 19, 22, 25
96-101	PM Peak TOD Accessibility to Productions by Purpose (AcTA41-47)	TOD Attraction Model	Total productions by purpose (SizeP1-5)	Transpose of AM Impedances (Impe15, 18, 21, 24)
102-108	Night TOD Accessibility to Productions by Purpose (AcTA51-57)	TOD Attraction Model	Total productions by purpose (SizeP1-5)	Transpose of Early Impedances (Impe14, 17, 20, 23)

3.3 Household Car-Ownership Model

Car ownership model is placed in the model system after the population synthesizer and calculation of accessibility measures and before the first set of travel models (tour generation). The number of cars available to the household is one of the strongest determinants of travel behaviour. Thus, the output of this model represents and important input to all subsequent travel models. Essentially, most of the travel sub-models are fully segmented by car-sufficiency index that is derived from the household car ownership and number of workers as explained below.

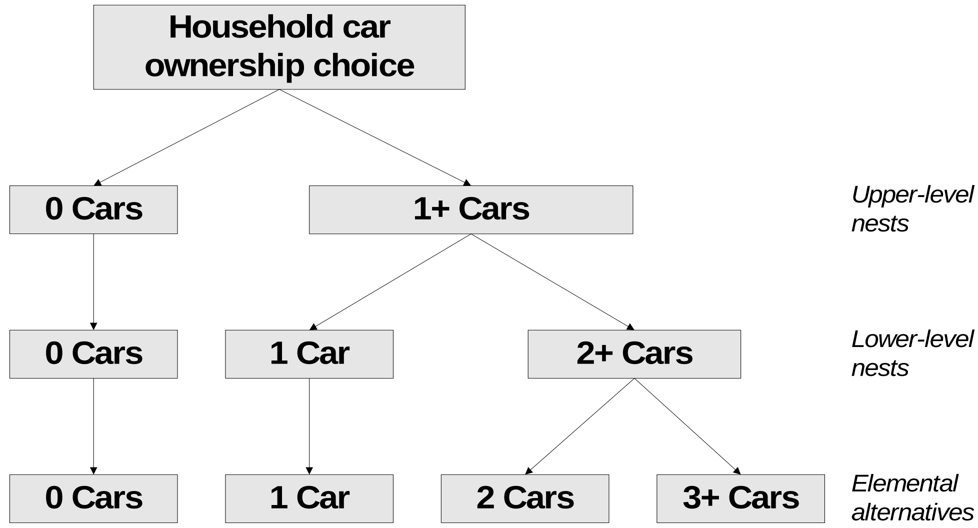
The car ownership model is formulated as a two-level nested logit model with the following set of four alternatives (with the observed frequencies calculated from the OD Survey):

- Zero cars (13.80%),
- 1 car (46.2%),
- 2 cars (31.2%),

- 3+ cars (8.8%) that includes:
    - 3 cars (6.8%),
    - 4 cars (1.5%),
    - 5 cars (0.4%),
    - 6+ cars (0.1%).

The truncation of car ownership alternatives at 3 is justified by the observed distribution of households by number of cars owned (very small share of household with 4 or more cars) and also by the fact that additional cars above 3 do not significantly change the household mobility and travel behaviour. The nested structure is essential since the car ownerships have a differential degree of similarity. It is fully captured by the 2-level structure depicted in Exhibit 3-7.

Exhibit 3-7 | Nested Structure of Car-Ownership Choice



The utility functions for car-ownership alternatives are formed in the following way:

$$V_h^c = \alpha_{w(h)}^c + \sum_k \beta_k^c x_{hk} + \sum_m \gamma_m^c z_{t(h)m} \qquad \text{Equation 6}$$

where:

c	=	car ownership alternatives from 0 through 3,
h	=	households,
$w(h)$	=	number of workers in the household (0,1,2,3+),
α_w^c	=	constants associated with the car-sufficiency (cars vs. workers),
k	=	household variables,
x_{hk}	=	values of the household variables,

β_k^c	=	alternative-specific coefficients for the household variables,
m	=	zonal variables,
$i(h)$	=	traffic zone of the household residence,
z_{im}	=	values of the zonal variables,
γ_m^c	=	alternative-specific coefficients for the zonal variables.

The following variables were statistically tested and included in the final model specification:

- Full set of car sufficiency constants (number of workers relative to the available number of cars):
  - 0 workers / 0 cars (reference case for households with no workers, enforced to zero),
  - 1 worker / 0 cars,
  - 2 workers / 0 cars,
  - 3+ workers / 0 cars,
  - 0 workers / 1 car,
  - 1 worker / 1 car (reference case for households with 1 worker, enforced to zero),
  - 2 workers / 1 car,
  - 3+ workers / 1 car,
  - 0 workers / 2 cars,
  - 1 worker / 2 cars,
  - 2 workers / 2 cars (reference case for households with 2 workers, enforced to zero),
  - 3+ workers / 2 cars,
  - 0 workers / 3+ cars,
  - 1 worker / 3+ cars,
  - 2 workers / 3+ cars,
  - 3+ workers / 3+ cars (reference case for households with 3+ workers, enforced to zero),
- Household attributes:
  - Number of non-workers in combination with a different number of workers,
  - Housing / dwelling type (detached house dummy where apartment served as the reference case),
  - Household income group
  - Auto Dependency to work and non-work locations
  - Transit and Walk accessibility to non-work locations
- Zonal characteristics at three spatial level of aggregation (TAZ, superzone, district):
  - Population density,

- Percentage of detached houses.

As the result of model application each household segment (defined by a combination of household size, number of workers, income group and dwelling type) in each zone is additionally stratified by four car-ownership alternatives. For the subsequent chain of demand models, it is more beneficial to restructure the joint household distribution by an aggregate car-sufficiency index that is more informative than car ownership itself. The following four car-sufficiency categories were defined: 0=zero cars, 1=cars fewer than workers (low), 2=cars equal to workers (balanced), 3=cars greater than workers (high) as shown in Table 3-5 below.

Table 3-5 | Household car sufficiency categories

Number of household workers	Number of household cars			
	0	**1**	**2**	**3+**
0	0=zero	3=high	3=high	3=high
1	0=zero	2=balanced	3=high	3=high
2	0=zero	1=low	2=balanced	3=high
3+	0=zero	1=low	1=low	2=balanced

As the result of this model application in each zone, a four-dimensional distribution of households (by 6 size categories, 4 number-of-workers categories, 2 dwelling types, 4 household income categories and 4 car-sufficiency categories) was constructed resulting in 168×4=672 cells. This level of segmentation can only be directly used however, in the tour production model that has a simple vector-based structure. For the subsequent models of tour/trip distribution and mode choice that have a matrix-based structure, only car sufficiency was used since it would otherwise result in a too large number of matrices, after being combined with trip purpose and time-of-day dimensions.

3.4 Tour Generation Sub-Models and Procedures

3.4.1 Household Daily Tour Production Model

Household-based daily tour production models were developed for the 7 travel purposes. This model was estimated as a linear regression. The model has the following general form of a tour production rate per household that depends on the household and zone-of-residence attributes:

$$R^{uc}_{s(h),w(h),d(h),g(h),i(h)} = r^{uc}_0 + \sum_k \beta^u_k x_{hk} + \sum_m \gamma^u_m z_{i(h)m} \quad \text{Equation 7}$$

where:

u	=	tour purpose from 1 through 7,
c	=	household car-sufficiency category from 0 through 3,
h	=	households,
$s(h)$	=	household size (1,2,3,4,5,6+),
$w(h)$	=	number of workers in the household (0,1,2,3+),
$d(h)$	=	household dwelling type (1,2),
$g(h)$	=	income group of the household (1,2,3,4),
R^{uc}_{swdi}	=	daily household tour production rate,
r_0^{uc}	=	rate component (bias) specified by car-sufficiency for each purpose,
k	=	household variables,
x_{hk}	=	values of the household variables,
β_k^u	=	coefficients for the household variables,
m	=	zonal variables,
$i(h)$	=	traffic zone of the household residence,
z_{im}	=	values of the zonal variables,
γ_m^u	=	coefficients for the zonal variables.

The following variables proved to be the most significant and included in the final model specification:

- Rate bias specified for each car-sufficiency category (0,1,2,3),
- Household attributes:
    - Presence of a 1st worker,
    - Presence of a 2nd worker,
    - Presence of a 3rd worker,
    - Number of non-workers in combination with a different number of workers,
    - Housing / dwelling type (detached house dummy where apartment served as the reference case),
    - Household income category
- Zonal characteristics at three spatial level of aggregation (TAZ, superzone, district):
    - Population density,
    - Rental apartments (applied for university tours only).
    - Accessibility to Locations by purpose

The model application results are combined into zonal tour production vectors by purpose and car sufficiency in the following straightforward way:

$$P_i^{uc} = \sum_{swdg} R_{swdg}^{uc} \times H_{swdgi}^{c} \qquad \text{Equation 8}$$

where:

u	=	tour purpose from 1 through 7,
c	=	car-sufficiency categories from 0 through 3,
P_i^{uc}	=	zonal tour production,
R_{swdg}^{uc}	=	daily household tour production rate,
H_{swdgi}^{c}	=	number of households in the zone by segments.

3.4.2 Zonal Tour Attraction Model for Primary Destination

Daily tour attraction models were developed for each tour purpose as zonal regressions of the observed daily tour primary destinations on the relevant socio-economic and land-use variables. In general, tour attraction models are similar to trip attraction models for the same purpose. It takes the following form of a linear regression without an intercept:

$$A_j^u = \sum_m a_m^u z_{jm} \qquad \text{Equation 9}$$

where:

u	=	tour purpose from 1 through 7,
j	=	traffic zone of the primary tour destination,
A_j^u	=	zone tour attraction for the primary destination,
m	=	zonal variables,
a_m^u	=	tour attraction rate per variable.
z_{jm}	=	values of the zonal variables,

The following variables were the ones that proved to be significant at least for one of the purposes:

- Employment (by place of work) in the traffic zone itself:
    - Total employment,
    - Major Shops employment in Ontario,
    - Street Shops employment in Ontario,
    - Retail employment for Quebec,
    - Restaurant Employment in Ontario,

- Theatre Employment in Ontario,
- Other Service employment in Ontario,
- Service employment in Quebec,
- Banks and Post office employment in Ontario,
- Office employment (public and private),
- Education employment,
- Hospital Employment in Ontario,
- Health employment in Ontario,
- Health employment in Quebec,

- Other characteristics of the traffic zone itself:
  - Sports Gross Area (hectares),
  - Total population,
  - Number of households living in detached houses,
  - Number of households living in apartments,
  - University enrolment (for university purposes),
  - Elementary and secondary school enrolment (for school, maintenance and discretionary purposes),
  - Accessibility to attractions by purpose

For work purposes, the total tour attractions are calculated for all the three work purposes. Then, a logit model is applied to split the attractions by low income, medium income and high income categories.

The utility functions for the work tour attraction split model alternatives are formed in the following way:

$$V_j^s = \alpha^s + \sum_m \gamma_m^s z_{jm} \qquad \text{Equation 10}$$

where:

s	=	split model alternatives from 1 through 3,
α^s	=	constants associated with alternatives,
m	=	zonal variables,
j	=	traffic zone of the primary tour destination,
z_{jm}	=	values of the zonal variables,
γ_m^s	=	alternative-specific coefficients for the zonal variables.

The following variables were statistically tested and included in the final model specification:

- Percentage of Employment (by place of work) in the traffic zone itself:

- % Retail employment,
- % Service Employment
- % Education Employment
- % Health Employment
- % Office Public Employment
- % Warehousing Employment
- % Industry Employment
- % High Tech Employment
- % Office Private Employment

- Other characteristics of the traffic zone itself:
  - Average Income by Place of Work (in 1000s)
  - Population Density
  - Employment Density
  - Accessibility to Work location from all production zones

3.4.3 Balancing of Total Daily Tour Productions and Attractions

After the zonal tour production and attraction vectors have been calculated they have to be balanced in order to match regional totals. The balancing procedure goes through the following three steps:

Step 1: Calculate regional production and attraction totals for each purpose:

$$P^u = \sum_{ci} P_i^{uc}, \qquad A^u = \sum_j A_j^u, \qquad \text{Equation 11}$$

Step 2: Calculate control regional total for each purpose:

$$T^u = \sqrt{P^u \times A^u} \qquad \text{for work,} \qquad \text{Equation 12}$$

$$T^u = A^u \qquad \text{for university,} \qquad \text{Equation 13}$$

$$T^u = P^u \qquad \text{for school, maintenance and discretionary,} \qquad \text{Equation 14}$$

Step 3: Scale original productions and attractions to match the regional total:

$$P_i^{uc} = \frac{T^u}{\sum_{ci} P_i^{uc}}, \qquad A_j^u = \frac{T^u}{\sum_j A_j^u}, \qquad \text{Equation 15}$$

The choice of the balancing control total at Step 2 is based on the reliability of the corresponding production and attraction model as well as the supporting socio-economic inputs and specifically for future years. For the work purpose, it is equally driven by both sides that are essentially based on the residential labour force (production) and employment by place of work (attraction). For the university purpose, the attraction side that is based on location of universities and enrolment is more reliable than production side driven by household distributions. For the school, maintenance, and discretionary purposes, production side driven by population is more reliable than attraction side that is driven by specific socio-economic and land-use variables.

3.5 Pre-Mode Choice Model (Walk vs. Non-Walk)

3.5.1 Percentage of Walk Tours

This is a revised model feature that estimates the percentage of walk produced and attracted in each traffic zone for the entire day, for each of the seven travel purposes. The previous TRANS Model estimated both walk and bicycle productions and attractions for each traffic zone and then operated with motorized tours ignoring non-motorized travel in subsequent model. In the current version of the new TRANS Model, walk travel is not modelled at the subsequent stages of time-of-day choice, tour/trip distribution, and mode choice, however, bicycles are explicitly modelled in the subsequent stages. Thus this sub-model is essentially used to only generate motorized and bicycle production and attraction vectors. Table 3-6 below shows the observed percentage of walk travel by tour purposes.

Table 3-6 | Observed % walk tours, OD Survey 2011

Purpose	Observed- % walk tours
1- Work Low	8.5%
2- Work Med	5.7%
3- Work High	3.8%
4- University	9.2%
5- School	17.6%
6- Maintenance	10.4%
7- Discretionary	12.6%
Total	**9%**

Logically, and in line with the other regions, the highest walk travel share is associated with school tours. In the proposed model structure the walk share of travel is estimated at the tour level and for entire day since walk level of service does not significantly depend on congestion.

3.5.2 Binary Pre-Mode Choice for Tour Productions

This sub-model was estimated and applied for each tour purpose and population segment defined by car-sufficiency and by place of residence (tour production origin zone). It has a form of binary logit choice model with motorized and bicycle mode as the reference alternative with zero utility and walk utility having the following form:

$$V_i^{uc} = \alpha^{uc} + \sum_m \gamma_i^u z_{im} , \qquad \text{Equation 16}$$

where:

u	=	tour purpose from 1 through 7,
c	=	household car sufficiency category from 0 through 3,
i	=	traffic zone of the household residence,
α^{uc}	=	walk bias,
m	=	zonal variables,
z_{im}	=	values of the zonal variables,
γ_m^u	=	coefficients for the zonal variables.

The following variables were the ones that proved to be significant at least for one of the purposes:

- Non-motorized bias specified for each car-sufficiency category (0,1,2,3),
- Zonal characteristics at three spatial level of aggregation (TAZ, superzone, district):
    - Share of population aged 45 or older,
    - Population density,
    - Retail & service employment density,
    - Logged product of population and employment density (proxy for mixed land use),
    - Percentage of low-income-population
    - Percentage of detached houses,
    - University enrolment (for university purpose),
    - Elementary and Secondary School enrolment (for school purpose).
    - Walk accessibilities

In the model application, tour production vectors are scaled to represent motorized travel by the following formula:

$$\tilde{P}_i^{uc} = P_i^{uc} \times \frac{1}{1+\exp\left(V_i^{uc}\right)}$$ Equation 17

where:

u	=	tour purpose from 1 through 7,
c	=	household car sufficiency category from 0 through 3,
i	=	traffic zone of the household residence,
P_i^{uc}	=	zonal tour production,
V_i^{uc}	=	non-motorized utility.

3.5.3 Binary Pre-Mode Choice for Tour Attractions

This sub-model was estimated and applied for each tour purpose by tour primary destination zone. Similar to the pre-mode choice sub-model for tour productions, it has a form of binary logit choice model with motorized and bicycle mode as the reference alternative with zero utility and walk utility having the following form:

$$V_j^u = \alpha^u + \sum_m \gamma_j^u z_{jm}$$ Equation 18

where:

u	=	tour purpose from 1 through 7,
j	=	traffic zone of the tour primary destination,
α^u	=	walk bias,
m	=	zonal variables,
z_{im}	=	values of the zonal variables,
γ_m^u	=	coefficients for the zonal variables.

The following variables proved to be significant at least for one of the purposes:

- Non-motorized bias specified for each purpose,
- Zonal characteristics at three spatial level of aggregation (TAZ, super-zone, district):
  - Population density,
  - Retail & service employment density,
  - Percentage of detached houses,
  - Walk Accessibilities

In the model application, tour attraction vectors are scaled to represent motorized travel by the following formula:

$$\tilde{A}_j^u = A_j^u \times \frac{1}{1+\exp\left(V_j^u\right)}$$ Equation 19

where:

u	=	tour purpose from 1 through 7,
j	=	traffic zone of the tour primary destination,
A_j^u	=	zonal tour attraction,
V_j^u	=	walk utility.

3.5.4 Balancing of Motorized and Bicycle Tour Productions and Attractions

After the zonal motorized and bicycle tour production and attraction vectors have been calculated they have to be balanced again in order to match the same regional total. The balancing procedure goes through the same three steps described for total number of tours in Sub-section 3.4.3 above. In addition to this, the walk tour productions and attractions are also balanced for reporting purposes only. The walk tour productions and attractions are not used in the model eventually.

3.6 Time-of-Day and Stop-Frequency Choice

3.6.1 Joint Choice of Time-of-Day and Stop-Frequency for Tour Productions

On the side of household tour production it is beneficial to consider time-of-day (TOD) choice and stop-frequency choice jointly since there are some strong cross-correlations between these choice dimensions. For example, one could reasonably expect that additional stop on the inbound commuting half-tour would generally result in a later arrival-home time. The choice model has a multinomial logit form, it is applied for each tour-origin zone and population segment (by car sufficiency), and is fully segmented by travel purpose since TOD profiles are distinctive in kind for different purposes.

Since tour destinations were not known at that stage, we could not apply variables like travel time or distance. For the model estimation, for each observed tour the outbound and inbound time were associated with a mid-point of the total travel time and activity duration of stops (if any) on the corresponding half-tour. This way, the trip departure times (reported in the OD Survey) were shifted to an expected network time (actually relevant for network assignments). Each half-tour with either one or two trips, was unambiguously related to a single outbound and single inbound TOD period. This is certain schematic representation of reality where some half-tours can span more than one TOD period and also have trips that belong to different TOD periods. This simplification, however, is essential to avoid an excessive complexity of the model and it does not affect the final trip TOD distribution significantly.

The choice model has 60 alternatives that are combined of 15 tour TOD period combinations and 4 stop-frequency categories. The 15 TOD period combinations are defined as all feasible combinations where inbound TOD is later or equal to the outbound TOD:

1. Early outbound / Early inbound,
2. Early outbound / AM inbound,
3. Early outbound / Midday inbound,
4. Early outbound / PM inbound,
5. Early outbound / Late inbound,
6. AM outbound / AM inbound,
7. AM outbound / Midday inbound,
8. AM outbound / PM inbound,
9. AM outbound / Late inbound,
10. Midday outbound / Midday inbound,
11. Midday outbound / PM inbound,
12. Midday outbound / Late inbound,
13. PM outbound / PM inbound,
14. PM outbound / Late inbound,
15. Late outbound / Late inbound.

The following four stop frequencies categories are defined:

1. No stops,
2. Stop on the outbound half-tour, but no stop on the inbound half-tour,
3. No stop on the outbound half-tour but stop on the inbound half-tour,
4. Stops on both half-tours.

In view of multiple alternatives of combinatorial nature, the utility functions were defined in a special (component-wise) way that is based on recognition that 15 TOD alternatives share many mutual components by outbound or inbound time as well as 4 stop-frequency alternatives share mutual components by presence of outbound or inbound stop. Thus, the utility function was formed in the following parsimonious way:

$$V_i^{ucghrs} = TO_i^{ucg} + SO_i^{ucr} + \alpha^{ugr} + TI_i^{uch} + SI_i^{ucs} + \beta^{uhs} + D_i^{ugh} + \gamma^{urs} \quad \text{Equation 20}$$

where:

u	=	tour purpose from 1 through 7,
c	=	household car sufficiency category from 0 through 3,
i	=	traffic zone of the tour origin,
g	=	outbound TOD period from 1 through 5,
h	=	inbound TOD period from 1 through 5,
r	=	outbound stop frequency (0,1),
s	=	inbound stop frequency (0,1),
TO_i^{ucg}	=	outbound TOD choice component,
SO_i^{ucr}	=	outbound stop-frequency component,
α^{ugr}	=	outbound TOD & stop-frequency interaction constant,
TI_i^{uch}	=	inbound TOD choice component,
SI_i^{ucs}	=	inbound stop-frequency component,
β^{uhs}	=	inbound TOD & stop-frequency interaction constant,

D_i^{ugh}	=	duration component where outbound and inbound TOD periods interact,
γ^{urs}	=	outbound & inbound stop-frequency interaction constant.

Outbound and inbound TOD choice utility components have the following form:

$$TO_i^{ucg} = \lambda^{ucg} + \sum_m \mu_m^{ug} z_{im} \,; \quad TI_i^{uc\tau} = \delta^{uch} + \sum_m \nu_m^{uh} z_{im} \,, \qquad \text{Equation 21}$$

where:

$\lambda^{ucg}, \delta^{uch}$	=	TOD period-specific constants by car-sufficiency segments,
m	=	zonal variables,
μ_m^{ug}, ν_m^{uh}	=	TOD period-specific coefficients for zonal variables,
z_{im}	=	values of the zonal variables at the tour origin.

Outbound and inbound stop-frequency choice utility components have the following form:

$$SO_i^{ucr} = \lambda^{ucr} + \sum_m \mu_m^{ur} z_{im} \,; \quad SI_i^{ucs} = \delta^{ucs} + \sum_m \nu_m^{us} z_{im} \,, \qquad \text{Equation 22}$$

where:

$\lambda^{ucr}, \delta^{ucs}$	=	stop-frequency-specific constants by car-sufficiency segments,
m	=	zonal variables,
μ_m^{ur}, ν_m^{us}	=	stop-frequency-specific coefficients for zonal variables,
z_{im}	=	values of the zonal variables at the tour origin.

Duration utility component serves as an important interaction term for outbound and inbound TOD choices. This term ensures consistency between outbound and inbound TOD choices in terms of the tour (and underlying primary activity) duration. It has the following form:

$$D_i^{ugh} = \Delta^{ugh} + \sum_m \rho_m^{ugh} z_{im} \,, \qquad \text{Equation 23}$$

where:

Δ^{ugh}	=	duration-specific constants,
m	=	zonal variables,
ρ_m^{ugh}	=	stop-frequency-specific coefficients for zonal variables,
z_{im}	=	values of the zonal variables at the tour origin.

The following variables proved to be significant at least for one of the purposes:

- In the outbound and/or inbound TOD choice components:

- Car-sufficiency dummies by category,
- Zonal characteristics at different levels of spatial aggregation (TAZ, super-zone, district):
    - Population density,
    - Percentage of low-income population (separate coefficients for Ontario and Quebec),
    - Percentage of detached houses,
    - School enrollment,
    - Retail & service density,
    - Time period specific accessibilities to attractions

- In the outbound and/or inbound stop-frequency components defined for cases with stop while the no-stop alternative serves as the reference alternative:
    - Car-sufficiency dummies by category,
    - Zonal characteristics at different levels of spatial aggregation (TAZ, super-zone, district):
        - Population density,
        - Percentage of low-income population (separate coefficients for Ontario and Quebec),
        - Retail & service density,
- In the outbound-inbound duration component:
    - Duration dummy by category:
        - Very short (outbound and inbound in the same TOD period),
        - Short (inbound TOD period is next to the outbound TOD period),
        - Medium (inbound TOD period is two periods later than the outbound TOD period),
        - Long (inbound TOD period is three or four periods later than the outbound TOD period),
    - Duration category dummy interacting with percentage of low-income households (separate coefficients for Ontario and Quebec),
- Directional TOD and stop-frequency interaction constants:
    - Outbound TOD-specific constants without stop,
    - Outbound TOD-specific constant with stop,
    - Inbound TOD-specific constants without stop,
    - Inbound TOD-specific constant with stop,
- Outbound & inbound stop-frequency interaction constant (specified for a case of both stops).

In the TOD & frequency model application on the tour production side, the motorized and bicycle tour production vectors are sliced by 15 TOD periods and by 4 stop-frequency categories according to the following formula:

$$P_i^{ucghrs} = \tilde{P}_i^{uc} \times \frac{\exp\left(V_i^{ucghrs}\right)}{\sum_{ghrs} \exp\left(V_i^{ucghrs}\right)}. \qquad \text{Equation 24}$$

After that, detailed joint probabilities by 4 car-sufficiency groups and 4 stop-frequency categories are calculated for each of 7 travel purposes and 9 relevant TOD slices. This results in 16×63=1008 vectors. They are prepared for further use in the half-tour distribution procedure (described in sub-section 3.6.3) and calculated according to the following formula:

$$p_i^{ugh}(crs) = \frac{P_i^{ucghrs}}{\sum_{crs} P_i^{ucghrs}}.$$ Equation 25

3.6.2 Time-of-Day Choice for Tour Attractions

On the side of zonal tour attraction, the choice model has a multinomial logit form; it is applied for each tour-destination zone, and is fully segmented by travel purpose since TOD profiles are distinctive in kind for different purposes. The choice model has 15 alternatives defined as tour TOD period combinations with no stop-frequency consideration at this stage. The 15 TOD period combinations are defined as all feasible combinations where inbound TOD is later or equal to the outbound TOD:

1. Early outbound / Early inbound,
2. Early outbound / AM inbound,
3. Early outbound / Midday inbound,
4. Early outbound / PM inbound,
5. Early outbound / Late inbound,
6. AM outbound / AM inbound,
7. AM outbound / Midday inbound,
8. AM outbound / PM inbound,
9. AM outbound / Late inbound,
10. Midday outbound / Midday inbound,
11. Midday outbound / PM inbound,
12. Midday outbound / Late inbound,
13. PM outbound / PM inbound,
14. PM outbound / Late inbound,
15. Late outbound / Late inbound.

In view of multiple alternatives of combinatorial nature, the utility functions were defined in a special (component-wise) way that is based on recognition that 15 TOD alternatives share many mutual components by outbound or inbound time. Thus, the utility function was formed in the following parsimonious way:

$$V_j^{ugh} = TO_j^{ug} + TI_j^{uh} + D_j^{ugh},$$ Equation 26

where:

u	=	tour purpose from 1 through 7,
j	=	traffic zone of the tour primary destination,
g	=	outbound TOD period from 1 through 5,
h	=	inbound TOD period from 1 through 5,
TO_j^{ug}	=	outbound TOD choice component,
TI_j^{uh}	=	inbound TOD choice component,
D_j^{ugh}	=	duration component where outbound and inbound TOD periods interact,

Outbound and inbound TOD choice utility components have the following form:

$$TO_j^{ug} = \lambda^{ug} + \sum_m \mu_m^{ug} z_{jm} \,; \quad TI_j^{uc\tau} = \delta^{uh} + \sum_m \nu_m^{uh} z_{jm} \,, \qquad \text{Equation 27}$$

where:

$\lambda^{ug}, \delta^{uh}$	=	TOD period-specific constants by car-sufficiency segments,
m	=	zonal variables,
μ_m^{ug}, ν_m^{uh}	=	TOD period-specific coefficients for zonal variables,
z_{jm}	=	values of the zonal variables at the tour primary destination.

Duration utility component serves as an important interaction term for outbound and inbound TOD choices. This term ensures consistency between outbound and inbound TOD choices in terms of the tour (and underlying primary activity) duration. Different from the duration term in the TOD choice model for tour productions that is based on the population characteristics this term is based on the employment type and other land-use characteristics at the tour primary destination. It has the following form:

$$D_j^{ugh} = \Delta^{ugh} + \sum_m \rho_m^{ugh} z_{jm} \,, \qquad \text{Equation 28}$$

where:

Δ^{ugh}	=	duration-specific constants,
m	=	zonal variables,
ρ_m^{ugh}	=	stop-frequency-specific coefficients for zonal variables,
z_{jm}	=	values of the zonal variables at the tour destination.

The following variables proved to be significant at least for one of the purposes:

- In the outbound and/or inbound TOD choice components:
    - CBD dummy,
    - Employment mix in the zone itself (for work tours):
        - Percentage of public offices in total employment,
        - Percentage of private offices in total employment,
        - Percentage of retail in total employment,
        - Percentage of service in total employment,
        - Percentage of health in total employment,
        - Percentage of education in total employment,
    - Additional zonal characteristics at different levels of spatial aggregation (TAZ, super-zone, district):
        - Population density,
        - Employment density,
        - Retail & service density,
        - Percentage of detached houses,
        - Percentage of low-income population (separate coefficients for Ontario and Quebec),
        - University enrollment,
        - School enrollment,

  - Time period specific accessibilities to productions
- Duration component currently estimated as a constant by category:
  - Very short (outbound and inbound in the same TOD period),
  - Short (inbound TOD period is next to the outbound TOD period),
  - Medium (inbound TOD period is two periods later than the outbound TOD period),
  - Long (inbound TOD period is three or four periods later than the outbound TOD period).

In the TOD model application on the tour attraction side, the motorized tour attraction vectors are sliced by 15 TOD periods categories according to the following formula:

$$A_j^{ugh} = \tilde{A}_j^u \times \frac{\exp\left(V_j^{ugh}\right)}{\sum_{gh} \exp\left(V_j^{ugh}\right)}. \qquad \text{Equation 29}$$

3.6.3 Production-Attraction Balancing by Time-of-Day Periods

After the zonal tour production and attraction vectors by TOD periods have been calculated they have to be balanced in order to match regional totals for each TOD period combination. The balancing procedure is similar to the balancing procedures applied previously for daily number of tours. It goes through the following three steps:

Step 1: Calculate regional production and attraction totals for each purpose and TOD slice:

$$P^{ugh} = \sum_{crsi} P_i^{ucghrs}, \qquad A^{ugh} = \sum_j A_j^{ugh}, \qquad \text{Equation 30}$$

Step 2: Calculate control regional total for each purpose:

$$T^{ugh} = \sqrt{P^{ugh} \times A^{ugh}} \quad \text{for work,} \qquad \text{Equation 31}$$

$$T^{ugh} = A^{ugh} \quad \text{for university,} \qquad \text{Equation 32}$$

$$T^{ugh} = P^{ugh} \quad \text{for school, maintenance and discretionary,} \qquad \text{Equation 33}$$

Step 3: Scale original productions and attractions to match the regional total:

$$P_i^{ucghrs} = \frac{T^{ugh}}{\sum_{crsi} P_i^{ucghrs}}, \qquad A_j^{ugh} = \frac{T^{ugh}}{\sum_j A_j^{ugh}}, \qquad \text{Equation 34}$$

3.6.4 Zonal Stop-Frequency Size Variable for Stop Location

The tour primary destination attraction model described in Sections 3.4.2(daily) and 3.6.2(stratified by TOD periods) was complemented by a stop attraction model for particular half-tour segments. This model is applied for chained half-tours only. It characterizes each zone by probability of the traveler to stop in this location on the way from the origin to primary destination (for the outbound half-tour) and on the way back from the primary destination to origin (for the outbound half-tour). The model is fully segmented by 7 travel purposes. Additionally, for work, university, and school tours it is also segmented by the half-tour direction since the mix of underlying activities is very different for outbound vs. inbound commuting. For maintenance and discretionary tours, both half-tour directions were pooled together.

Stop attraction models by purpose and direction were developed as zonal regressions of the observed daily stop frequency on the relevant socio-economic and land-use variables. If there are more than one stop on the half-tour, for this model all additional stops where counted to enlarge the sample. Additional stratification of the model by time-of-day periods was impractical because of the proliferation of segments. However, the stratification by direction applied for work, university, and school purposes served as a good proxy for time-of-day period as well. The models take the following form of a linear regression without an intercept:

$$S_k^{ud} = \sum_m s_m^{ud} \times z_{km} ,$$ Equation 35

where:

u	=	tour purpose from 1 through 7,
k	=	intermediate stop location zone,
d	=	direction (1=outbound, 2=inbound),
S_k^{ud}	=	zone attraction for the intermediate stop,
m	=	zonal variables,
s_m^{ud}	=	stop frequency rate per variable,
z_{km}	=	values of the zonal variables.

The following variables were the ones that proved to be significant at least for one of the purposes and directions:

- Employment (by place of work) in the traffic zone itself:
    - Major Shops Employment in Ontario ,
    - Street Shops Employment in Ontario ,
    - Retail Employment in Quebec ,
    - Restaurant Employment in Ontario ,
    - Theatre Employment in Ontario,
    - Bank Employment in Ontario,
    - Post Office Employment in Ontario,
    - Service Employment in Quebec ,
    - Office (public) Employment ,

  - Health Employment in Ontario ,
  - Hospital Employment in Ontario ,
  - Office (private) Employment,
  - Education Employment
- Other characteristics of the traffic zone itself:
  - Shopping Gross Leasable Area ,
  - Parks Gross Area (hectares),
  - Theatre Gross Leasable Area (hectares),
  - Total Population,
  - University Enrollment,
  - Elementary and Secondary School Enrolment,

3.7 Tour Ends' Distribution

3.7.1 Preparation of Seed Tour Matrices from OD Survey

The core model for spatial distribution of tours requires seed matrices to be prepared from the OD survey. These matrices provide a seed spatial pattern of observed travel flows in the region that is further combined with the gravity principle as explained in the sub-section that follows. The seed matrices are prepared for each travel purpose and TOD period combination of outbound and inbound periods. Since we have 7 travel purposes and 9 TOD period combinations relevant for either AM or PM periods the procedure builds 7*9=63 seed matrices. The procedure includes the following three steps:

- Building initial (raw) daily tour matrices for each purpose by <u>aggregation</u> of the observed tour records from the OD survey with the expansion factors,
- <u>Smoothing</u> initial daily matrices for each travel purpose in order to eliminate "lumpiness" and "sparseness",
- <u>Scaling</u> smoothed matrices for each TOD slice based on the previously estimated total number of generated tours.

<u>Aggregation</u> of the observed tour records from the OD survey is a straightforward data-processing procedure since the tour record file has been built. It is implemented according to the following formula:

$$R_{ij}^{u} = \sum_{n \in N_{ij}^{u}} W_n \,, \qquad \text{Equation 36}$$

where:

u	=	tour purpose from 1 through 7,
i	=	tour origin TAZ,

j = tour destination TAZ,

R_{ij}^{u} = raw tour matrix,

$n \in N_{ij}^{u}$ = tour records for the given purpose, origin, and destination,

W_n = tour expansion factor.

The raw tour matrices after aggregation suffer from “lumpiness” and “sparseness” and cannot be immediately used in the modelling procedure. Lumpiness means that certain matrix cells are severely over-estimated by the expansion factor that is roughly equal to 20. Sparseness means that many other cells (in fact a vast majority of cells) obtain zero values. Thus, statistical significance of the raw matrices at the TAZ-to-TAZ cell level is very low. This is not a flaw in the OD Survey but rather an objective statistical fact. The survey 5% sample produced 67,002 tour records. This is not enough to cover 7 purpose-specific matrices with 672 TAZs (i.e 7×672×672=3,161,088 cells) in a statistically significant way. Thus, direct expansion of the OD survey records should be supported by a statistically valid “smoothing” procedure.

Smoothing procedure is based on the assumption that raw matrices that are built by direct expansion of the OD Survey contain valuable and statistically reliable information at the level of aggregate superzone-to-superzone (94×94) flows as well as with respect to the matrix marginals (production and attraction vectors) at the TAZ level.

The proposed procedure is based on the following principles:

- Preserve the observed aggregated superzone-to-superzone flows,
- Smooth up the internal trip distribution within each aggregate cell by using an auxiliary gravity model.

The matrix smoothing procedure can be formalized in three steps using the following notation:

u = tour purpose from 1 through 7,

$i, j \in I$ = origin and destination TAZs,

$m, n \in M$ = origin and destination superzones,

$i \in I_m, j \in J_n$ = grouping of TAZs by origin/destination superzones,

R_{ij}^{u} = observed raw TAZ-to-TAZ matrix,

Step 1: We want to find a “smooth” matrix S_{ij}^{u} that would satisfy the following condition of preservation of the district-to-district flows, so we have to calculate aggregate superzone-to-superzone flows:

$$\sum_{i \in I_m} \sum_{j \in J_n} S_{ij}^{u} = \sum_{i \in I_m} \sum_{j \in J_n} R_{ij}^{u} = T_{mn}^{u} ,$$ Equation 37

Step 2: Now we calculate (smooth) internal proportions in each cell based on an auxiliary gravity model:

$$p_{ij}^{u} = \frac{P_i^u A_j^u \exp\left(-\lambda^u c_{ij}\right)}{\sum_{i \in I_m} \sum_{j \in J_n} P_i^u A_j^u \exp\left(-\lambda^u c_{ij}\right)},$$ Equation 38

where:

$P_i^u = \sum_{j \in I} R_{ij}^u$	=	TAZ productions from the raw matrix,
$A_j^u = \sum_{i \in I} R_{ij}^u$	=	TAZ attractions from the raw matrix,
c_{ij}	=	TAZ-to TAZ impedance measure (free flow auto time),
λ^u	=	dispersion coefficient.

Step 3: The smooth matrix is calculated by the following simple formula:

$$S_{ij}^{u} = T_{m(i),n(j)}^{u} \times p_{ij}^{u}.$$ Equation 39

Scaling of the smooth matrix is the final step where the seed matrices are prepared by TOD slices. It is assumed that the spatial distribution pattern is the same for each TOD slice. The difference between TOD slices is in the total amount of tours according to the balanced production and attraction total previously calculated for each slice. Scaling can be expressed as the following straightforward calculation:

$$S_{ij}^{ugh} = S_{ij}^{u} \times \frac{T^{ugh}}{\sum_{ij} S_{ij}^{u}},$$ Equation 40

where:

u	=	tour purpose from 1 through 7,
$i, j \in I$	=	origin and destination TAZs,
g, h	=	relevant outbound and inbound TOD period combinations (slices),
S_{ij}^{u}	=	smoothed matrices before scaling,
T^{ugh}	=	tour total for the TOD slice,
S_{ij}^{ugh}	=	seed matrix for TOD slice.

3.7.2 Construction of Tour Matrices in PA Format

There are several methods for construction of spatial distributions, amongst which the following two are the most widely used:

- The **Balancing or Iterative Proportional Fitting (IPF)** method that assumes that the future spatial distribution is proportional to the present (seed) distribution and only has to be modified by the growth factors of the zone productions and attractions. This method is especially effective for short term forecasting when the changes in the zone productions and attractions are small and the same distribution can be reasonably expected. There is however a known problem with application of this method to long-term forecasting when significant changes in productions and attractions are expected. The observed distribution pattern may not be relevant anymore for zones that have undergone significant changes. This drawback is particularly obvious for newly built zones that had zero productions or attractions for the base year.
- The **Gravity** method that assumes that the spatial interaction between two zones is directly related to the production and attraction power in these zones and inversely related to the travel impedance between the zones (travel time, distance, composite measure like mode choice logsum, river crossing impedance etc). This method can handle newly built zones and is not dependent on the observed distribution pattern. However, it is generally not as effective as balancing for short-term forecasting and requires introduction of numerous K-factors to match the observed distribution for the base year with a reasonable level of accuracy.

The updated TRANS distribution procedure for tours allows for the incorporation of a seed matrix (derived from the OD survey expansion as explained in the previous sub-section) in a flexible combination with gravity principle. In contrast to either simple balancing, or gravity model alone this model is equally effective for both short-term and long-term forecasting. For zones where there is a little or no change between the base and future years, the balancing component of the model will dominate and the distribution pattern will be similar to the observed one. The gravity component comes into play if employment and population change significantly, impacting the distribution accordingly. The optimal proportion between the balancing and gravity principles is defined automatically in the procedure and is based on the growth indices calculated for each production and attraction zone.

The effective analytical combination of the balancing and gravity models is possible because both models are based on the same entropy-maximizing principle and can be written as convex programming problems with the same constraints. This model is applied separately for 63 segments generated by 7 travel purposes and 9 relevant TOD period combinations. It currently has a doubly-constrained form for all segments. Singly-constrained or relaxed-constrained forms can also be considered for maintenance and discretionary purposes in future versions of the model. The correspondent modification of the model is straightforward. In order to explain the model structure and derivation from the entropy-maximizing principle we consider a single segment (thus, the indices that relate to travel purpose, and TOD periods are temporarily dropped). We first reproduce the standard model formulations for balancing and gravity models and then combine them in a single “hybrid” formulation.

The balancing model can be written as the following convex programming problem:

$$\min \sum_{ij} X_{ij} \ln \frac{X_{ij}}{S_{ij}},$$ (i.e. find the closest possible matrix to the seed one) Equation 41

subject to marginal constraints:

$$\sum_j X_{ij} = P_i \,,$$ (i.e. match the tour productions) Equation 42

$$\sum_i X_{ij} = A_j \,,$$ (i.e. match the tour attractions) Equation 43

where:

$i, j \in I$	=	origin and destination TAZs,
$X_{ij} > 0$	=	tour distribution matrix in PA format,
$S_{ij} > 0$	=	seed tour distribution matrix in PA format,
P_i	=	tour productions,
A_j	=	tour attractions.

The balancing model has the following solution:

$$X_{ij} = P_i \alpha_i A_j \beta_j S_{ij} \,,$$ Equation 44

where:

α_i	=	balancing factors for productions,
β_j	=	balancing factors for attractions.

The gravity model can be written as the following convex programming problem:

$$\min \sum_{ij} Y_{ij} \ln \frac{Y_{ij}}{\exp\left(-\lambda c_{ij}\right)} \,,$$ (i.e. find the closest possible matrix to the impedance) Equation 45

subject to the same marginal constraints as (42,43)

$$\sum_j Y_{ij} = P_i \,,$$ (i.e. match the tour productions) Equation 46

$$\sum_i Y_{ij} = A_j \,,$$ (i.e. match the tour attractions) Equation 47

where:

$Y_{ij} > 0$	=	tour distribution matrix in PA format,
λ	=	dispersion coefficient that is known (calibrated).
c_{ij}	=	impedance function (logsums, distance, river crossings).

The gravity model has the following solution:

$$Y_{ij} = P_i \alpha_i A_j \beta_j e^{(-\lambda C_{ij})}$$ Equation 48

The <u>hybrid</u> formulation is based on the growth indices calculated for productions and attractions in the following way:

$$\mu_i = \min\left(\frac{\sum_j S_{ij}}{P_i}, 1\right), \qquad \nu_j = \min\left(\frac{\sum_i S_{ij}}{A_j}, 1\right),$$ Equation 49

where:

$0 \le \mu_i \le 1$ = share of observed productions, that should be balanced,

$0 \le \nu_j \le 1$ = share of observed attractions, that should be balanced,

$0 \le 1 - \mu_i \le 1$ = share of new productions, that should be subject to gravity,

$0 \le 1 - \nu_j \le 1$ = share of new attractions, that should be subject to gravity.

The hybrid model can be written as the following convex programming problem:

$$\min F = B^1 + B^2 + G^1 + G^2,$$ Equation 50

where:

$$B^1 = \sum_{ij} X_{ij}^1 \ln \frac{X_{ij}^1}{S_{ij}},$$ (distribution of observed productions modelled by balancing) Equation 51

$$B^2 = \sum_{ij} X_{ij}^2 \ln \frac{X_{ij}^2}{S_{ij}},$$ (distribution of observed attractions modelled by balancing) Equation 52

$$G^1 = \sum_{ij} Y_{ij}^1 \ln \frac{Y_{ij}^1}{\exp(-\lambda c_{ij})},$$ (distribution of new productions modelled by gravity) Equation 53

$$G^2 = \sum_{ij} Y_{ij}^2 \ln \frac{Y_{ij}^2}{\exp(-\lambda c_{ij})},$$ (distribution of new attractions modelled by gravity) Equation 54

subject to the same marginal constraints as (42-43) and (46-47):

$$\sum_j Z_{ij} = P_i,$$ (i.e. match the tour productions) Equation 55

$$\sum_i Z_{ij} = A_j,$$ (i.e. match the tour attractions) Equation 56

where:

$Z_{ij} > 0$	= tour distribution matrix in PA format,
$X_{ij}^1 = \mu_i Z_{ij}$	= share of observed productions modelled by balancing,
$X_{ij}^2 = \nu_j Z_{ij}$	= share of observed attractions modelled by balancing,
$Y_{ij}^1 = (1-\mu_i) Z_{ij}$	= share of new productions modelled by gravity,
$Y_{ij}^2 = (1-\nu_j) Z_{ij}$	= share of new attractions modelled by gravity.

The hybrid model has the following solution:

$$Z_{ij} = P_i \alpha_i A_j \beta_j \left[S_{ij}\right]^{(\mu_i+\nu_j)/2} \times \left[\exp\left(-\lambda c_{ij}\right)\right]^{1-(\mu_i+\nu_j)/2} \times \exp\left(-\frac{W_{ij}}{2}\right), \quad \text{Equation 57}$$

where:

$$W_{ij} = w_i + w_j , \quad \text{Equation 58}$$

$$w_i = \begin{cases} \mu_i \ln \mu_i + (1-\mu_i)\ln(1-\mu_i) & if \quad 0 < \mu_i < 1 \\ 0 & if \quad \mu_i = 0,1 \end{cases}, \quad \text{Equation 59}$$

$$w_j = \begin{cases} \nu_j \ln \nu_j + (1-\nu_j)\ln(1-\nu_j) & if \quad 0 < \nu_j < 1 \\ 0 & if \quad \nu_j = 0,1 \end{cases}. \quad \text{Equation 60}$$

The balancing and gravity models can be derived as particular cases of the hybrid model. The general solution (7) is reduced to the balancing formula (36) if all growth indices are equal to 1 (i.e. there is no growth). The general solution (57) is reduced to the gravity formula (45) if all growth indices are equal to 0 (i.e. all zones are newly built). In general case, the model perform as a mixed of balancing and gravity models with the proportion depending on the growth index for each production and attraction zone.

The impedance measure are calculated based on a simplified mode choice logsums based the corresponding network time and cost "skims" by TOD period(see subsection 3.2 for more information). In addition to impedance measures, free flow auto with calibrated dispersion coefficient is also used in tour distribution to replicate the observed average distance between the tour origin and primary destination for each segment (travel purpose). In future versions of the TRANS Model, the impedance function can be extended to include the following components (if statistically significant):

- Linear and non-linear distance terms allowing for shaping the trip-length distribution,
- Borders of province / municipalities / school districts,
- Ethnic clusters (French vs. English),
- High-frequency transit service dummy for captive transit riders (school trips and zero-car households).

These variables proved to be significant in many tour destination choice models applied elsewhere. It should be noted however, that most of these models have been based solely on the gravity principle. By mixing gravity and balancing components in the current model, many of the effects that would have been captured by a more sophisticated impedance function come into play through the seed matrix that inherits peculiarities of the observed spatial distribution pattern. Inclusion of the full mode choice logsums might also be beneficial for a better feedback between the mode choice and tour distribution models. It should be noted that it is a time-consuming procedure that would slow down the model system performance.

As the result of model application, tour matrices in PA format are built for 63 segments:

$$\left\{Z_{ij}^{ugh}\right\}, \quad \text{Equation 61}$$

where:

$i, j \in I$	=	origin and destination TAZs,
u	=	tour purpose from 1 through 7,
g, h	=	9 relevant outbound and inbound TOD period combinations.

3.8 Trip Distribution

3.8.1 Construction of Half-Tour Matrices in OD Format

This model splits 63 tour matrices in PA format by directional half-tour matrices (outbound and inbound), 4 car-sufficiency groups, and stop frequency (direct vs. chained) according to the production proportions prepared as explained in sub-section 3.7.1 above. The half-tour matrices are also aggregated into 2 relevant TOD periods (AM and PM). The directionality is taken into account by transposing the inbound half-tours. The calculations are implemented in the way shown below and resulted in 8 half-tour types (2 directions by 2 chaining categories and by 2 relevant TOD periods) for each travel purpose and car-sufficiency group:

$$D_{ij}^{ucg,d=1} = \sum_{h=g}^{5} Z_{ij}^{ugh} \sum_{s=0}^{1} p_i^{ugh}(c, r=0, s), \quad \text{(outbound direct half-tours),} \quad \text{Equation 62}$$

where:

$i, j \in I$	=	origin and destination TAZs,
u	=	tour purpose from 1 through 7,
c	=	household car sufficiency category from 0 through 3,
g	=	relevant outbound TOD period (2=AM, 4=PM),
h	=	feasible inbound TOD periods from g through 5
d	=	direction (1=outbound),
$r=0$	=	outbound stop frequency (0=no stops),
s	=	inbound stop frequency (0,1),

$$C_{ij}^{ucg,d=1} = \sum_{h=g}^{5} Z_{ij}^{ugh} \sum_{s=0}^{1} p_i^{ugh}(c, r=1, s),$$ (outbound chained half-tours), Equation 63

where:

$r=1$ = outbound stop frequency (1=stop),

$$D_{ij}^{uch,d=2} = \sum_{g=1}^{h} Z_{ji}^{ugh} \sum_{r=0}^{1} p_i^{ugh}(c, r, s=0),$$ (inbound direct half-tours), Equation 64

where:

h = relevant inbound TOD period (2=AM, 4=PM),
g = feasible outbound TOD periods from 1 through h,
d = direction (2=inbound),
r = outbound stop frequency (0,1),
$s=0$ = inbound stop frequency (0=no stops),

$$C_{ij}^{uch,d=2} = \sum_{g=1}^{h} Z_{ji}^{ugh} \sum_{r=0}^{1} p_i^{ugh}(c, r, s=1),$$ (inbound chained half-tours), Equation 65

where:

$s=1$ = inbound stop frequency (1=stop),

The procedure results in 224 directional (OD format) half tour matrices built for 28 segments (7 travel purposes by 4 car-sufficiency categories) by 8 half-tour types. Direct half-tours already represent elemental assignable trips. Chained half-tours have to be further processed in order to break each half-tour into a sequence of elemental trips.

3.8.2 Construction of OD Trip Matrices for Direct Half-Tours

Direct half-tours (with no stops) are converted into trips by purpose, car-sufficiency group, and TOD in the following straightforward way by summing outbound and inbound directional half-tour matrices (explained in the previous subsection 3.8.1) consequently:

$$TD_{ij}^{uch} = \sum_{d=1}^{2} D_{ij}^{uchd},$$ Equation 66

where:

$i, j \in I$ = half-tour origin and destination TAZs,
u = tour purpose from 1 through 7,
c = household car sufficiency category from 0 through 3,

h	=	relevant trip TOD periods (2=AM, 4=PM),
d	=	direction (1-outbound, 2=inbound),
D_{ij}^{uchd}	=	matrix of direct half-tours,
TD_{ij}^{uch}	=	trip matrix resulted from direct half-tours.

Note that at this stage, there is no need to transpose inbound half-tours since they have been already made directional at the previous stage. This means that for outbound half-tours, the origin and destination coincide with those for the entire tour in PA format, while for the inbound half-tours, the origin and destination are switched.

3.8.3 Construction of OD Trip Matrices for Chained Half-Tours

Distribution of trips on chained half-tours is modelled explicitly through choice of the main stop on each half-tour. This model is applied separately for each segment defined as a combination of travel purpose, car-sufficiency group, TOD period (AM or PM), and direction (outbound or inbound). The essence of the model is to convert the corresponding matrix of chained half-tour flows (explained in subsection 3.8.1 above):

$$C_{ij}^{uchd} \qquad \text{Equation 67}$$

into two trip matrices $TC_{ik}^{uchd}(1)$ and $TC_{kj}^{uchd}(2)$ convoluted at the main stop location and anchored at the half-tour origin and primary destination according to the following formulas:

$$\sum_j C_{ij}^{uchd} = \sum_k TC_{ik}^{uchd}(1), \quad \text{(flows from the origin are preserved),} \qquad \text{Equation 68}$$

$$\sum_i C_{ij}^{uchd} = \sum_k TC_{kj}^{uchd}(2), \quad \text{(flows to the destination are preserved),} \qquad \text{Equation 69}$$

$$\sum_i TC_{ik}^{uchd}(1) = \sum_j TC_{kj}^{uchd}(2), \quad \text{(flows through the intermediate stops are convoluted),} \qquad \text{Equation 70}$$

where:

$i, j, k \in I$	=	half-tour origin, destination, and stop TAZs,
u	=	tour purpose from 1 through 7,
c	=	household car sufficiency category from 0 through 3,
h	=	relevant trip TOD periods (2=AM, 4=PM),
d	=	direction (1-outbound, 2=inbound),

The underlying stop-location choice model has a multinomial logit form and can be written in the following way:

$$p_{ikj}^{uchd} = \frac{\exp\left(V_{ikj}^{uchd}\right)}{\sum_k \exp\left(V_{ikj}^{uchd}\right)} = \frac{\exp\left(V_{ikj}^{uchd}\right)}{DEN_{ij}^{uchd}}, \quad \text{Equation 71}$$

where the stop-location utility function is defined as

$$V_{ikj}^{uchd} = \begin{cases} \ln S_k^{ud} - \left(\lambda_1^{ud} d_{ik} + \lambda_2^{ud} d_{kj}\right), & if \quad \max\left(d_{ik}, d_{kj}\right) \le \bar{d}^u \\ -999, & if \quad \max\left(d_{ik}, d_{kj}\right) > \bar{d}^u \end{cases}, \quad \text{Equation 72}$$

where:

S_k^{ud}	=	zone attraction for intermediate stops explained in subsection 3.6.4 above,
d_{ik}	=	free-flow time from the half-tour origin to intermediate stop,
d_{kj}	=	free-flow time from the half-tour intermediate stop to destination,
$\lambda_1^{ud}, \lambda_2^{ud}$	=	dispersion coefficients,
$\bar{d}^u$	=	maximum observed free-flow for stop making for a particular segment (purpose).

This type of stop location utility function has been successfully applied in several activity-based models and proved to realistically replicate the observed spatial patterns of trip chaining. It expresses the general principle of rational travel behaviour that is that travelers tend to stop at the most attractive locations with a minimal route deviation on the way to the primary destination. Having differential dispersions coefficients for the first and second trip legs allows for capturing specific impacts of familiarity with the area around home vs. familiarity with the area at the primary destination. It is also convenient for a sequential implementation of the trip chaining procedure if two stops are modelled.

The stop location utility is currently not differentiated by either car-sufficiency group or TOD period because of the relatively small sub-sample size (it is already differentiated by 7 travel purposes and 2 directions that yields 14 segments). The dispersion coefficients were calibrated to reproduce the average observed distance for each trip leg (from origin to stop and from stop to destination) by main segments defined by trip purpose and half-tour direction.

Additional underlying assumption of the proposed method for trip chaining is that both trip legs belong to the same TOD period defined for the half-tour. Relaxation of this principle, i.e. considering different departure times for each trip leg within the same half-tour, is only possible within a micro-simulation modelling framework.

The stop-location utility after exponentiation can be written in the following way:

$$\exp\left(V_{ikj}^{uchd}\right) = U_{ik}^{uchd} \times U_{kj}^{uchd}, \quad \text{Equation 73}$$

where:

$$U_{ik}^{uchd} = \begin{cases} S_k^{ud} \times \exp\left(-\lambda_1^{ud} d_{ik}\right), & if \quad d_{ik} \leq \bar{d}^{u} \\ 0, & if \quad d_{ik} > \bar{d}^{u} \end{cases},$$ Equation 74

$$U_{kj}^{uchd} = \begin{cases} \exp\left(-\lambda_2^{ud} d_{kj}\right), & if \quad d_{kj} \leq \bar{d}^{u} \\ 0, & if \quad d_{kj} > \bar{d}^{u} \end{cases}.$$ Equation 75

The model can be conveniently implemented using the matrix convolution module of EMME where only the resulted trip matrices are saved:

$$TC_{ik}^{uchd}(1) = \sum_j C_{ij}^{uchd} \times p_{ikj}^{uchd} = U_{ik}^{uchd} \times \sum_j \frac{C_{ij}^{uchd}}{DEN_{ij}^{uchd}} \times U_{kj}^{uchd},$$ Equation 76

$$TC_{kj}^{uchd}(2) = \sum_i C_{ij}^{uchd} \times p_{ikj}^{uchd} = U_{kj}^{uchd} \times \sum_i \frac{C_{ij}^{uchd}}{DEN_{ij}^{uchd}} \times U_{ik}^{uchd}.$$ Equation 77

Since this model component is not a trivial matrix or vector calculation a more detailed technical description is provided in terms of the EMME Modules 3.21 (Matrix calculation) and 3.23 (Matrix convolution) in Appendix A1. This modelling technique can be applied sequentially in order to incorporate multiple stops if needed in the future versions of the TRANS Model. In this case, each leg is considered the same way as the half-tour and is broken into elemental trips based on a similar stop-location model.

Finally, trip legs of the chained half-tours are converted into trips by purpose, car-sufficiency group, and TOD in the following straightforward way by summing outbound and inbound directional half-tour matrices for the first and second leg consequently:

$$TC_{ij}^{uch} = \sum_{d=1}^{2} \left[TC_{ij}^{uchd}(1) + TC_{ij}^{uchd}(2) \right],$$ Equation 78

where:

TC_{ij}^{uch} = trip matrix resulted from chained half-tours.

3.8.4 Combination of Final (Assignable) Trip Matrices

Finally, assignable matrices (containing trips that can be loaded onto the auto and transit networks) are combined including both trips from direct half tours (explained in subsection 3.8.2 above) and chain half-tours (explained in subsection 3.8.3 above) in the following straightforward way:

$$T_{ij}^{uch} = TD_{ij}^{uch} + TC_{ij}^{uch},$$ Equation 79

where:

$i, j \in I$	=	trip origin and destination TAZs,
u	=	tour purpose from 1 through 7,
c	=	household car sufficiency category from 0 through 3,
h	=	relevant trip TOD periods (2=AM, 4=PM),
TD_{ij}^{uch}	=	trip matrix resulted from direct half-tours,
TC_{ij}^{uch}	=	trip matrix resulted from chained half-tours.

The assignable trip matrices are segmented by 7 travel purposes, 4 car-sufficiency groups, and 2 TOD periods (AM and PM) resulting in 56 full trip matrices that constitute demand input to the mode choice model.

3.9 Mode Choice Model

3.9.1 Mode Choice Structure

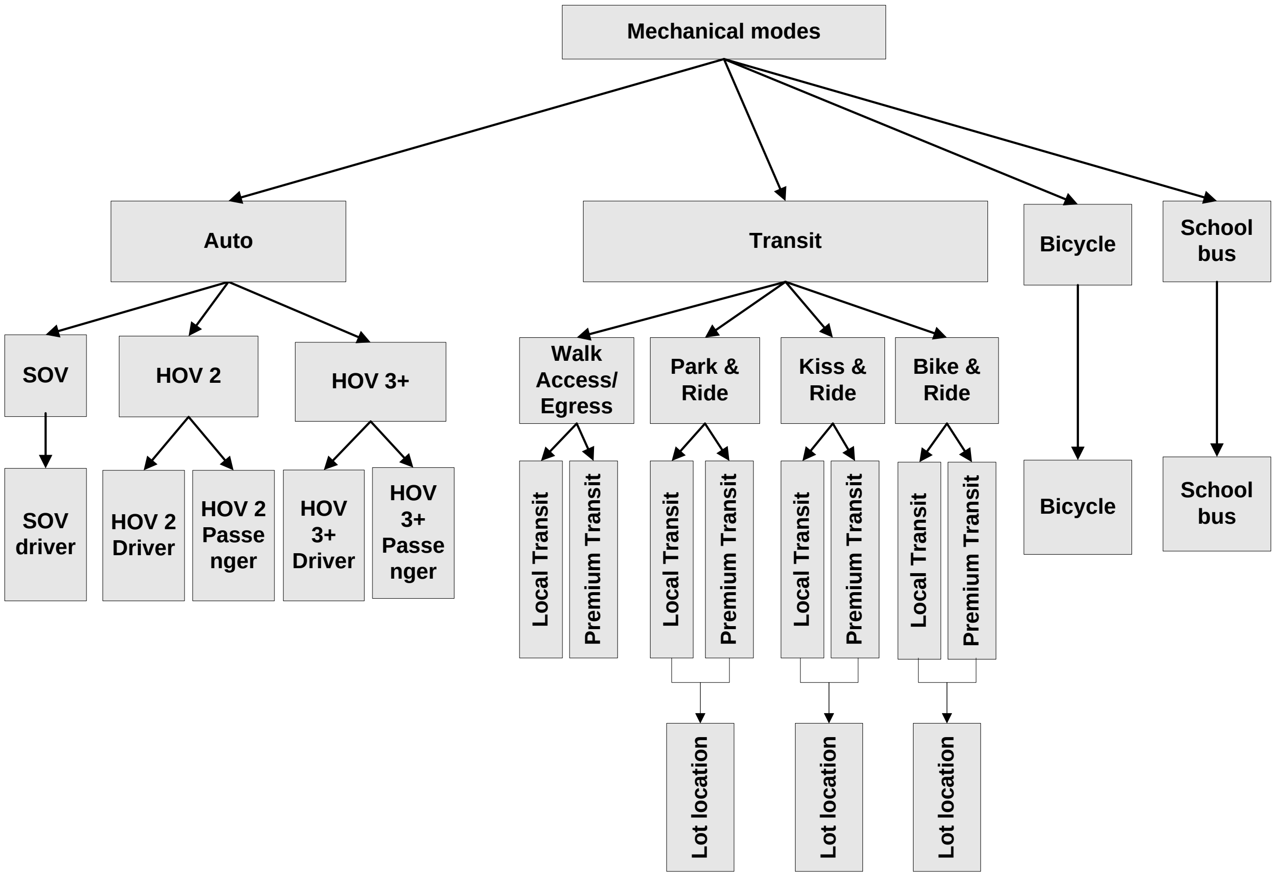
The mode choice model is estimated and applied at the trip level. It included mechanical modes (i.e. motorized modes and bicycle) only. The model operates with 15 modes grouped into 4 nests. The auto nest is further divided into 3 sub-nests and the transit nest is further sub-divided into 4 sub-nests based on access/egress type. The choice model has the following nested logit form shown in Exhibit 3.6 below. The model is fully segmented by 7 travel purposes, and 2 TOD periods (AM and PM). In addition to that, some model utility parameters are segmented by 4 car-sufficiency groups. The following numbering and notation of nests and modes is used in the model:

- (n=1) Auto nest including:
  - SOV sub-nest including:
    - (m=1) SOV driver (SOVd),
  - HOV 2 sub-nest including:
    - (m=2) HOV 2 driver (HOV2d),
    - (m=3) HOV 2 passenger (HOV2p),
  - HOV 3+ sub-nest including:
    - (m=4) HOV 3+ driver (HOV3d),
    - (m=5) HOV 3+ passenger (HOV3p)
- (n=2) Transit nest including:
  - Walk Access Transit sub-nest including:
    - (m=6) Local Transit with walk access (WLoc),
    - (m=10) Premium Transit with walk and/or bus access/egress (WPrem),
  - PNR Access Transit sub-nest including:
    - (m=7) Park and Ride Local Transit (PLoc),

  - ○ (m=11) Park and Ride Premium Transit (PPrem) that can also include bus access/egress,
- KNR Access Transit sub-nest including:
  - ○ (m=8) Kiss and Ride Local Transit (KLoc),
  - ○ (m=12) Kiss and Ride Premium Transit (KPrem) that can also include bus access/egress,
- BNR Access Transit sub-nest including:
  - ○ (m=9) Bike and Ride Local Transit (BLoc),
  - ○ (m=13) Bike and Ride Premium Transit (BPrem) that can also include bus access/egress,

- (n=3) Bicycle nest including:
  - (m=14) Bicycle (Bike).
- (n=4) School bus nest including:
  - (m=15) School bus (SB) available for school trips only.

Exhibit 3-8 | Nested Logit Model of Mode Choice



The conventional aggregate 4-step structure does not allow for modelling linkages across mode choice decisions for trips on the same tour. Thus, mode choice for each travel segment and TOD period was modelled independently. Bi-modal combinations like P&R, K&R and B&R were modelled in an explicit way including choice of the parking lot that ensures the shortest multimodal path between the trip origin and destination. The AM bi-modal combinations assume outbound order of legs (first auto, then transit). PM bi-model combinations assume inbound order of legs (transit first, then auto). For park & ride locations, capacity constraints were introduced for both AM and PM periods. Modelling of constrained parking is implemented through iterative adjustment of shadow prices for each overloaded parking lot. There is almost no computational overhead associated with these iterations since they are combined with global model iterations that are always needed for mode choice. The iterative algorithm that integrates the mode choice and assignment models are discussed in (the subsequent) Subsection 3.9.2 below.

The observed frequency of trip modes by tour purpose is shown in Table 3-7 below. The shadowed entries correspond to infrequent (non-modelled) modes. In general, there is a problem with estimation of coefficients specific to the bike and ride modes since there are only a few trips in the OD Survey across all purposes. In most cases, the bike-and-ride household attribute coefficients were either not estimated or adopted from another mode (other transit modes or bicycle mode).

Table 3-7 | Observed frequency of trip modes by tour purpose

Mode	Mode Name	1- Work	2- Univ	3- School	4- Maintenance	5- Discretionary	All Purposes
1	SOV	29,448	1,656	159	19,195	7,581	58,039
2	HOV2 - Driver	5,172	309	77	10,375	3,599	19,532
3	HOV2 - Passenger	2,744	296	1,922	4,645	3,039	12,646
4	HOV3+ - Driver	1,861	145	50	3,074	1,158	6,288
5	HOV3+ - Passenger	1,453	328	2,880	2,909	2,749	10,319
6	Local-Walk	3,976	1,481	1,895	1,327	595	9,274
7	Local-PNR	308	58	2	8	-	376
8	Local- KNR	71	28	13	4	3	119
9	Local- Bike	6	2	2	1	-	11
10	Premium -Walk	3,904	1,264	355	414	243	6,180
11	Premium-PNR	458	104	6	17	3	588
12	Premium- KNR	123	59	15	8	8	213
13	Premium- Bike	8	1	-	2	-	11
16	Walk	3,009	429	3,589	4,540	2,601	14,168
14	Bike	1,466	107	311	430	354	2,668
15	School Bus	*98*	*30*	6,055	*3*	*18*	6,204
	Total	**54,105**	**6,297**	**17,331**	**46,952**	**21,951**	**146,636**

Note: The red shadowed entries correspond to infrequent (non-modelled) modes.

The nested logit model of mode choice calculates mode probabilities according to the following formula:

$$p_{ij}^{uch}(m) = p_{ij}^{uch}[n(m)] \times p_{ij}^{uch}(m|n(m)), \qquad \text{Equation 80}$$

where:

$i, j \in I$	=	trip origin and destination TAZs,
u	=	tour purpose from 1 through 7,
c	=	household car sufficiency category from 0 through 3,
h	=	relevant trip TOD period (AM or PM),
m	=	modes from 1 through 15,
n	=	nests from 1 through 6,
$n(m)$	=	nest which the current mode belongs to,
$p_{ij}^{uch}(m)$	=	probability of mode to be chosen,
$p_{ij}^{uch}(n)$	=	marginal probability of nest to be chosen,
$p_{ij}^{uch}(m\|n(m))$	=	conditional probability of mode to be chosen within the nest.

The conditional probability of mode to be chosen is calculated by the following formula:

$$p_{ij}^{uch}(m) = \frac{\exp\left(V_{ijm}^{uch}\right)}{\sum_{m \in M_{n(m)}} \exp\left(V_{ijm}^{uch}\right)}, \qquad \text{Equation 81}$$

where:

V_{ijm}^{uch}	=	mode utility,
$m \in M_{n(m)}$	=	modes from the same nest.

The marginal probability of nest to be chosen is calculated by the following formula:

$$p_{ij}^{uch}(n) = \frac{\exp\left(\mu \tilde{V}_{ijn}^{uch}\right)}{\sum_{n} \exp\left(\mu \tilde{V}_{ijn}^{uch}\right)}, \qquad \text{Equation 82}$$

where:

$\tilde{V}_{ijn}^{uch} = \ln \sum_{m \in M_n} \exp\left(V_{ijm}^{uch}\right)$	=	composite nest utility (logsum),
$0 < \mu \le 1$	=	nesting coefficient (utility scale).

The mode utilities are specified in the following parsimonious way:

$$V_{ijm}^{uch} = \Delta_{g(ij)m}^{h} + UO_{im}^{uh} + UD_{jm}^{uh} + \Omega_{m}^{uch} + US_{ijm}^{uh}, \qquad \text{Equation 83}$$

where:

$g(ij)$	=	major transit corridors defined in terms of OD-pairs for validation and calibration,
Δ_{gm}^{h}	=	calibration constants by mode and corridor (not estimated),
UO_{im}^{uh}	=	purpose-specific mode utility component by trip origin TAZ characteristics,
UD_{jm}^{uh}	=	purpose-specific mode utility component by trip destination TAZ characteristics,
Ω_{m}^{uch}	=	purpose and car-sufficiency specific constants,
US_{ijm}^{uh}	=	LOS dependent utility component by OD-pairs.

The purpose-specific mode utility component dependent on trip origin TAZ characteristics is specified in the following way:

$$UO_{im}^{uh} = \alpha_{m}^{uh} + \sum_{q} \beta_{mq}^{uh} z_{iq} ,$$ Equation 84

where:

α_{m}^{uh}	=	mode-specific constants by travel purpose,
q	=	zonal variables,
z_{iq}	=	values of the zonal variables for trip origin TAZ.
β_{mq}^{uh}	=	coefficients for zonal variables.

The purpose-specific mode utility component dependent on trip destination TAZ characteristics is specified in the following way:

$$UD_{jm}^{uh} = \sum_{q} \gamma_{mq}^{uh} z_{jq} ,$$ Equation 85

where:

z_{jq}	=	values of the zonal variables for trip destination TAZ.
γ_{mq}^{uh}	=	coefficients for zonal variables.

The LOS dependent utility component is calculated as linear combination of time, cost, distance, and other skims:

$$US_{ijm}^{uh} = \sum_{k} \eta_{mk}^{uh} C_{ijk}^{h}(m)$$ Equation 86

where:

k	=	LOS skims and derived full OD matrix variables,
$C_{ijk}^{h}(m)$	=	values of LOS skims by modes,
η_{mk}^{uh}	=	coefficients for LOS skims.

The mode utility formulation is parsimonious because it allows for addressing the variety of segments (7 purposes x 4 car sufficiency segments for each TOD period), modes (15), and variables (more than 20 zonal variables, and more than 50 different skims). A full segmentation would have resulted in 28×15=420 mode utility expressions to estimate for each TOD period. With all mode-specific coefficients, it would have resulted in about 10,000 coefficients to estimate that is infeasible and cannot be supported by the OD survey. The suggested structure covers all segments and mode utilities with a reasonable partial segmentation. In particularly, car-sufficiency constants are separated and the rest of utility components are generic across car-sufficiency groups. Mode-specific constants are included in the origin-based components, thus there is no need in inclusion of them in the destination-based components.

The only dimension used for a full segmentation was the TOD period. The mode choice models for AM and PM periods were estimated separately. The sets of origin and destination related variables were switched for PM versus AM taking into account that while the majority of AM trips is outbound, the majority of PM trips is inbound.

The following variables will be statistically tested in the mode utility:

- Car-sufficiency-specific constants by purpose and mode,
- SOV, HOV2 and HOV3+ mode LOS skims for Driver, Passenger, and School Bus:
    - Free-flow time,
    - Congestion delay,
    - Toll
    - Operating cost proportional to distance (16 cents per km); scaled down for HOV2 and HOV3+ categories,
- Transit mode skims for Walk to Local Transit and Walk to Premium:
    - In-vehicle time, by guideway and stop density
    - Wait time, differentiated by initial and transfer
    - Walk time,
    - Number of boardings (to capture perceived transfer penalty),
    - Fare
- Combined LOS skims for P&R / K&R Local and Premium transit:
    - Auto access (in-vehicle) time,
    - Auto operating cost proportional to distance (16 cents per km)
    - Parking cost at park-and-ride location; only for P&R
    - In-vehicle transit time, by guideway and stop density,
    - Wait time, differentiated by initial and transfer
    - Walk time,

  - Number of boardings (to capture perceived transfer penalty),
  - Transit fare,
- Combined LOS skims for B&R Local and Premium transit:
  - Bike access (in-vehicle) time,
  - In-vehicle transit time, by guideway and stop density, Wait time, differentiated by initial and transfer
  - Walk time,
  - Number of boardings (to capture perceived transfer penalty),
  - Transit fare,
- Bicycle LOS skims:
  - Bike time by facility type,
- Zonal land-use and socio-economic variables for trip origins in AM period / destinations in PM period statistically tested at three levels of spatial aggregation (TAZ, superzone, and district):
  - Percentage of low-income households or population
  - Percentage of detached houses (proxy for transit accessibility and school bus need),
  - Population density (proxy for transit accessibility),
- Zonal land-use and socio-economic variables for trip destinations in AM period / origins in PM period statistically tested at three levels of spatial aggregation (TAZ, superzone, and district):
  - Parking cost (applied for auto modes; halved to account for half-tours and additionally scaled for high occupancy modes; long/daily parking cost is assumed for work, university, and school trips; short/2-hour parking cost is assumed for maintenance and discretionary trips),
  - Employment density (proxy for transit accessibility),
  - University enrolment (for university purpose as proxy for transit accessibility),
  - School enrolment (for school purpose as proxy for transit accessibility).

Travel times are modelled with differential impacts of different travel time components. Free flow time was distinguished from congestion delays for auto modes; in-vehicle-time, wait time, walk time, auto access time, and transfer penalties were distinguished for transit modes and sub-modes. This allows for better model sensitivity, thereby permitting the model to respond to changes in transportation networks. In particular, separation of congestion delay from free-flow time (on the auto side) as well as separation of in-vehicle time on Transitway \from in-vehicle time in mixed traffic (on the transit side) and in-vehicle time on low density stops compared to in-vehicle time on high density stops served as important proxies for travel time reliability. Reliability is highly evaluated by travelers along with average travel time and cost and has a strong impact on mode preferences.

In addition to traveler preferences expressed by mode utility functions, the following mode unavailability rules where applied in order to exclude unobserved cases–see Table 3-8 below.

Table 3-8 | Mode Unavailability Rules

Mode	Unavailability criteria					
	Zero-car household	Purpose not school	Walk longer than threshold	Maximum number of transfers	Minimum transit IVT share	Positive IVT by mode
1 = SOV driver	X					
2 = HOV 2 driver	X					
3 = HOV 2 passenger						
4 = HOV 3+ driver	X					
5 = HOV 3+ passenger						
6 = Walk to Local			X (60 min)	X (3)		Local
7 = P&R Local	X		X (30 min)	X (2)	X (1/4)	Local/Auto
8 = K&R Local			X (30 min)	X (2)	X (1/4)	Local/Auto
9 = B&R Local				X (2)		Local/ Bike
10 = Walk to Premium			X (60 min)	X (3)		Premium
11 = P&R Premium	X		X (60 min)	X (2)		Premium/Auto
12 = K&R Premium			X (60 min)	X (2)		Premium/Auto
13 = B&R Premium			X (60 min)	X (2)		Premium/Bike
14 = Bicycle						
15 = School bus		X				X (30 kms)

3.9.2 Integration of Mode Choice and Assignment Procedures

In the model application, mode choice is fully integrated with the auto, bicycle and transit assignment procedures. This integration is essential since the mode choice is driven by Level-of-Service (LOS) variables skimmed in the network assignment procedures. On the other hand, the assignment procedures (in particularly, chosen routes for each Origin-Destination zone pair) are highly sensitive to the mode demand matrices produced by the mode choice model. The integrative framework ensures that the equilibrium conditions are reached where the modal split and LOS variables match each other and have become stable.

Another important aspect of the integration relates to the fact that trip matrices produced for combined modes (P&R, K&R and B&R) cannot be immediately assigned as such. These trips have to be broken into mode legs including an auto/bike leg and transit leg that are assigned onto the auto/bike and transit networks respectively. This requires a choice model for identification of the mode interchange (parking lot for P&R, dropping-off / picking-up point for K&R and bike parking location for B&R) at the TAZ level. The mode interchange TAZ is subsequently used to construct auto, bicycle and transit LOS skims for the combined modes.

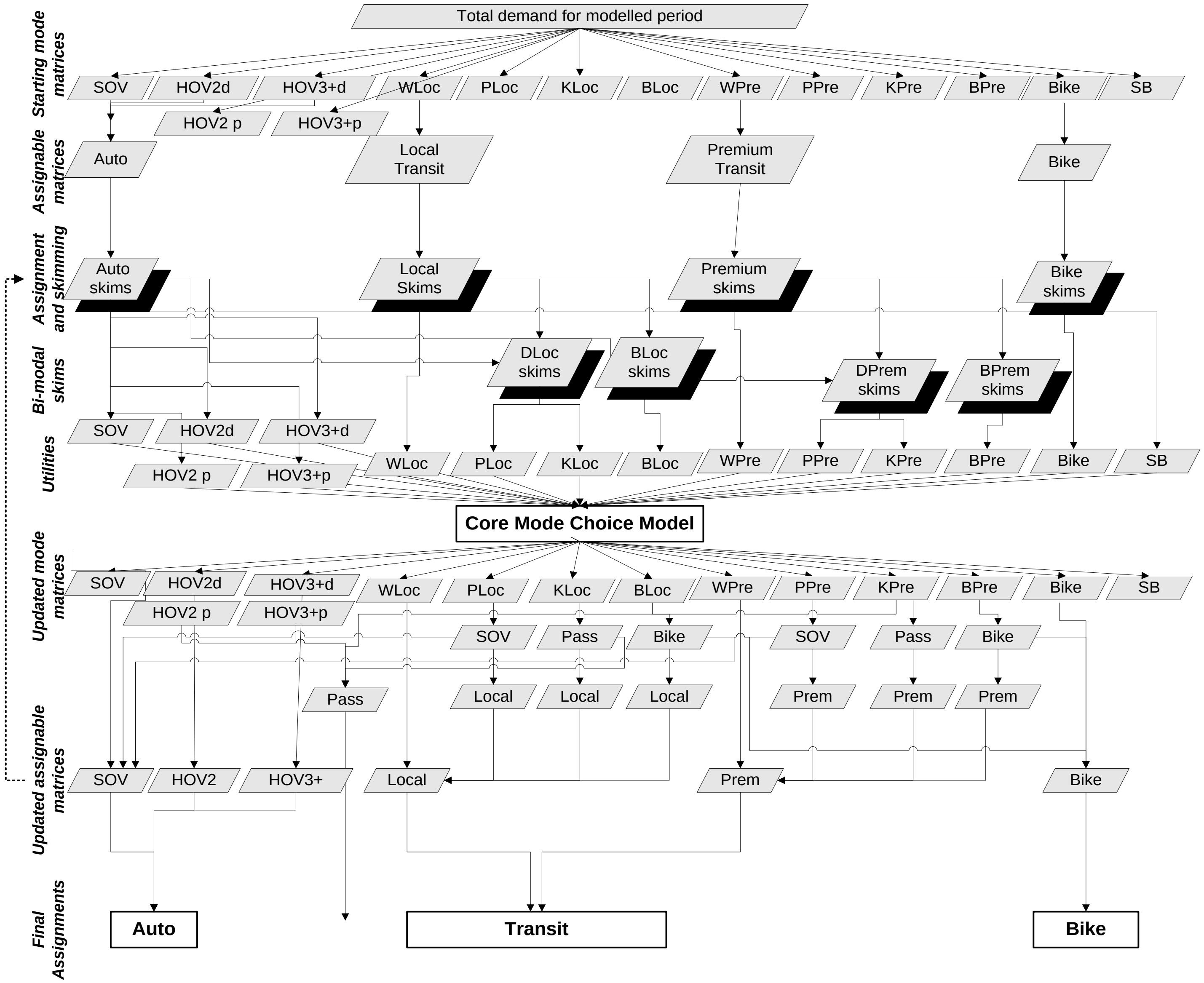
Taking into account the equilibrium and combined-modes procedures, the integrated mode choice and assignment algorithm has been developed and implemented – see Exhibit 3-9 below. The equilibrium procedure is implemented separately for each TOD period (AM and PM). Within each TOD period mode matrix calculations are fully segmented by 7 travel purposes and 4 car-sufficiency groups (that yields 28 full matrix segments split into 15 modes each). At the assignment stage, all purposes and car-sufficiency groups are combined together.

The integrated procedure is organized by the following major steps:

1. Preliminary mode choice (starting demand matrices by mode and assignable matrices),
2. Iterative assignment and skimming for auto, bicycle and transit modes,
3. Combination of skims for P&R, K&R and B&R based on the parking lot / station choice,
4. Calculation of mode utilities,
5. Calculation of mode probabilities by the core mode choice model,
6. Updating demand matrices by mode,
7. Updating assignable matrices and go to 2 until equilibrium has been reached,
8. Final assignments.

Step 1 is implemented only once at the beginning of the procedure. Steps 2-7 are repeated at each global iteration until the equilibrium has been reached. Step 8 is implemented once at the very end of the procedure. Below is a description of each of the steps.

Exhibit 3-9 | Integrated Mode Choice & Assignment Framework



Step 1: Starting demand matrices by mode and assignable trip matrices

This is an auxiliary step implemented in order to start the procedure and provide initial demand matrices and assignable matrices to get 1st-iteration LOS skims. The calculation is not segmented by either travel purpose or car-sufficiency group since a high level of accuracy is not required. The starting mode matrices are calculated by the following formula:

$$T_{ij}^{h,n=0}(m) = T_{ij}^{h} \frac{TS(m)}{\sum_{m=1}^{9} TS(m)}, \qquad \text{Equation 87}$$

where:

$i, j \in I$	= trip origin and destination TAZs,
h	= relevant trip TOD period (AM or PM),
m	= modes from 1 through 15,
$n = 0$	= global iteration number (set to 0 for start),
$T_{ij}^{h} = \sum_{u=1}^{5}\sum_{c=0}^{3} T_{ij}^{uch}$	= total trip matrix for the period for all purposes and car-sufficiency groups,
T_{ij}^{uch}	= trip matrix segments produced as explained in Subsection 3.8.4 above,
$TS(m)$	= total trips by mode observed in the OD survey for the modelled TOD period,
$T_{ij}^{h}(m)$	= starting mode matrices.

At the beginning of the first iteration the assignable matrices are defined in the following simplified way:

$S_{ij}^{h,n=0} = T_{ij}^{h,n=0}(m=1)$, (auto assignment with the SOV driver matrix m=1), Equation 88

$H_{ij}^{h,n=0} = T_{ij}^{h,n=0}(m=2)$, (auto assignment with the HOV 2 driver matrix m=2), Equation 89

$G_{ij}^{h,n=0} = T_{ij}^{h,n=0}(m=4)$, (auto assignment with the HOV 3+ driver matrix m=4), Equation 90

$L_{ij}^{h,n=0} = T_{ij}^{h,n=0}(m=6)$, (local transit assignment with the walk-to-local matrix m=6), Equation 91

$P_{ij}^{h,n=0} = T_{ij}^{h,n=0}(m=10)$, (premium transit assignment with the walk-to-premium matrix m=10), Equation 92

Step 2: Basic assignment and skimming for auto, bicycle and transit modes

At the result of basic auto assignment the following auto skims are created (these LOS skims are shared between driver and passenger modes):

$C_{ijkm}^{h}(m=1,2,4)$, Equation 93

where:

$k = 1$	=	free-flow auto time,
$k = 2$	=	free-flow auto distance,
$k = 3$	=	congested auto time,
$k = 4$	=	congestion delay (congested time minus free-flow time),
$k = 5$	=	tolls (currently, there are no tolls in the network, but for future scenarios this can have a value),

At the result of basic bicycle assignment the following bike skims are created:

$$C_{ijk}^{h}(m = 14),$$ Equation 94

where:

$k = 1$	=	bike time in mixed traffic,
$k = 2$	=	bike time on paved shoulders with traffic,
$k = 3$	=	bike time in sharrow lanes
$k = 4$	=	bike time on bike lanes in traffic,
$k = 5$	=	bike time on exclusive bike lanes,
$k = 6$	=	bike time on multi-use (stone dust) facilities,
$k = 7$	=	bike time on multi-use (asphalt) facilities,
$k = 8$	=	Total bike time.

At the result of basic local transit assignment (onto the network of only local transit lines) the following walk-to-local skims are created:

$$C_{ijkm}^{h}(m = 6),$$ Equation 95

where:

$k = 1$	=	total transit time (in-vehicle, walk, and wait),
$k = 2$	=	in-vehicle time,
$k = 3$	=	walk time,
$k = 4$	=	initial wait time,
$k = 5$	=	transfer wait time,
$k = 6$	=	total in-vehicle distance,
$k = 7$	=	local transit fare,
$k = 8 - 13$	=	in-vehicle time components by stop density type (low, medium, high) and right-of-way type (Transitway or mixed),

At the result of basic premium transit assignment (onto the network including all transit lines) the following walk-to-premium skims are created:

$$C^{h}_{ijkm}(m=10),$$ Equation 96

where:

$k = 1$ = total transit time (in-vehicle, walk, and wait),
$k = 2$ = in-vehicle time,
$k = 3$ = walk time,
$k = 4$ = initial wait time,
$k = 5$ = transfer wait time,
$k = 6$ = total in-vehicle distance,
$k = 7$ = premium transit fare,
$k = 8$ = in-vehicle time for premium transit only
$k = 9 - 14$ = in-vehicle time components by stop density type (low, medium, high) and right-of-way type (Transitway or mixed),

Step 3: Construction of skims for P&R, K&R and B&R based on the parking lot / station choice

LOS skims for the bi-modal combinations like P&R / K&R/ B&R for either local or premium transit are constructed by convoluting the corresponding auto/bike and transit skims through the chosen interchange. The mode interchange is defined as a TAZ that represents the parking lot for P&R and station for K&R /B&R. The possible lots are predefined as subsets of TAZs for each of the access/egress modes separately.

Choice of the mode interchange TAZ is modelled as all-or-nothing choice of the TAZ from the list of possible lots based on the minimum total travel time for each Origin-Destination pair of TAZs. The calculation is also implemented separately for each period (AM and PM) since identification of the shortest path through possible interchanges is a function of congested auto time used for the auto leg. Additionally, a different order of mode legs is assumed for different periods. In the AM period, an auto leg/bike leg is followed by the transit leg. In the PM period, the order is reversed. The P&R LOS skims are also dependent on parking lot capacity and parking cost. The parking lot capacity constraint is implemented by means of shadow pricing. It also should be mentioned that there is no explicit coordination between AM and PM period (i.e. there is no logical control for consistency between outbound and inbound directions for the same P&R tour). This level of logical control can be only implemented in an individual micro-simulation framework.

For P&R and K&R local transit in the AM period (h=2), choice of interchange can be formalized in the following way:

$$l^{h=2}_{ij}(m=7,8) = \left\{ l \in L(m=7,8) \middle| \min\left[C^{h=2}_{il,k=3}(m=1) + C^{h=2}_{il,k=2}(m=6) \right] \right\},$$ Equation 97

where:

$l \in L(m = 7,8)$ = possible P&R/K&R lots for local transit in the region,
$C_{il,k=3}^{h=2}(m = 1)$ = congested SOV time from trip origin to parking lot in AM period,
$C_{il,k=2}^{h=2}(m = 6)$ = in-vehicle transit time by local transit from parking lot to trip destination in AM period,
$l \in L(m = 7,8)$ = the best interchange for P&R/K&R local transit for the given OD-pair in AM period.

Similarly, for P&R and K&R premium transit in the AM period, choice of interchange can be formalized in the following way:

$$l_{ij}^{h=2}(m = 11,12) = \left\{l \in L(m = 11,12)|\min\left[C_{il,k=3}^{h=2}(m = 1) + C_{il,k=2}^{h=2}(m = 10)\right]\right\}, \quad \text{Equation 98}$$

where:

$l \in L(m = 11,12)$= possible P&R/K&R lots for premium transit in the region,
$C_{il,k=2}^{h=2}(m = 10)$ = in-vehicle transit time by premium transit from parking lot to trip destination in AM period,
$l \in L(m = 11,12)$ = the best interchange for P&R/K&R premium transit for the given OD-pair in AM period.

Similarly, for B&R local and premium transit in the AM period, choice of interchange can be formalized in the following way:

$$l_{ij}^{h=2}(m = 9) = \left\{l \in L(m = 9)|\min\left[C_{il,k=7}^{h=2}(m = 14) + C_{il,k=2}^{h=2}(m = 6)\right]\right\}, \quad \text{Equation 99}$$

where:

$l \in L(m = 9)$ = possible B&R lots for local transit in the region,
$C_{il,k=7}^{h=2}(m = 14)$ = Bike time from trip origin to parking lot in AM period,
$l \in L(m = 9)$ = the best interchange for B&R local transit for the given OD-pair in AM period.

$$l_{ij}^{h=2}(m = 13) = \left\{l \in L(m = 13)|\min\left[C_{il,k=7}^{h=2}(m = 14) + C_{il,k=2}^{h=2}(m = 10)\right]\right\}, \quad \text{Equation 100}$$

where:

$l \in L(m = 13)$ = the best interchange for B&R premium transit for the given OD-pair in AM period.

For the PM period (h=4), the same logic is applied but with a reversed order of mode legs (first transit followed by auto/bike):

$$l_{ij}^{h=4}(m = 7,8) = \left\{l \in L(m = 7,8)|\min\left[C_{il,k=2}^{h=4}(m = 6) + C_{il,k=3}^{h=4}(m = 1)\right]\right\}, \quad \text{Equation 101}$$

where:

$l \in L(m = 7,8)$ = possible P&R/K&R lots for local transit in the region,
$C_{il,k=3}^{h=2}(m = 1)$ = congested SOV time from parking lot to trip destination in PM period,
$C_{il,k=2}^{h=2}(m = 6)$ = in-vehicle transit time by local transit from trip origin to parking lot in PM period,
$l \in L(m = 7,8)$ = the best interchange for P&R/K&R local transit for the given OD-pair in PM period.

$$l_{ij}^{h=4}(m = 11{,}12) = \left\{l \in L(m = 11{,}12)\middle|\min\left[C_{il,k=2}^{h=4}(m = 10) + C_{il,k=3}^{h=4}(m = 1)\right]\right\},$$ Equation 102

where:

$l \in L(m = 11{,}12) =$ possible P&R/K&R lots for premium transit in the region,
$C_{il,k=2}^{h=2}(m = 10) =$ in-vehicle transit time by premium transit from trip origin to parking lot in PM period,
$l \in L(m = 11{,}12) =$ the best interchange for P&R/K&R premium transit for the given OD-pair in PM period.

$$l_{ij}^{h=4}(m = 9) = \left\{l \in L(m = 9)\middle|\min\left[C_{il,k=2}^{h=4}(m = 6)+C_{il,k=7}^{h=4}(m = 14)\right]\right\},$$ Equation 103

where:

$l \in L(m = 9) =$ possible B&R lots for local transit in the region,
$C_{il,k=7}^{h=2}(m = 14) =$ Bike time from parking lot to trip destination in PM period,
$l \in L(m = 9) =$ the best interchange for B&R local transit for the given OD-pair in PM period.

$$l_{ij}^{h=4}(m = 13) = \left\{l \in L(m = 13)\middle|\min\left[C_{il,k=2}^{h=4}(m = 10) + C_{il,k=7}^{h=4}(m = 14)\right]\right\},$$ Equation 104

where:

$l \in L(m = 13) =$ the best interchange for B&R premium transit for the given OD-pair in PM period.

Based on the identified parking lot / station for each OD pair, P&R / K&R/ B&R skims are constructed for local and premium transit and for AM and PM periods including the auto leg time, bike leg time and all transit components previously listed for walk-to-local and walk-to-premium modes according to the following logic:

$$C_{ij,k=0}^{h=2}(m = 7) = C_{i,l_{ij}^{h=2}(m=7),k=3}^{h=2}(m = 1),$$

(P&R local transit auto leg for AM period), Equation 105

$$C_{ij,k=0}^{h=2}(m = 9) = C_{i,l_{ij}^{h=2}(m=9),k=3}^{h=2}(m = 14),$$

(B&R local transit bike leg for AM period), Equation 106

$$C_{ij,k=0}^{h=2}(m = 7{,}8{,}9) = C_{l_{ij}^{h=2}(m=7,8,9),jk}^{h=2}(m = 7{,}8{,}9),$$

(P&R/K&R/B&R local transit leg for AM period), Equation 107

$$C_{ij,k=0}^{h=2}(m = 11) = C_{i,l_{ij}^{h=2}(m=11),k=3}^{h=2}(m = 1),$$

(P&R premium transit auto leg for AM period), Equation 108

$$C_{ij,k=0}^{h=2}(m = 13) = C_{i,l_{ij}^{h=2}(m=13),k=3}^{h=2}(m = 14),$$

(B&R premium transit bike leg for AM period), Equation 109

$$C_{ij,k=0}^{h=2}(m = 11{,}12{,}13) = C_{l_{ij}^{h=2}(m=11,12,13),jk}^{h=2}(m = 11{,}12{,}13),$$

(P&R/K&R/B&R premium transit leg for AM period), Equation 110

$C_{ij,k=0}^{h=4}(m=7)=C_{l_{ij}^{h=4}(m=7),j,k=3}^{h=4}(m=1),$

(P&R local transit auto leg for PM period), Equation 111

$C_{ij,k=0}^{h=4}(m=9)=C_{l_{ij}^{h=4}(m=9),j,k=3}^{h=4}(m=14),$

(B&R local transit bike leg for PM period), Equation 112

$C_{ij,k=0}^{h=4}(m=7,8,9)=C_{i,l_{ij}^{h=4}(m=7,8,9),k}^{h=4}(m=7,8,9),$

(P&R/K&R/B&R local transit leg for PM period), Equation 113

$C_{ij,k=0}^{h=4}(m=11)=C_{l_{ij}^{h=4}(m=11),j,k=3}^{h=4}(m=1),$

(P&R premium transit auto leg for PM period), Equation 114

$C_{ij,k=0}^{h=4}(m=13)=C_{l_{ij}^{h=4}(m=13),j,k=3}^{h=4}(m=14),$

(B&R premium transit bike leg for PM period), Equation 115

$C_{ij,k=0}^{h=4}(m=11,12,13)=C_{i,l_{ij}^{h=4}(m=11,12,13),k}^{h=4}(m=11,12,13),$

(P&R/K&R/B&R premium transit leg for PM period), Equation 116

Step 4: Calculation of mode utilities

This step was described in detail in (the previous) Subsection 3.9.1.

Step 5: Calculation of mode probabilities by the core mode choice model

This step was described in detail in (the previous) Subsection 3.9.1.

Step 6: Updating demand matrices by mode

After the new demand matrices by mode and segment (purpose and car-sufficiency group) have been produced by the mode choice model, they are aggregated by mode and then the old (previous-iteration) matrices are updated according the following strategy:

$$T_{ij}^{h,n}(m)=\left(1-\lambda^{n}\right)T_{ij}^{h,n-1}(m)+\lambda^{n}\sum_{u=1}^{5}\sum_{c=0}^{3}T_{ij}^{uch,n}(m),$$ Equation 117

where:

m	=	modes from 1 through 15,
u	=	tour purpose from 1 through 7,
c	=	household car-sufficiency category from 0 through 3,
n	=	global iteration number,

$T_{ij}^{uch,n}(m)$	=	mode matrices by segment resulted from mode choice model at current iteration,
$T_{ij}^{h,n-1}$	=	aggregate mode matrices from the previous iteration,
$T_{ij}^{h,n}$	=	updated aggregate mode matrices,
$0 < \lambda^n < 1$	=	updating parameter defined by a modified MSA method to speed up convergence:

$\lambda^n = \max[(1.2 - 0.2 \times n), (1/n)]$.

Step 7: Updating assignable matrices

After the demand matrices by mode have been updated the assignable matrices are re-calculated taking in to account that for P&R, K&R and B&R modes, the trips are broken into mode legs using the same best interchange logic employed for LOS skims and explained above. The basic assignable matrices are produced for SOV , HOV 2 driver, HOV3+ driver, Local transit, premium transit and bicycle modes. Additionally, at the last iteration, an assignable matrix for HOV passenger trips is produced in order to get link-level HOV-passenger volumes. The calculations are implemented in the following straightforward way:

- SOV assignable trip matrix includes SOV driver trips (m=1), auto leg from P&R local transit trips (m=7), and auto leg from the P&R premium transit trips (m=11),
- HOV 2 driver assignable trip matrix includes HOV2 driver trips (m=2),
- HOV 2 passenger assignable trip matrix includes HOV2 passenger trips (m=3), auto leg from K&R local transit trips (m=8) and auto leg from the K&R premium transit trips (m=12); these tables are not assigned as part of regular traffic assignment,
- HOV 3+ driver assignable trip matrix includes HOV3+ driver trips (m=4),
- HOV 3+ passenger assignable trip matrix includes HOV3+ passenger trips (m=5); these tables are not assigned as part of regular traffic assignment,
- Local transit assignable trip matrix includes walk-to-local transit trips (m=6), transit leg from P&R local transit trips (m=7), transit leg from K&R local transit trips (m=8) and transit leg from B&R local transit trips (m=9),
- Premium transit assignable trip matrix includes walk-to-premium transit trips (m=10), transit leg from P&R premium transit trips (m=11), transit leg from K&R premium transit trips (m=12) and transit leg from B&R premium transit trips (m=13),
- Bicycle assignable trip matrix includes bicycle trips (m=14), bike leg from B&R local transit trips (m=9), and bike leg from B&R premium transit trips (m=13).

The formal expressions below reflect this logic as well as the reversed order of mode legs for P&R / K&R / B&R in the PM period compared to AM period.

$$S_{ij}^{h=2,n} = T_{ij}^{h=2,n}(m=1) + T_{i,l_{ij}^{h=2}(m=7)}^{h=2,n}(m=7) + T_{i,l_{ij}^{h=2}(m=11)}^{h=2,n}(m=11),$$ (SOV driv./ AM Period), Equation 118

$$H_{ij}^{h=2,n} = T_{ij}^{h=2,n}(m = 2),$$ (HOV 2 driv./ AM Period), Equation 119

$$G_{ij}^{h=2,n} = T_{ij}^{h=2,n}(m = 4),$$ (HOV 3 driv./ AM Period), Equation 120

$$L_{ij}^{h=2,n} = T_{ij}^{h=2,n}(m = 6) + T_{l_{ij}^{h=2}(m=7),j}^{h=2,n}(m = 7) + T_{l_{ij}^{h=2}(m=8),j}^{h=2,n}(m = 8) + T_{l_{ij}^{h=2}(m=9),j}^{h=2,n}(m = 9),$$

(Local / AM Period), Equation 121

$$P_{ij}^{h=2,n} = T_{ij}^{h=2,n}(m = 10) + T_{l_{ij}^{h=2}(m=11),j}^{h=2,n}(m = 11) + T_{l_{ij}^{h=2}(m=12),j}^{h=2,n}(m = 12) + T_{l_{ij}^{h=2}(m=13),j}^{h=2,n}(m = 13),$$

(Prem./ AM Period), Equation 122

$$B_{ij}^{h=2,n} = T_{ij}^{h=2,n}(m = 14) + T_{i,l_{ij}^{h=2}(m=9)}^{h=2,n}(m = 9) + T_{i,l_{ij}^{h=2}(m=14)}^{h=2,n}(m = 14),$$ (Bicycle / AM Period), Equation 123

$$S_{ij}^{h=4,n} = T_{ij}^{h=4,n}(m = 1) + T_{l_{ij}^{h=4}(m=7),j}^{h=4,n}(m = 7) + T_{l_{ij}^{h=4}(m=11),j}^{h=4,n}(m = 11),$$ (SOV driv./ PM Period), Equation 124

$$H_{ij}^{h=4,n} = T_{ij}^{h=4,n}(m = 2),$$ (HOV 2 driv./ PM Period), Equation 125

$$G_{ij}^{h=4,n} = T_{ij}^{h=4,n}(m = 4),$$ (HOV 3 driv./ PM Period), Equation 126

$$L_{ij}^{h=2,n} = T_{ij}^{h=2,n}(m = 6) + T_{il_{ij}^{h=2}(m=7)}^{h=2,n}(m = 7) + T_{il_{ij}^{h=2}(m=8)}^{h=2,n}(m = 8) + T_{il_{ij}^{h=2}(m=9)}^{h=2,n}(m = 9),$$

(Local / PM Period), Equation 127

$$P_{ij}^{h=2,n} = T_{ij}^{h=2,n}(m = 10) + T_{il_{ij}^{h=2}(m=11)}^{h=2,n}(m = 11) + T_{il_{ij}^{h=2}(m=12)}^{h=2,n}(m = 12) + T_{il_{ij}^{h=2}(m=13)}^{h=2,n}(m = 13),$$

(Prem./ PM Period), Equation 128

$$B_{ij}^{h=2,n} = T_{ij}^{h=2,n}(m = 14) + T_{l_{ij}^{h=2}(m=9),j}^{h=2,n}(m = 9) + T_{i,l_{ij}^{h=2}(m=14),j}^{h=2,n}(m = 14),$$

(Bicycle / PM Period) Equation 129

Step 8: Final assignments

This step is described in detail in (the next) Section 3.10 below.

3.10 Assignment & Skimming Procedures

3.10.1 Auto Assignment and Skimming

The TRANS Model incorporates several auto assignments with the corresponding skimming procedures as part of mode choice models applied for AM and PM periods. Auto assignment is part of an iterative auto-bicycle assignment applied sequentially to account for cross impacts of autos and bicycles. The iterative procedure and cross impacts are discussed in Subsection 3.9.2. These procedures serve the following purposes:

- Properly incorporate <u>all traffic components</u> that contribute to congestion in the integrated multi-class framework with a proper scaling to represent the peak hour, including:
  - Auto driver trips including P&R auto legs; three matrices with vehicle occupancy distinction are modelled for each TOD period,
  - Commercial vehicles that are singled out since they have a class-specific network; a single matrix of trucks / commercials synthesized from traffic counts is currently applied for each TOD period; it is kept fixed through the TRANS Modelling procedure,
  - External vehicle trips (to, from, and between the external zones) that share the same class with auto driver, however it makes sense to save their volumes separately for purpose of analysis; a single matrix is currently applied for each TOD period; it is kept fixed through the TRANS Modelling procedure,
  - Bus volume preloads based on the coded bus route frequency,
  - Bicycle volumes preloads based on bicycle assignment results,
  - Two auto passenger matrices (HOV2 and HOV3+) assigned as additional demand (not contributing to the congested travel time through Volume-Delay functions) to get the passenger link volume estimates;
- Provide necessary <u>LOS skims</u> for the mode choice model - see (the previous) **Section 3.9**:
  - Free-flow auto travel time,
  - Congested auto travel time by 3 vehicle classes (SOV, HOV2, HOV3+),
  - Auto distance,
  - Auto Tolls by 3 vehicle classes (SOV, HOV2, HOV3+).
- Provide <u>class-specific link volumes</u> for which the following link extra attributes are created:
  - @sovd (peak hour SOV driver vehicle volume),
  - @hov2d (peak hour HOV 2 driver vehicle volume),
  - @hov3d (peak hour HOV 3+ driver vehicle volume),
  - @hov2p (peak hour HOV 2 passenger volume),
  - @hov3p (peak hour HOV 3+ passenger volume),
  - @comm (peak hour commercial vehicle volume),
  - @exte (peak hour external traffic volume).

The saved volumes for the peak hour meet the following constraint:

Volau = @sovd+@hov2d+@hov3d+@comm+@exte, Equation 130

where $Volau$ represents the basic auto volume in EMME. Bus preloads are represented by the $Volad$ parameter of EMME (“additional volume”).

The logic and details of the auto assignment and skimming procedures are summarized in the Table 3-9 below. Saving class-specific link volumes (that is a time consuming procedure) is done only at the final stage. Assignment within the equilibrium loop are simplified and intended to support the necessary LOS variables to the mode choice model. Additional dichotomy (two assignments at each iteration) is necessary because of the EMME limitation in treating additional auto volumes $Volad$. They can be used either as bus preloads or for additional options assignment (but not for both unless an additional extra attribute for bus preloads is created and incorporated in the Volume-Delay functions).

Peak factors are currently defined in the following way (based on the observed variation of traffic volumes within each period):

- For the AM period (6:30 – 9:00 AM), scaling factor (the entire-period volume divided by the peak hour volume) is defined for zone groups and vary between 1.9 and 2.1, which means that the peak hour volume is by 30% -19% higher than the average AM period volume. Table 3-10 shows the AM peak hour factor by zone groups,
- For the PM period (3:30 – 6:30 PM), scaling factor is set to 2.5, which means that the peak hour volume is by 20% higher than the average PM period volume. The PM peak hour factor did not vary significantly between zone groups and therefore, a single global value was adopted.

Table 3-9 | Auto Assignment and Skimming Procedures

Placement in mode choice macro	Function	Assignment type	Demand matrices	Scale (referred to as vehicle occupancy in EMME)	Bus Preloads	Bicycle Preload	OD skims	Link attributes saved	Number of assignment iterations
Within the equilibrium loop (run at each iteration)	1. Skim free flow auto time and distance	Single class (a) additional options	Zero matrix	No	Cannot be used	Cannot be used	Free-flow time, Distance (additional options with length as link attribute)		**Min×IterMod**
	2. Skim congested auto time	Multiclass:			Volad	Not Available for first Auto – bicycle iteration, ul2	Congested time (basic) and tolls for SOV, HOV2 and HOV3+		**Min×IterMod**
		1(d) – SOV	SOV+P&R auto legs+Ext×PeakF	PeakF					
		2(j) – HOV 2	HOV 2 driver	PeakF					
		3(k) – HOV 3+	HOV 3+ driver	PeakF					
		4(c) – comm.	Commercial	=1					
Final assignments (after the last iteration)	3. Save HOV2 passenger link volumes	Multiclass :			Cannot be used	Cannot be used		@hov2p (additional options with Pass matrix divided by PeakF for additional volumes)	**Min×IterMax**
		1(j) – HOV 2	HOV 2 driver	PeakF					
		2(d) – SOV	SOV+P&R auto legs	PeakF					
		3(k) – HOV 3+	HOV 3+ driver	PeakF					
		4(c) – comm.	Commercial	=1					
		5(d) – ext	External	=1					
	4. Save HOV3+ passenger link volumes	Multiclass:			Cannot be used	Cannot be used		@hov3p (additional options with Pass matrix divided by PeakF for additional volumes)	**Min×IterMax**
		1(k) – HOV 3+	HOV 3+ driver	PeakF					
		2(d) – SOV	SOV+P&R auto legs	PeakF					
		3(j) – HOV 2	HOV 2 driver	PeakF					
		4(c) – comm.	Commercial	=1					
		5(d) – ext	External	=1					
	5. Save SOV, HOV2, HOV3+ driver, commercial, and external link volumes	Multiclass with saved class-specific volumes:			Volad	ul2			**Min×IterMax**
		1(d) – SOV	SOV+P&R auto legs	PeakF					
		2(j) – HOV 2	HOV 2 driver	PeakF					
		3(k) – HOV 3+	HOV 3+ driver	PeakF					
		4(c) – comm.	Commercial	=1					
		5(d) – ext	External	=1					

Table 3-10 | AM Peak Hour Factor

	Destination				
Origin	**Ottawa CBD**	**Ottawa Urban**	**Other Ottawa**	**Gatineau CBD**	**Other Gatineau**
Ottawa CBD	1.9	2.1	1.9	2.1	2.1
Ottawa Urban	2.1	1.9	1.9	2.1	2.1
Other Ottawa	2.1	2.1	1.9	2.1	2.1
Gatineau CBD	2.1	2.1	2.1	1.9	1.9
Other Gatineau	2.1	2.1	2.1	2.1	1.9

The number of assignment iterations is currently set in the following flexible way that allows for economizing in runtime:

- Minimal number of auto assignment iterations Min that is applied for the first global iteration of integrated mode choice an assignment procedure described in Subsection 3.9.2 above is set to 10 since a high level of accuracy is not needed at this stage,
- Number of auto assignment iterations for each subsequent global iteration $IterMod$ is defined as $Min \times IterMod$; thus for the second global iteration it would yield 20 assignment iterations, for the third global iteration it would yield 30 assignment iterations, etc.
- Number of auto assignment iterations for the last global iteration $IterMax$ (number of global iterations currently set to 5) and final assignments is 50; this ensures a high level of convergence and accuracy in volume predictions; the assignment accuracy at the last global iteration also matches the (high) convergence level of the integrated mode choice and assignment procedure.

3.10.2 Bicycle Assignment and Skimming

The TRANS Model incorporates an iterative auto and bicycle assignment procedure. The volume delay function and generalized costs for bicycle assignments is dependent on auto volumes. The framework for calculating generalized costs, volume delay functions and iterative assignment procedure is discussed below.

3.10.2.1 Bike Facility Type

The bike facility type affects the bicyclist's travel time as well as travel times of motorized vehicles in mixed traffic. For example, a bicyclist using a bike separated facility will not impact motorized vehicles and get impacted by motorized vehicle as much as a bicyclist using a mixed-traffic lane. There are 7 bike facility types specified in the Ottawa network:

1. Multi-use Stone pathway
2. Multi-use Asphalt pathway
3. Separated Bike Lanes
4. At-grade Bike Lanes
5. Sharrow Lanes (curb lane is marked for used by bikes but not exclusively)
6. Bikes allowed in mixed traffic
7. Paved Shoulders

3.10.2.2 Impact on Travel Time (Bicycles)

Different variables affect the bicycle level of service. This Bicycle Level-of-Service (BLOS) can be interpreted as the additional time required for traversing a link compared to free flow conditions. For example, if it takes 6 minutes to traverse a link on a bike under ideal free flow conditions, then in the presence of vehicular traffic, it will take more time. Assume that BLOS for link (i,j) for a bicyclist of type m is defined as $\mathrm{LOS}_{\mathrm{ijm}}$. Then, the delay experienced by the bicyclist is given by:

$$\text{Link Delay}_{ijm} = \text{LDF}_{ijm} \times \text{Bike Free Flow Time} \qquad \forall (i,j) \in A \;\; \forall m \in M$$ Equation 131

where, the link delay factor (LDF) is defined as:

$$\text{LDF}_{ijm} = 1 + \text{LOS}_{ijm} \qquad \forall (i,j) \in A \;\; \forall m \in M$$ Equation 132

In turn, LOS_{ijm} is defined as:

$$\text{LOS}_{ijm} = \text{Max}\{f(A_{ij,}\; P_{i,}\; P_{j,}\; M_m \times A_{ij}),\; 0\}$$ Equation 133

where:

A_{ij} = Link specific variables,

P_i = Downstream node-specific variables,

P_j = Upstream node-specific variables,

$M_m \times A_{ij}$ = Link-user specific interaction variables.

Table 3-11 shows an example of the LOS computation with the initial parameters set by the project team based on the literature review. New link and node level attributes can be added in the LOS computation in the future.

Table 3-11 | An Example showing Bicycle LOS computation

Variables		Bicyclist		
	Units	Value [A]	Effect	Coefficient [B]
Link-Level				
Bicycle Lane (yes/no)	N/A	0	Good	-1.12
Sharrow Lanes	N/A	1	Good	-0.5
Bike Lane Width	Feet	5	Good	-0.4
Curb Lane Width	Feet	10	Good	-0.0498
Traffic Speed	kph	35	Not Good	0.01375
Curb Lane Volume	Vph	600	Not Good	0.002
Other Lane Volume	Vph	1200	Not Good	0.0004
Parking Lane (yes/no)	N/A	1	Not Good	0.506
% HV Volume	Ratio	15	Not Good	0.034
Frequency of driveways	N/A	3	Not Good	0.019
Pavement Condition (good/bad)	0-4	0	Not Good	0.05
Node-Level				
Signal	N/A	1	Not Good	0.011
LOS ([A]x[B])		**0.23625**		
Free Flow Travel Time	mins	6		
Delayed FF Travel Time	mins	**7.4835**		

3.10.3 Segmentation of Variables (Bicyclist Type)

Research shows that bicyclists can be categorized based on their biking ability and inclination towards biking[1]. This implies that different bicyclists experience different travel times and have different impacts on the travel times of motorized vehicles. Furthermore, bike facility type also affects the bicyclist's travel time and the travel times of motorized vehicles. For example, a novice bicyclist using a bike separated facility will not impact motorized vehicle as much as a novice bicyclist using a mixed-traffic lane. This suggests that segmentation of LDF and LOS variables by bicyclist type will improve the model. However, for the current model implementation, only one bicyclist type has been considered due to data limitations. In order to create LOS variables by bicyclist type, it is required to divide the bicycle trip table by bicyclist type and the bicyclist specific LOS variables should be fed back into mode choice model. However, the modelled trip table is based on the OD Survey and the current survey does not have information on bicyclist type. Also, due to the aggregate nature of the model, person attributes are not retained in the model chain. Consultants and TRANS team discussed possible ways of including bicyclist types in the model using data from other bicycle surveys. However, using flat percentages to split the bicyclist will not be correct since different bicyclist types might also have very different trip length frequencies. Bicycle trips are identified at OD level by purpose in the mode choice model. However, bicyclist type is not a mode choice level decision but the characteristic of a person himself. A micro-simulation model will be better suited to retain person attributes in the model chain and will allow creating the bicycle trip table by bicyclist type.

3.10.3.1 Link Volume Delay Function (Bicycle)

LDF does not account for the delay caused due to traffic congestion at a link. To account for these delays, a link volume delay function for bicycle is defined. The following factors affect delays experienced by bicyclists:

1. **Auto volume –** high V/C ratio for autos implies a steeper bicycle VDF as they have to navigate through high congestion for mixed-traffic
2. **Bike lane type** – easier to navigate through dedicated bike lane than mixed traffic
3. **Total effective capacity** – effective capacity available to bikes conditional on the modelled traffic volumes

A link-based bike VDF that accounts for these factors was specified. Let the capacity of the link be C, the auto volume on that link be V_a, the bicycle free flow travel time be t_0, and the link delay factor be LDF. In addition, a few calibration parameters are also defined - $\alpha_b\ (0.1)$, $\beta_b(=4)$, $\gamma(=1)$, $\theta(=1)$, $\zeta_b(=0.1)$. Now, the travel time on a link with bike volume V_b is specified by a function $t(V_b)$ that is defined as:

$$t(V_b) = ACF \times \left(1 + \zeta_b \left(\frac{V_b}{C_{eff}}\right)^{Exp_{eff}}\right) \quad \text{Equation 134}$$

[1] Furth, P. G., & Mekuria, M. C. (2013). Network Connectivity and Low-Stress Bicycling. In *Transportation Research Board 92nd Annual Meeting* (No. 13-0427).

Examining a Typology to Better Understand Bicycling Behavior and Potential. In *Transportation Research Board 92nd Annual Meeting* (No. 13-5213).

where, effective exponential factor is calculated in the following way:

$$\mathrm{Exp_{eff}} = \max\left\{\gamma, \min\left\{\left(\frac{C}{V_a+\epsilon}\right)^{\theta}, \beta_b\right\}\right\}, \qquad \text{Equation 135}$$

Effective capacity is calculated in the following way:

$$C_{eff} = \max\{C - V_a,\ \alpha_b C\}, \qquad \text{Equation 136}$$

Auto Congestion Factor (ACF) is calculated in the following way:

$$\mathrm{ACF} = \mathrm{LDF} \times t_0 \times \left(1 + \mu\left(\frac{V_a}{C}\right)^{\nu}\right). \qquad \text{Equation 137}$$

The cross impacts of auto congestion on bicycle LOS are incorporated into this VDF using the auto congestion factor (ACF).

3.10.3.2 Link Volume Delay Function (Auto)

In addition to examining how auto traffic affects bicycle congestion, one also needs to examine the effect bicycles have on auto congestion and link travel times. Auto travel times increase due to the presence of bicycles. Bicycles take up part of capacity, and since they move slower than autos, they take up even more capacity than their physical dimensions. The travel time delay that motorized vehicles experience because of the presence of bicycles can be accounted by the amount of effective car capacity bicycles take up.

Mathematically, this can be expressed as follows. Let the capacity of the link be C, the bike volume on that link be V_b, the auto free flow travel time be t_0, the link factor be LF, let Passenger Car Equivalent (PCE) for bike user b and link type be p_{b_l}. In addition, calibration parameters β_a, ζ_a are also specified. The link factor is a parameter whose value is dependent on the link type (mixed-traffic, bike lane etc.). Now, the travel time on a link with auto volume V_a is given by $t(V_a)$ and is specified as:

$$t(V_a) = t_0 \times \mathrm{LF} \times \left(1 + \zeta_a \left(\frac{V_a + \sum_b p_{b_l} V_b}{C}\right)^{\beta_a}\right). \qquad \text{Equation 138}$$

3.10.3.3 Iterative Implementation of Equilibrium Auto- Bicycle Assignment

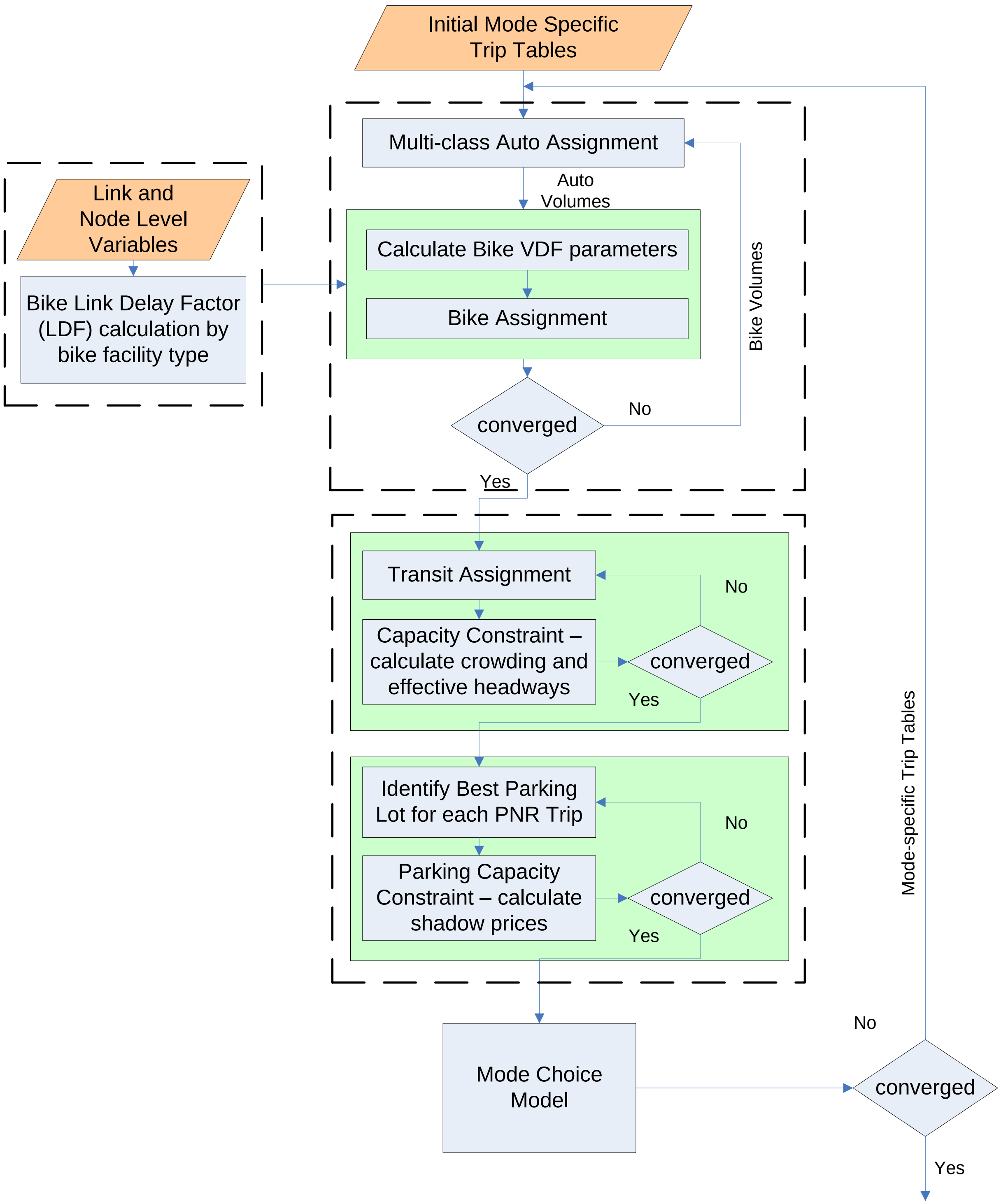
The final goal of defining the LOS variables and VDFs is to study the effects bicycles have on vehicular traffic and vice-versa in a coherent equilibrium framework. This objective is met by iteratively assigning autos and bicycles onto the network with the linkages between them. Exhibit 3-10 explains the entire iterative framework for the mode choice and assignment procedure. In the first step, auto assignment is carried out assuming that there are no bikes on the network. After auto assignment, effective capacity and other VDF parameters are computed for the bike assignment based on auto volumes and travel times. After bike assignment, the bike volumes in PCEs are preloaded on the auto network for auto assignment. The process iterates between these two assignments until the stopping criteria (equilibrium) is obtained. If the stopping criterion is met, the LOS skims are passed on to the mode choice model.

It should be noted that a possible alternative way is to assign both auto and bicycle trips as different vehicle classes in one multi-class assignment procedure. However, a multi-class assignment would restrict the classes to share same VDF while it is evident that the VDFs for autos and bicycles are very different. Overall, there are three levels of equilibration: (a) bike and auto assignment each one separately; (b) equilibrium between bike and auto assignments achieved by iterations with a feedback between them; (c) demand (mode choice) global equilibrium. For bicycle mode, skims are generated by 7 facility types and fed into the mode choice model. The sensitivity to bicycle time varies across different bike facility type which makes bicycles more attractive between Origin-Destination pairs which have higher proportion of travel time on bike friendly lanes.

3.10.3.4 Bicycle LOS Skimming

- The following LOS skims are generated as part of the bicycle assignment and skimming procedure for the model choice model:
    - Bicycle Time on Multi-use Stone Pathway,
    - Bicycle Time on Multi-use Asphalt Pathway,
    - Bicycle Time on Separated Bike Lanes,
    - Bicycle Time on At-grade Bike Lanes,
    - Bicycle Time on Sharrow Lanes (curb lane is marked for used by bikes but not exclusively),
    - Bicycle Time on Bikes in Mixed Traffic,
    - Bicycle Time on Paved Shoulders.
- Provide bicycle link volumes for which the following link extra attributes are created:
    - @bkvol

Exhibit 3-10 | Mode Choice and Assignment Framework Incorporating Bicycles



3.10.4 Transit Assignment and Skimming

The regional travel demand model incorporates several transit assignments with the corresponding skimming procedures as part of mode choice models applied for AM and PM periods. These procedures serve the following purposes:

- Properly incorporate all transit services including:
  - Regular bus (express and local),
  - Guided bus (Transitway),
  - Rail including commuter rail and future LRT projects,
- Provide necessary LOS skims for the mode choice model - see (the previous) **Section 3.9**:
  - Total transit time,
  - In-vehicle time by transit mode (local premium), stop density (low, medium, high) and right-of-way (fixed guideway vs mixed),
  - Wait time (Initial and Transfer),
  - Walk time,
  - Number of boardings by transit mode (local, premium),
  - Fare by transit mode (local, premium)
- Provide the following detailed transit ridership statistics:
  - Ridership by line and direction,
  - Transit volume for each transit line segment,
  - Number of boarding and alighting passengers at each bus stop and rail station.

Extended transit assignment algorithm implemented in EMME ("strategies with variants") is sensitive to transit capacity constraints and crowding. The transit assignments are carried out for the entire peak period and therefore, transit assignment trip tables are not scaled by peak hour factor. The ridership statistics are generated by the final assignment procedures after the last global mode choice iteration has been completed. The transit assignment and skimming procedures have been greatly enhanced in the TRANS Model update. There are four main transit modes identified in the TRANS transit network based on current network and allowing for expansion in future:

1. Regular Bus
2. Express Bus
3. Rapid Transit System (LRT and BRT)
4. Commuter Rail (CR)

The features of these transit services are shown below in Table 3-12.

In traditional labeled approach, mode groups are defined at a very detailed level such as local bus, express bus, rapid bus, LRT, commuter rail etc. In the model, constants are defined for each of the mode to be able to match the aggregate mode shares. These constants are included to account for the unobserved or unaccounted features of the modes which make them less or more attractive. For example, the constant on LRT will be stronger than bus to show that transit users' prefer LRT even when LRT and bus have the same travel time. It could be due to a number of factors such as reliable service, comfortable ride, less crowding etc. which are not accounted for in the model. A non-labeled approach is a way to explicitly account for as many service features as possible for each mode in order to eliminate flat mode specific constants which are not behaviorally appealing.

In a non-labeled approach, mode groups are identified based on the type of transit service within non-competing modes. For TRANS, two groups of transit modes were identified: local transit (regular bus) and premium transit (express bus, LRT, BRT, commuter rail). The level-of-service skims are used to include as many features as possible for any service type in the model to differentiate between modes. The in-vehicle time coefficients are segmented by part of time spent, different stop density, and use of fixed guideway. In future, if a new service is added, it will be identified based on the right of way and stop frequency, and not the label of the service.

Table 3-12 | Features of the Transit Services

Service Features	Regular Bus	Express Bus	Rapid Transit System	Commuter Rail
Time Available	All day	Peak Only	All day	All day
Density of Stops	High (spacing <300m)	Medium (spacing 300-600m)	Low (spacing 600m+)	Low (spacing 600m+)
Right of Way (ROW)	No, runs in mixed traffic	Partial, mostly on fixed guideway	Yes, mostly on fixed guideway	Yes, runs on fixed guideway
Fares	Low	High	Low	High

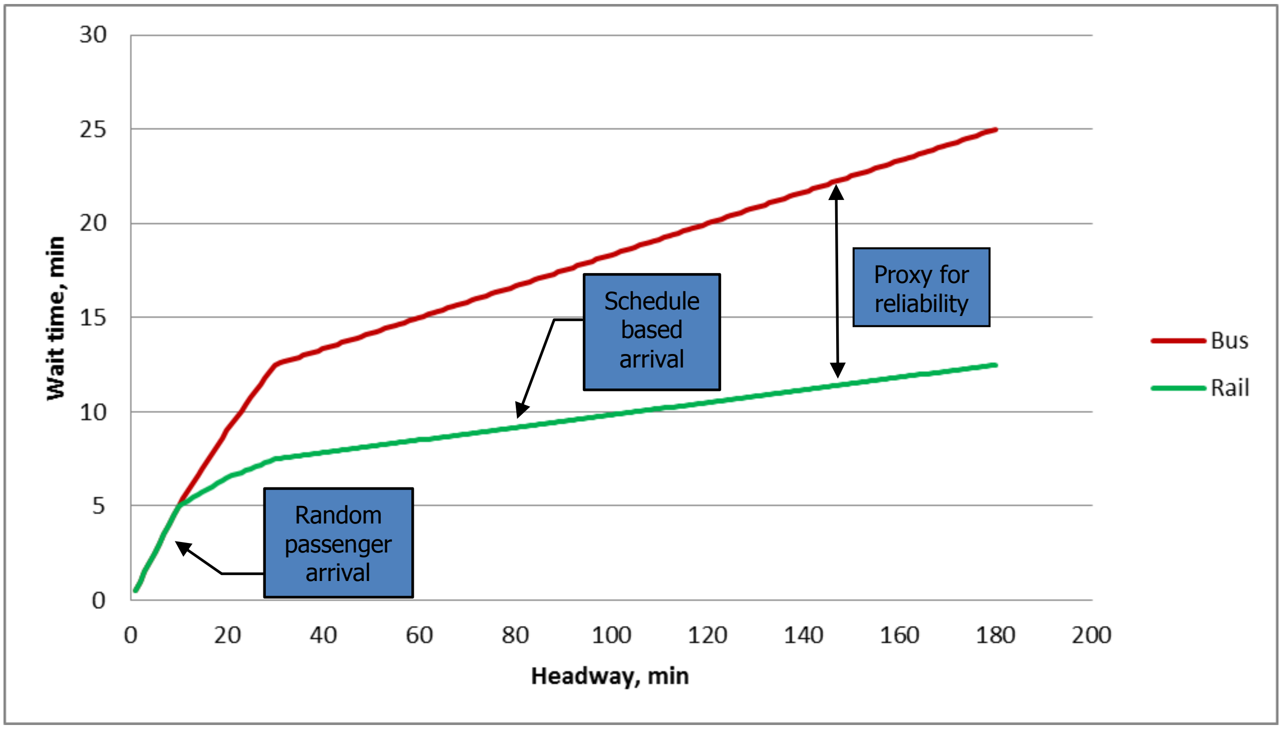
Transit assignments and skimming procedures are organized in the following way. First, basic pure transit modes with walk access are processed with the following networks:

- <u>Local Transit</u> assignment and skimming including regular bus only
- <u>Premium transit</u> assignment and skimming including all transit modes (rail, LRT, regular bus, express bus,); this allows to take into account multiple trips where different transit modes are combined and regular bus serves as a feeder mode to premium modes; the specific attraction of the premium modes in terms of reliability is taken into account in the mode choice model by having the in-vehicle time split by stop density and Transitway proportion. It should be taken into account that the EMME transit assignment algorithm allows for multiple paths of which some might deviate to local transit & walk only.

In the updated TRANS Model, the following specific features were added to the transit assignment procedures that are not parts of a standard EMME assignment (both require some equilibrating):

- Apply Strategy Transit Assignment with Variants (5.32) that is a new option available with EMME:
  - Cost attributes can be specified for boarding, in-vehicle, and auxiliary transit time components
  - Perception factor of each time and cost component can be element-specific
  - Time and cost matrices can be saved separately
- Non-linear (piece-wise) wait time functions instead of the half-headway with maximum (that is especially relevant for better modelling of infrequent transit services) as well as skimming the transit vehicle load factor as a proxy for probability of having a seat. Exhibit 3-11 shows the wait time function for buses and rail to account for schedule based arrival of passengers.

Exhibit 3-11 | Wait Time Function



The wait time function is calculated based on the equation below.

$$\mathrm{WaitTime} = \min[\alpha_1.\mathrm{Hdwy}, \alpha_1.\beta_1 + \alpha_2.(\mathrm{Hdwy} - \beta_1),\ \alpha_1.\beta_1 + \alpha_2.\beta_2 + \alpha_3.(\mathrm{Hdwy} - \beta_1 - \beta_2),\ \alpha_1.\beta_1 + \alpha_2.\beta_2 + \alpha_3.\beta_3 + \alpha_4.(\mathrm{Hdwy} - \beta_1 - \beta_2 - \beta_3)\ ]$$

Equation 139

where,

$\alpha_1, \alpha_2, \alpha_{3,}\ \alpha_4$ = the slopes for the 1st, 2nd 3rd and 4th segments (The first segment represents high frequency transit and the fourth segment represent very low frequency transit service.

The values of slopes are shown in Table 3-13. $\beta_1, \beta_2, \beta_3$ are the length of the 1st, 2nd and 3rd segments. Currently, the values are set to 10 minutes for each of the segments.

Hdwy = headway of the transit service

Table 3-13 | Parameters for Wait Time Function

Parameter	Transit Service Type	
	Bus	Rail
α_1	0.5000	0.5000
α_2	0.4000	0.1500
α_3	0.3500	0.1000
α_4	0.0833	0.0333

- Capacity-constrained assignment through wait time functions / boarding penalties defined as shadow prices for overloaded lines; Exhibit 3-12 shows an example how capacity constraining is applied at boarding nodes and not for each transit segment.

  Effective headway function is applied on top of the non-linear wait time function before calculation of combined headways. It imposes additional equilibrium conditions:

  - Effective headway is equal to actual headway if segment is underutilized
  - Effective headway is greater than or equal to actual headway if segment is fully utilized

The effective headway (Hdwy_i^s) for a given iteration (i) is calculated based on the following equation:

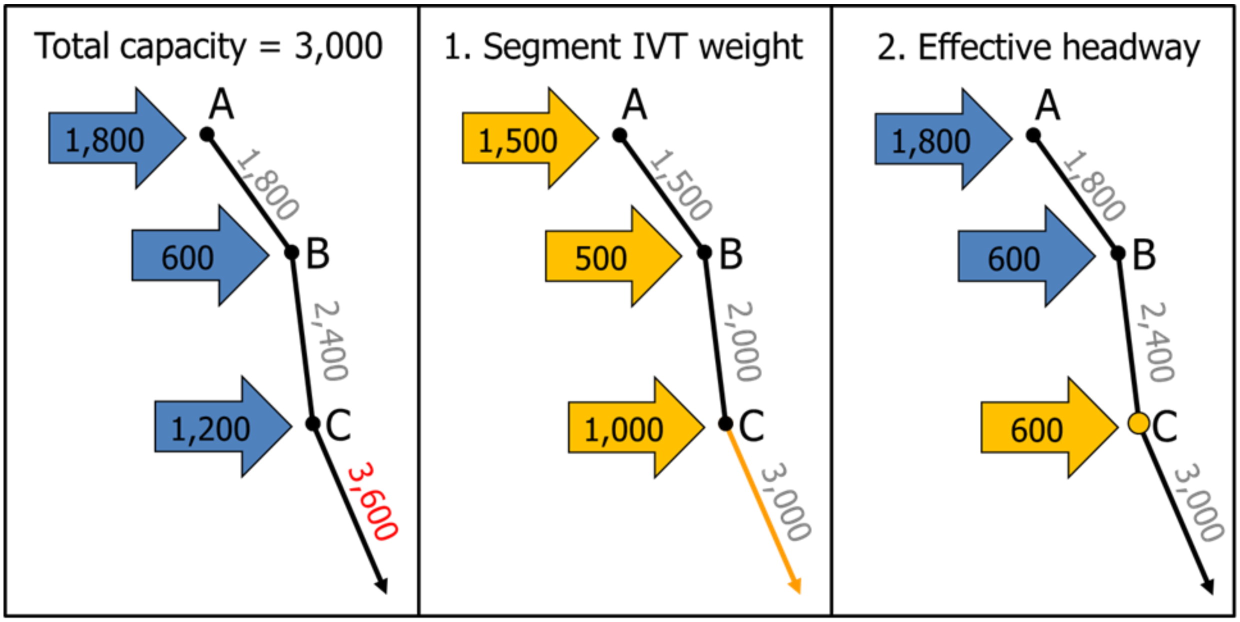
$$\mathrm{Hdwy}_i^s = \max\left[\mathrm{Hdwy}_{i-1}^s, \mathrm{Hdwy}_{i-1}^s \times \min\left(\frac{\mathrm{Board}+1}{\Delta\mathrm{Cap}+1}, 3\right)\right]$$ Equation 140

where,

Board = Number of segment boardings,

ΔCap = Total capacity - segment transit volume + number of segment alightings,

Exhibit 3-12 | Capacity Constrained at Boarding Nodes and Not by Segments



- In-vehicle time perception factors in transit assignment accounts for the following:
  - Convenience of Transit service – the factor takes a value between 0.90 -1.00 for different transit services based on convenience and quality of service.
  - Productivity Bonus for seated passengers – some of the transit services are convenient for seated passenger to work on board. This improves the perception of travel time since passengers could use the transit time more productively. Currently, a 10% reduction in transit in-vehicle time is considered for express buses, BRT and LRT modes for seated passengers only.
  - Crowding of the transit vehicle makes the ride uncomfortable for both seated and standing passengers; Standing passengers are affected more strongly than the seated passengers. The function, defined for both seated and standing passengers, increases the perceived in-vehicle time as the crowding levels increase. Exhibit 3-13 shows the crowding function based on the equation below.

$$\text{Crowd} = \left[\frac{\left(\gamma_1+\alpha_1 \cdot \left(\frac{V_t}{C_t}\right)^{\beta_1}\right)\times N_{seat}+\left(\gamma_2+\alpha_2\left(\frac{V_t}{C_t}\right)^{\beta_2}\right)\times N_{stand}}{N_{seat}+N_{stand}}\right] \quad \text{Equation 141}$$

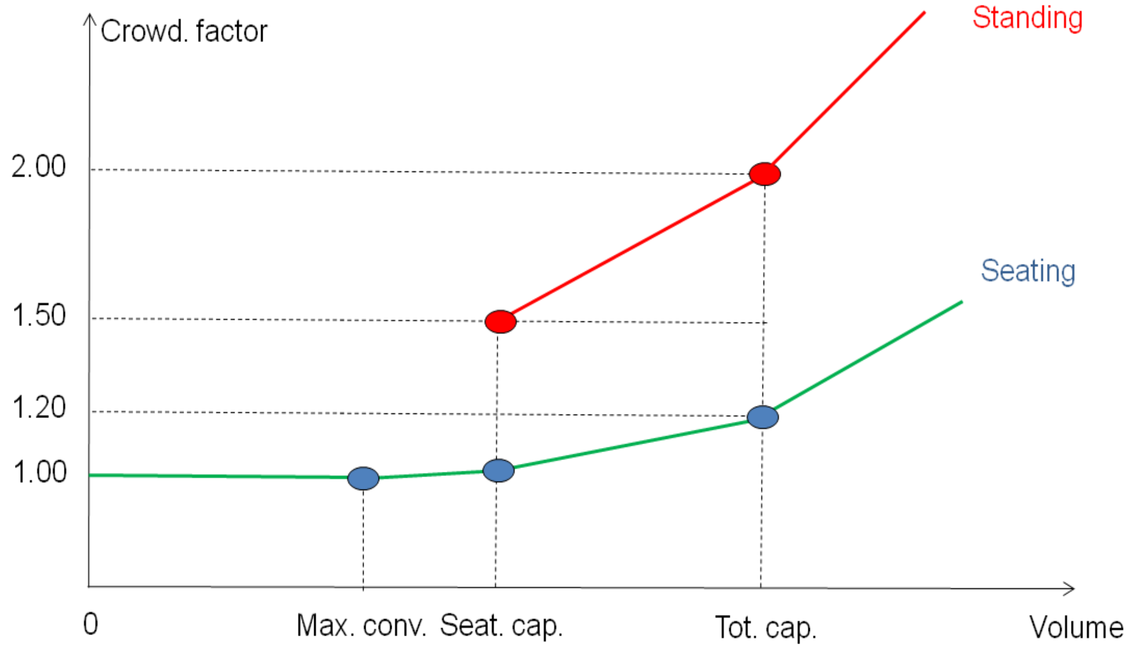
where,

V_t	=	transit segment volume,
C_t	=	transit segment capacity,
N_{seat}	=	number of seated passengers,
N_{stand}	=	number of standing passengers,
γ_1, γ_2	=	IVT weights under ideal conditions for seated (1.0) and standing (1.2) passengers,

α_1, α_2 = additional IVT weights at full capacity for seated (0.2) and standing (0.5) passengers,

β_1, β_2 = curves for seated (2) and standing (3) passengers,

Exhibit 3-13 | Crowding Function for Seated and Standing Passengers



Park & Ride, Kiss & Ride and Bike & Ride modes were modelled explicitly with each trip broken into an auto/bike leg and transit leg each added to the corresponding demand matrix (auto, bike or transit). Thus no specific bi-modal assignment is needed. The bi-modal LOS skims area created by convoluting the auto or bike access/egress skims and transit skims through the available parking lots as described in the Subsection 3.9.2 above.

The main features and parameters used in the transit assignment and skimming procedures are summarized in Table 3-14 below.

Table 3-14 | Transit Assignment and Skimming Procedures

Parameter / feature	**Within mode choice model loop**		**Final ridership**	
	For local transit skimming	For premium transit skimming		
	Local	Premium	Local	**Premium**
New or add volumes	New	New	New	Add
Demand matrix	WLoc	WPrem	WLoc plus local transit legs from P&R, K&R and B&R	WR plus premium transit legs from P&R, K&R and B&R
Total transit time	Skim	Skim		
Total in-vehicle time	Skim	Skim		
Premium IVTT		Skim		

Parameter / feature	Within mode choice model loop: For local transit skimming	Within mode choice model loop: For premium transit skimming	Final ridership	
	Local	Premium	Local	Premium
Walk time	Skim	Skim		
Initial Wait Time	Skim			
Transfer Wait Time	Skim	Skim		
Total boardings	Skim	Skim (rail and bus)		
Transit modes for path building	Regular Bus (osh)	Rail (rl), Regular and Express Bus (oshefg)	Regular Bus (osh)	Rail (rl), Regular and Express Bus (oshefg)
Auxiliary modes	Walk (p)	Walk (p)	Walk (p)	Walk (p)
Active modes for skimming	Same as for path	Same as for path		
Source for wait time	Effective Headway	Effective Headway	Effective Headway	Effective Headway
Maximum	30 min	30 min	30 min	30 min
Source for boarding time:	Extra attributes:	Extra attributes:	Extra attributes:	Extra attributes:
- node-specific	@timbf (0.5-1)	@timbf (0.5-1)	@timbf (0.5-1)	@timbf (0.5-1)
- line specific	@tboa	@tboa	@tboa	@tboa
Wait time weight	@wconv (2-2.5)	@wconv (2-2.5)	@wconv (2-2.5)	@wconv (2-2.5)
Walk time weight	2.0	2.0	2.0	2.0
Node boarding time perception factor	@perbf	@perbf	@perbf	@perbf
Lines boarding time perception factor	1.0	1.0	1.0	1.0
IVTT perception time factor	@ivtf1	@ivtf1	@ivtf1	@ivtf1
Boarding costs	@fare	@fare	@fare	@fare
Boarding cost perception factor (1/VOT, min/cent)	0.06 (equivalent of $10/hr)	0.06 (equivalent of $10/hr)	0.06 (equivalent of $10/hr)	0.06 (equivalent of $10/hr)
Additional options	Yes	Yes	Yes	Yes

3.11 TRANS Population Synthesizer

3.11.1 Purpose of Population Synthesis

A TRANS Population Synthesizer was developed by the Project Team to consolidate various sources of information on population in the modelled area (control zonal targets, household distribution from the OD Survey, etc.) and produce a multidimensional distribution of households in each zone that then serves as input to the travel demand model. It is an additional model component that is implemented in JAVA and is external to the core demand model implemented entirely in EMME environment. The Population Synthesizer needs to be run for each target year (base or future) and/or socio-economic scenario associated with different zonal controls.

It should be noted that the concept of Population Synthesis has been developed and applied with the new generation of Activity-Based Tour-Based travel demand models that need a virtual list of individual households and persons for microsimulation of individual travel choices. As was explained in Section 3.1 above, the TRANS Model represents an intermediate construct that includes certain advanced features of the Tour-Based models but is still implemented in an aggregate fashion. Thus, the list of individual households is not needed. However, the developed technique of Population Synthesis is still beneficial for consolidation of the different data sources and zonal targets / controls. The only difference in application of the Population Synthesizer for the current version of the TRANS Model versus Activity-Based microsimulation models is that the list of weighted households in the sample is converted into zonal household distributions needed as the structural input for the core demand model as was explained in Subsection 3.1.3 above. For a truly Activity-Based microsimulation model, a list of individual households would be created. Thus, the developed Population Synthesizer would be a useful component for future enhancements of the TRANS Model system and migrating to advanced Activity-Based model structures.

3.11.2 Input Data – Zonal Controls

Zonal controls correspond to the basic population forecast and socio-economic characteristics discussed in Subsection 2.2.4.1 above. The following data are available for each TAZ ($i \in I$):

- Total population (P_i) subdivided by age brackets (P_i^a):
    - 0-4 years old ($a = 1$)
    - 5-14 years old ($a = 2$)
    - 15-24 years old ($a = 3$)
    - 25-44 years old ($a = 4$)
    - 45-64 years old ($a = 5$)
    - 65+ years old ($a = 6$)
- Total number of households (H_i) subdivided by:
    - Size (H_i^s):
        - 1 person ($s = 1$)

- 2 persons ($s = 2$)
- 3 persons ($s = 3$)
- 4-5 persons ($s = 4$)
- 6+ persons ($s = 5$)

- Dwelling type (H_i^d):
  - Detached, semi-detached, low-stories ($d = 1$)
  - Apartment ($d = 2$)
- Income (H_i^j):
  - Income Less than $30,000
  - Income from $30,000 to $59,999
  - Income from $60,000 to $89,999
  - Income $90,000 or more
- Number of Workers (H_i^w):
  - Number of Workers = 0
  - Number of Workers = 1
  - Number of Workers = 2
  - Number of Workers = 3+

- Total employed labour force (number of workers by place of residence) (L_i) - this control was part of the original population synthesizer and has been replaced with household distribution by number of workers. However, this control has been retained in case the user would like to use this during running of population synthesizer.

3.11.3 Input Data – Seed Households from OD Survey

The OD survey provides a set of households ($n \in N_i$) for each zone with the following characteristics:

- From the household file:
  - Household size (s_n)
  - Household dwelling type (d_n)
  - Household income (i_n)
  - Number of Workers (w_n)
- From the person file:
  - Number of workers ($\tilde{w}_n$)
  - Number of persons in each age bracket (p_n^a)

Preparation of these data items from the OD Survey requires joining and processing the original household and person files. Household and person records that contain the relevant items as missing/ unknown / unclassified should be excluded. The whole household is excluded if one of the persons has a missing item.

3.11.4 Output Data Format

The output file contains a multi-dimensional distribution of households in each zone by size, number, of workers, dwelling type and income group (H_i^{swdj}). Age distribution of population is not included as an output variable but it has an impact on the household distribution through the correlation between the age and other variables (household size, number of workers, and dwelling type) captured in the balancing procedure. Population distribution by age (P_i^a) will be used in several travel models along with the household distribution.

The proposed household distribution includes the following 168 feasible combinations listed in Table 3-15 below.

Table 3-15 | Household Categories

Category	Household size	Number of workers	Dwelling type	Income Group	Code
1	1	0	1	1	
2	1	0	1	2	
3	1	0	1	3	
4	1	0	1	4	
5	1	0	2	1	
6	1	0	2	2	
7	1	0	2	3	
8	1	0	2	4	
9	1	1	1	1	
….	….	….	….	….	….
….	….	….	….	….	….
…..	…..	…..	…..	…..	…..
160	6+	2	2	4	
161	6+	3+	1	1	
162	6+	3+	1	2	
163	6+	3+	1	3	
164	6+	3+	1	4	
165	6+	3+	2	1	
166	6+	3+	2	2	
167	6+	3+	2	3	
168	6+	3+	2	4	

In the output file the number of households (H_i^{swdj}) for each category is listed for each zone in the following format (Table 3-16 below) with 1 key field (TAZ) and 168 data fields by household categories:

Table 3-16 | Output file format for synthetic household distribution

TAZ	S1W0D1I1	S1W0D1I2	S1W0D1I3	…
1	10	10	15	…
2	5	6	20	…
3	0	0	0	…
4	0	0	0	…
5	3	3	6	…
…	…	…	…	…

Additionally, the population synthesis procedure provides an expansion factor (ω_n) for each individual household in the list that can be used for tabulating additional distributions if necessary.

3.11.5 Steps of Population Synthesis Algorithm

The algorithm includes 4 successive stages:

- Create ***synthetic seed sample of households*** in each zone with non-zero target population,
- ***Meta-balancing*** (logical checks for zonal controls) for each zone with non-zero target population,
- ***Balancing of households*** in the seed sample with zonal control targets,
- ***Tabulating of multi-dimensional household distribution*** for each zone.

Each stage is described in detail below.

3.11.6 Synthetic Seed Sample of Households

The purpose of this stage is to create a representative sample of households (N_i) in each TAZ that will be subsequently used as a seed in the balancing procedure. The OD survey provides a sample of 25,300 households (however, the sample size will be reduced by at least 10% exclusion of households with missing household/person information). Taking into account that the number of TAZs is about 672 this will lead to approximately 35 households per TAZ.

To ensure convergence of the balancing procedure with any controls, the seed sample should have at least one household for any of the 168 possible combinations of household size, dwelling type, household income categories (1,2,3,4) and number of workers category (0,1,2,3+) as well as have representative persons in each age bracket $a = 1,2,\ldots 6$,. Taking into account that we have 168 household categories, and with the addition of all-age-brackets coverage requirement, many zones might not have a sufficiently large sample.

To overcome this problem the following algorithm is suggested for building representative seed samples. The algorithm is built on the principle of adding (similar) households from the adjacent zones. It requires a definition of a hierarchical geographical structure that should include the following 3 levels:

- 672 TAZs ($i \in I$)
- 100-150 superzones ($j \in J$)
- 20-40 districts ($k \in K$)

The geographical hierarchy should be built based on the following principles:

- maximum socio-economic homogeneity within aggregate zones and districts
- ensuring a size of 5,000 inhabitants (2,000 households) in each aggregate zone
- ensuring a size of 20,000 inhabitants (8,000 households) in each district
- obeying the basic geographic subdivision (Ontario, Quebec, Ottawa CBD)

The algorithm is applied for each TAZ with non-zero population and includes the following successive stages:

1. Identification of the list of households in the TAZ in the OD survey (N_i)
2. Identification of non-zero marginals (control targets) by household size ($H_i^s > 0$)
3. Identification of non-zero marginals (control targets) by dwelling type ($H_i^d > 0$)
4. Identification of non-zero marginals (control targets) by income group ($H_i^j > 0$)
5. Identification of non-zero marginals (control targets) by number of workers ($H_i^w > 0$)
6. For each combination (s, d, w, n) of non-zero marginals check if there is at least one household in this cell; if not go to 9. There are some zones which do not pass this test.
7. Identification of non-zero marginals by person age groups ($P_i^a > 0$)
8. For each non-zero age marginal check if there is at least one person of this age in the households; if not go to 8
9. If there is a problem, expand the geography to the next level up and go to 2.
10. If no problem, go to the next zone

As the result, an expanded list of households will be created for each TAZ. Large TAZ will probably have enough households in the original sample. For small TAZ, the aggregate zone (or district) will provide the seed sample of households. It is expected that the call for the district level will happen rarely.

The output file has the following format shown in Table 3-17 below (also convenient for the subsequent balancing procedure):

Table 3-17 | Synthetic sample of households

TAZ	HHID	S1	S2	S3	S4	S5	S6	W0	W1	W2	W3	I1	I2	I3	I4	D1	D2	A1	A2	A3	A4	A5	A5	Exp
1	1				1					1				1		1			2	1	1			20.0
	…																							
2	…																							
	…																							
	…																							
	…																							

The table contains the following data items:

- TAZ (i)
- List of households IDs in each TAZ after expansion ($n \in N_i$)
- Boolean indicator of the household size ($s_n = 0{,}1$); in the table for the 1st household it is assumed 4 persons
- Number of workers (w_n); in the table for the 1st household it is assumed 2 workers
- Boolean indicator of the dwelling type ($d_n = 0{,}1$) in the table for the 1st household it is assumed a detached type
- Boolean indicator of the household income ($i_n = 0{,}1$) in the table for the 1st household it is assumed as income between $60,000 and $89,999
- Number of persons in each age bracket (p_n^a); in the table for the 1st household it is assumed that there are two children 5-14 years old, one person 15-24 years old, and on person 25-44 years old
- Original household expansion factor (ω_n); in the table for the 1st household it is assumed equal to 20

3.11.7 Meta-balancing of Controls

The purpose of meta-balancing is to ensure consistency amongst the controlled targets themselves for each TAZ. If the targets are not consistent the balancing procedure cannot work and will never converge. In the current version of the population synthesizer, we only implement logical checks with no automatic balancing. The reported inconsistencies are supposed to be fixed manually and the software stops after reporting of inconsistencies. The following logical checks are applied for each zone:

- Total number of households should be equal to a sum over the distribution by household size,
- Total number of households should be equal to a sum over the distribution by household size,
- Total population should be equal to a sum over the distribution by age brackets,
- Labour force should not exceed the total population,
- Number of households should not exceed total population,
- Total population and number of household should either both be positive or both equal to zero.

3.11.8 Balancing of Households

The purpose of balancing is to calculate new household expansion factors (ω_n) that ensure exact match to the controlled margins. The following equations should be held for each TAZ:

Matching controls by household size (for sizes 4 and 5, a combined equation is applied):

$$\sum_{n \in N_i} s_n \times \omega_n = H_i^s$$ Equation 142

Matching controls by dwelling type:

$$\sum_{n \in N_i} d_n \times \omega_n = H_i^d$$ Equation 143

Matching the controls by household income:

$$\sum_{n \in N_i} I_n \times \omega_n = H_i^j$$ Equation 144

Matching the controls by number of workers in the household:

$$\sum_{n \in N_i} w_n \times \omega_n = H_i^w$$ Equation 145

Matching the population controls by age brackets:

$$\sum_{n \in N_i} p_n^a \times \omega_n = P_i^a$$ Equation 146

The balancing algorithm is based on Newton-Raphson method and iterates over all controls. In numerical analysis, Newton–Raphson method, named after Isaac Newton and Joseph Raphson, is a method for finding successively better approximations to the roots (or zeroes) of a real-valued function (Source: Wikipedia). This procedure is implemented with relaxation factors which allow deviation from controls targets in order to converge the balancing procedure. Different controls have different weights, which signify how much relaxation can be applied to these controls in order to better match the distributions in the sample. The procedure loops over 5 controls by household type, 2 controls by dwelling type, 4 controls by household income, 4 controls by number of workers, and 6 controls by age (at each iteration). It starts with the original expansion factors defined in the OD-Survey (ω_n) and iteratively adjust them until the reasonable match is achieved. For each control an adjustment by a single factor is applied. Below is an example of the adjustment calculation for the first category (household size equal to 1):

Calculate the adjustment factor:

$$f_i = 1 - \frac{\sum_{n \in N}(s_{in} \times \omega_n) - H_i^s \times r_i^s}{\sum_{n \in N}(s_{in} \times s_{in} \times \omega_n) + \frac{H_i^s \times r_i^s}{T^s}} \qquad \text{Equation 147}$$

Where, r_i^s is the relaxation factor for TAZ i and control s, s_{in} is a Boolean indicator if control s is true or not for the household n in TAZ i, T^s is the priority assigned for the control s.

Then, adjust the expansion factors for households of size 1:

$$\omega_n = \omega_n \times f_i \qquad \text{where } s_{in} = 1 \text{ and household n is in TAZ i} \qquad \text{Equation 148}$$

The relaxation parameter is recalculated for the zone

$$r_i^s = r_i^s \times \left(\frac{1}{f_i}\right)^{\frac{1}{T_s}} \qquad \text{Equation 149}$$

The other controls are processed in the same way. If convergence cannot be achieved within 100 iterations it is proposed to stop it after the household controls (i.e. sacrificing the population distribution by age as the least reliable control). The reason for non-convergence might be an internal disagreement between the marginal household distribution, marginal population distribution by age, and seed household distribution in the list that is difficult to diagnose in advance.

3.11.9 Tabulating of Multi-dimensional Household Distribution

This is a straightforward tabulation:

$$H_i^{swdj} = \sum_{n \in N_i} \omega_n \times s_n \times w_n \times d_n \times i_n \qquad \text{Equation 150}$$

4.0 ZONES AND NETWORK ADJUSTMENTS

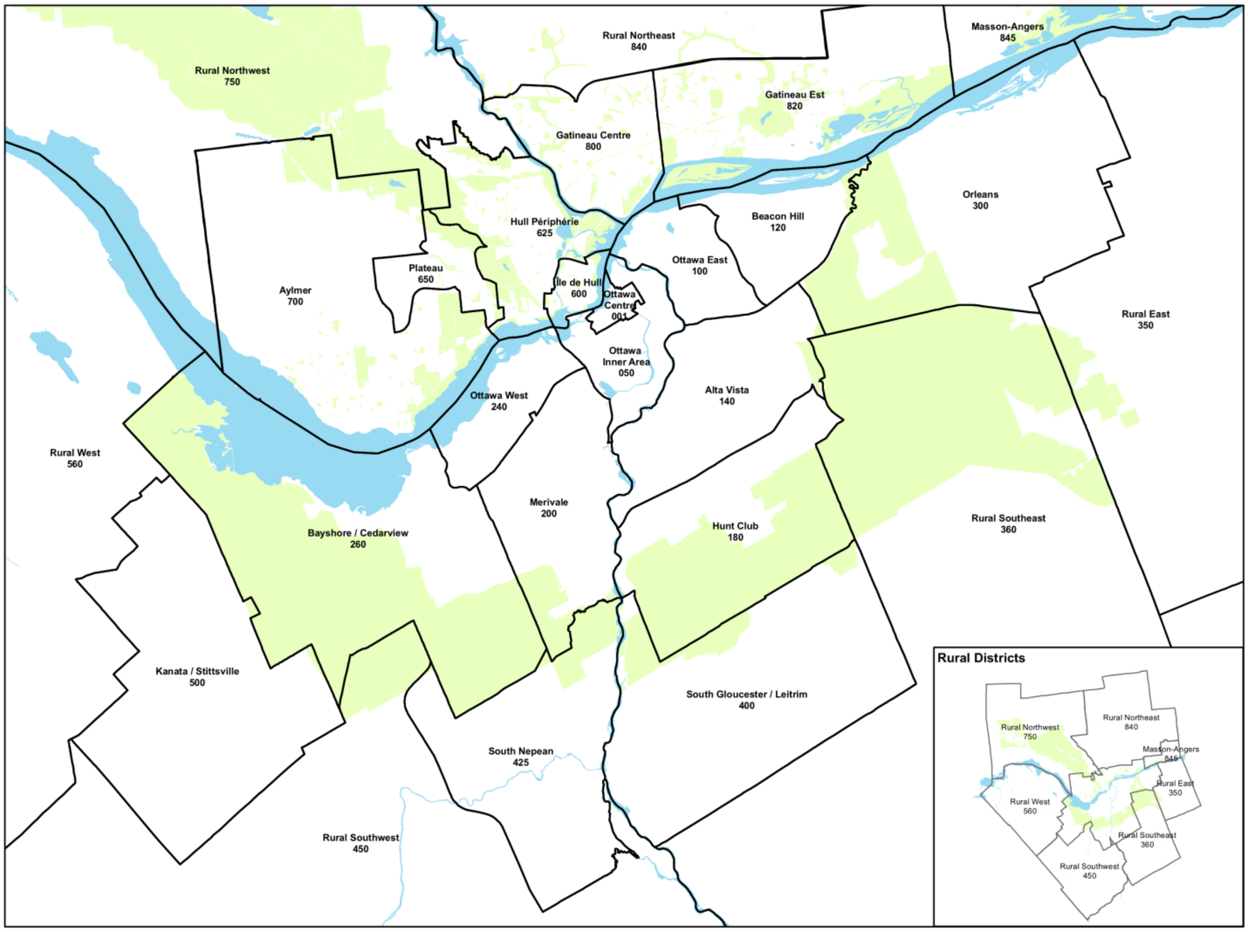
The TRANS Model traffic zone system and road, bicycle and transit networks have undergone various levels of revision and updates in recent years. A primary outcome of this review was to ensure the zone structure and their connections to the underlying transportation networks were designed:

- to enhance the uniformity of the network connections by refining the road network;
- to ensure homogenous traffic zones in terms of land uses;
- to remain relevant throughout the planning horizons;
- to update transit routes and services;
- to develop bicycle network;
- to revise/add link characteristics to refine volume delay functions

4.1 Traffic Zone Review

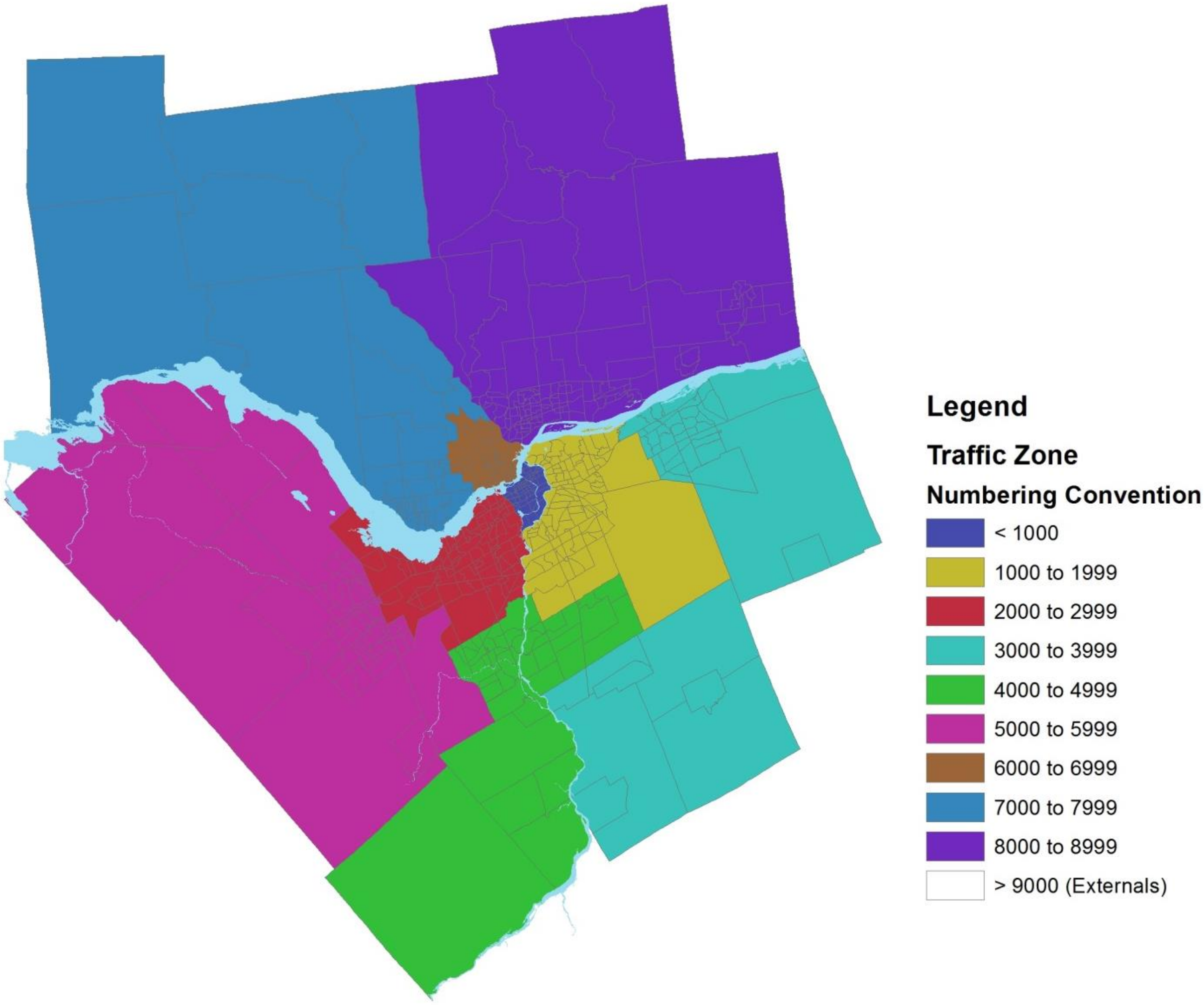
The 2005 TRANS OD Survey and 2008 TRANS Model update were based on a zone system consisting of 26 districts and approximately 600 traffic zones. In preparation for the 2011 OD Survey, this zone system was updated to create new zones and adjust zone boundaries based on development in the National Capital Region that has occurred since 2005. These modifications have resulted in a system of 701 zones, 672 representing the Cities of Ottawa and Gatineau and 29 representing external municipalities and regions. The 26-district aggregation of these traffic zones used for reporting the 2005 survey results, illustrated in Exhibit 4-1, has been maintained for this model update, with minor adjustments to district boundaries to align with updated zone boundaries.

Exhibit 4-1 | Revised TRANS District Map (2011)



The revised 701 traffic zone system maintains the zone numbering convention used in the 2008 TRANS Model; providing some spatial logic to facilitate understanding of the zone system by new and casual users. This convention uses a four digit non-continuous numbering for zones arranged by nine spatial clusters based on the first digit; traffic zone ID numbers starting between 0 and 8 encompass segments of the National Capital Region, while zone ID numbers starting with 9 are reserved for external zones. As it uses non-continuous numbering, the zone structure provides considerable flexibility in accommodating future network expansion while maintaining the numbering convention. Exhibit 4-2 provides a general layout of the traffic zone numbering system, showing each of the eight segments of the National Capital Region encompassed by each zone group.

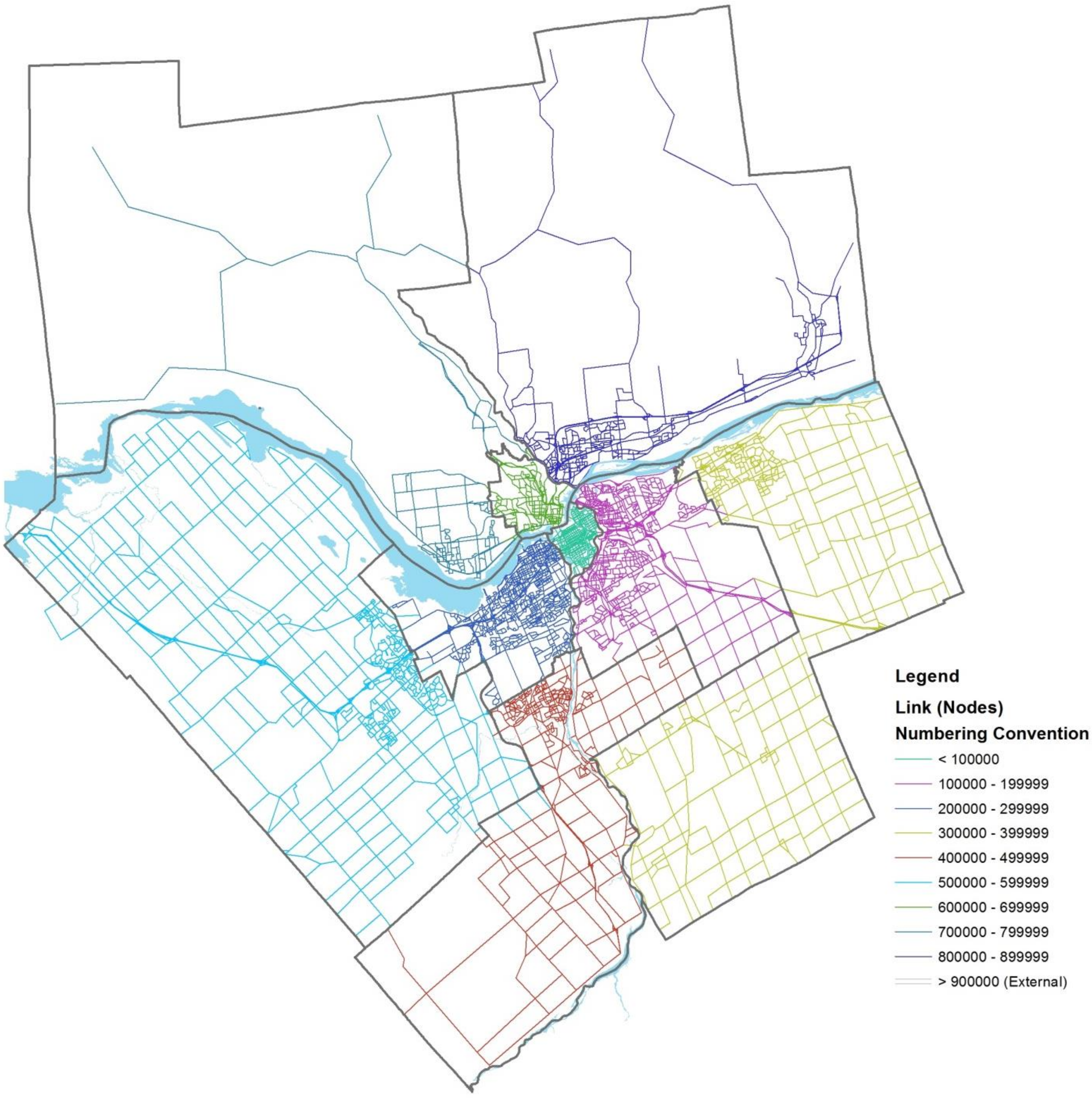
Exhibit 4-2 | TRANS Traffic Zone Numbering Convention



Traffic zones with ID numbers less than 6,000 represent the City of Ottawa, while numbers between 6,000 and 8,999 represent Gatineau.

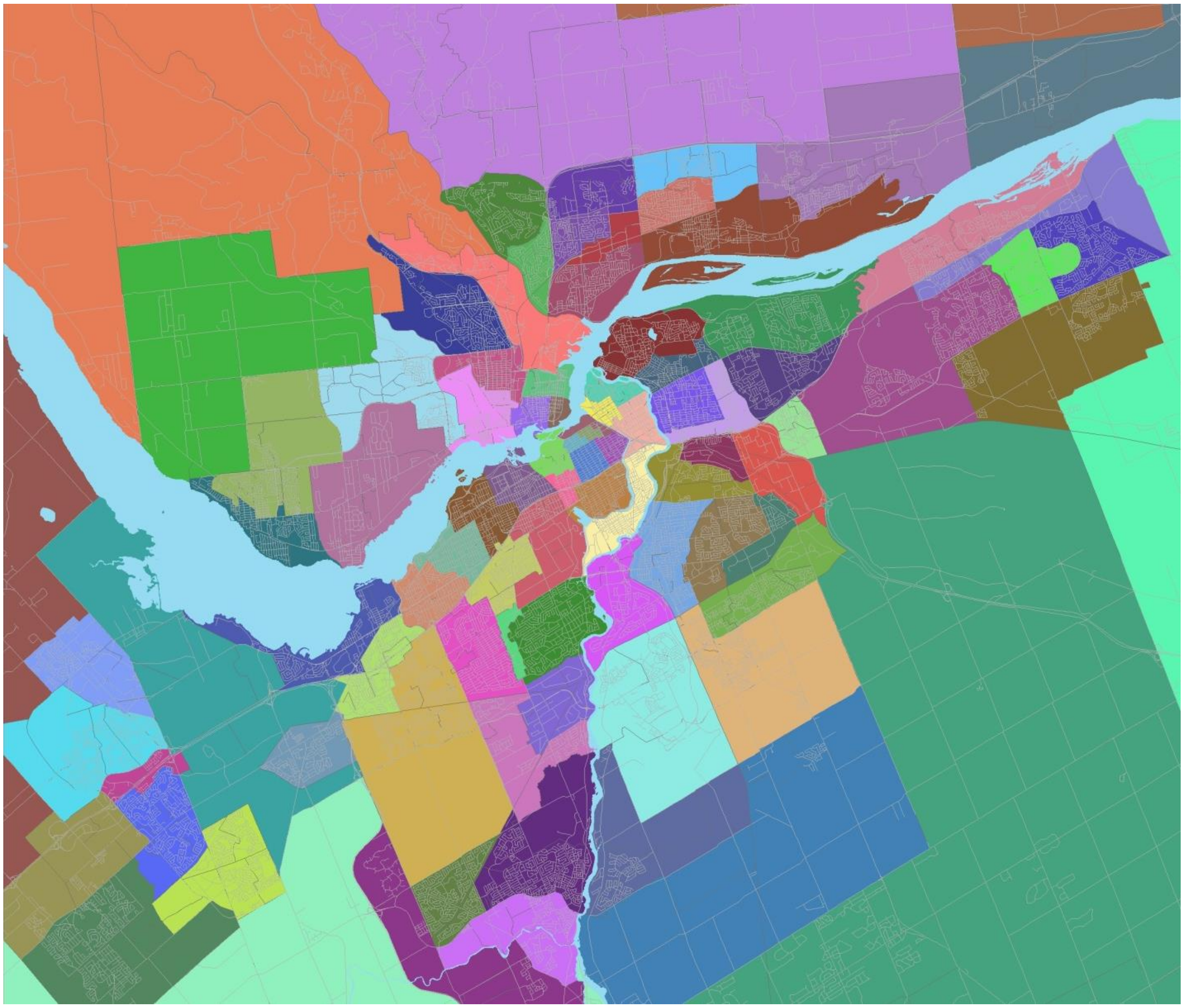
The link-node numbering convention used in the TRANS Model network has been adopted to conform to the traffic zone numbering system. In this respect, link nodes were assigned six digits with the first four being associated with the neighbouring traffic zone, again providing spatial relationships and providing a framework to facilitate modifications to the expansive transportation network included as part of the model. The 2011 network used in the model is illustrated in Exhibit 4-3, again corresponding to the eight segments established for traffic zone groupings.

Exhibit 4-3 | Revised TRANS Link-Node Numbering Convention



Often in modelling efforts, it is valuable to create spatial relationships between various groupings of geography. In many cases, the detailed traffic zone system is rolled up to a broader district level so that many of the results can be aggregated and thereby more easily digested or understood by the planner/practitioner analyzing model forecasts. To strengthen the analysis and to provide for opportunities to relate specific model parameters across smaller groups of traffic zones, the traffic zone system has been aggregated into a system of super-zones. These super-zone aggregations have been selected to combine areas of similar land use and socioeconomic features, and have been sized to target approximately 3-4 traffic zones per super-zone and 7 super-zones per district. The 2011 TRANS zone system has resulted in the creation of 94 super-zones for analysis, illustrated in Exhibit 4-4.

Exhibit 4-4 | TRANS Super-zones Map



4.2 Network Review

4.2.1 Expanding Modelled Networks

The number of nodes and links included with this new model has increased substantially over the previous model. TRANS has and continues to update its road and transit networks and include new roadway links and as such a finer road, including bicycle and transit elements include both more accurate transit modelling and smoother loading of trips on the modelled networks. Significant efforts by TRANS member agencies have been focused on developing a supporting bicycle network which includes both separate and distinct bicycle facilities as well as combined mixed operations of motorized and non-motorized travel modes.

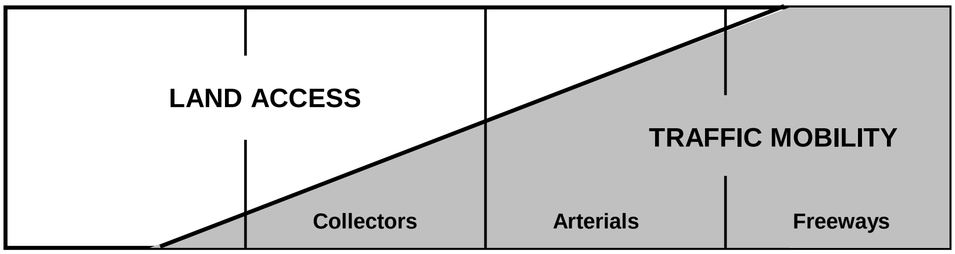
4.2.2 Link Characteristics

TRANS adopted a road network classification system in the previous model. The roadway classification system includes six (6) classes of roadways based primarily on roadway function hierarchy, following closely the Transportation Association of Canada functional classification system:

- Freeway
- Expressway
- Arterial
- Major Collector
- Minor Collector
- Local Road

This traditional functional classification system (FCS) has become the predominant method for grouping roads and also serves as a means in communicating the road's character of service. A functional hierarchy is the most common type which ranks roads according to how the roads are expected to function with respect to local through-traffic. In doing so, it recognizes that the roads form part of an interconnected network and addresses the competing road uses of mobility and access. Fundamentally, streets and highways perform two types of service, either providing traffic mobility or land access. The proportion of service they provide will determine the rank each road is assigned in the hierarchy.

Exhibit 4-5 | Typical Traffic Function versus Land Function



Defining the hierarchy in this way describes how traffic should flow in a logical and efficient manner through the network, as well as how it should operate and be managed. In the most basic form the FCS articulates information about the roads setting (i.e., urban or rural) and the extent to which it provides access to adjacent land and travel mobility.

In addition to these roadway classes three link types have been identified to address transit and non-motorized facilities as well as defining the link types used to accommodate the loading of travel demand through centroid connectors.

The table below provides some of the key characteristics identified and related to link type.

Table 4-1 | TRANS road and link types with related characteristics

ROAD TYPES

	Road Type	*Function*	*Access from/to adjacent lots*	*Median*	*Intersections*	*% Green*	*Posted speed*	*Practical speed*	*Parking*	*Bicycles*	*Pedestrians*	*Distance between intersections*
1	Freeway ("Autoroute")	Optimum mobility	None	Grass strip or New Jersey barrier	Stacked		100	70-100	None	None	None	1.6 km
2	Expressway ("Route express")	Priority to through traffic	None		Interchanges or traffic lights	> 70%	90	60-90				800 m
3	Arterial ("Artère majeure")	Priority to through traffic	Restricted (regulated)	Raised divider with opening at major intersections	Traffic lights	> 50%	80	50-90	None during peak periods	Extra width or bicycle lane	Sidewalk	400 m
4	Major Collector ("Artère mineure")	Through traffic greater than access to adjacent lots	Allowed (regulated)	Double solid line	Traffic lights or stop signs	< 50%	70	40-60	Restricted during peak periods	Allowed		200 m
5	Minor Collector ("Collectrice")	Through traffic and access to adjacent lots are similar	Free	Dashed line	Traffic lights or stop signs	< 35%	60	40-50	Allowed		Sidewalk where necessary	60 m
6	Local ("rue locale")	Access to adjacent lots greater than through traffic	Free	None	Stop signs		50	20-40				60 m

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ADDITIONAL LINK TYPES

7. Centroid connector 8. Transit Facilities 9. Non-motorized links

From a planning perspective, the widely accepted practice has been to define the capacity of roadway links based on key characteristics. In this respect, a roadway classification system (link type) is often used to define primarily the physical attributes of the roadway. Recognizing that the individual lane capacity within each of these broad groups of facility types can vary considerably, a second dimension is often employed to narrow the range in observed link capacities within these groupings. Often planning agencies have made use of the adjacent land use and its intensity as a means to better define the operating characteristics of specific roadway types.

The TRANS Agencies rather than attempting to establish the intensity of land uses for both the existing and future scenarios for individual traffic zones and relating individual traffic zones to all roadways across the network has opted to define each of the broad roadway types further based on the level of interference associated to the roadway. In this respect roadway types with differing levels of access control would relate to the various levels of interference and consequently provide a direct means to vary the lane carrying capacity within each of the broader roadway types appropriately. This approach effectively provides a lookup table (two dimensions) of roadway type and the level of interference to obtain a default vehicle capacity per lane per hour for each of the validated cells in the matrix (Table 4-2). Considering the various potential combinations of roadway elements, the following link classification scheme developed to take to account the specific variables identified such as the level of interference and traffic flow characteristics for individual links. The three digit roadway types adopted and applied uniformity across the networks was based on the following convention;

- 1st digit: link functional classification;
- 2nd digit: level of interference; and
- 3rd digit: first digit of the posted speed limits less than 100 kph; with roadways with speeds of 100 kph being coded as zero (0).

Table 4-2 | TRANS proposed roadway types and level of interference

ROAD TYPE		Level of Interference: 1 Rural / no interference	2 Low inteference	3 Medium interference	4 High interference	5 Ramp	6 Bridge
1	Freeway (Autoroute)	●	●	●	●	●	●
2	Expressway (Route Express)	●	●	●	●	●	
3	Arterial (Artère majeure)	●	●	●	●		●
4	Major Collector (Artère mineure)	●	●	●	●		
5	Minor Collector (Collectrice)		●	●	●		
6	Local (rue locale)				●		
7	Centroid Connector				●		

ROAD TYPE		1 Transitway / Bus Only	2 Rail Transit
8	Transit	●	●

ROAD TYPE		1 Multi-Use / Bike	2 Pedestrian Only	3 Transfer
9	Non motorized	●	●	●

The vehicle capacities assigned to each of the above categories is described in detail in section 4.3.1.

4.2.3 HOV Network

In order to accommodate modelling of high occupancy vehicles (HOV), the HOV network has been further defined in the following manner:

- HOV 2 (two passengers, mode “j”) and
- HOV 3 (three passengers, mode “k”)

By including separate links in the roadway network that coincide with the auto links, but are designated with mode “j” or “k” , allows the model to assign the HOV vehicles to the network and thereby offer a mode advantage using less congested links (and reduced travel time) while single occupancy vehicles (SOV) are accommodated on the regular roadway network. Attributes for these links are the same as for the typical auto links (i.e. includes type of roadway, level of interference, and posted speed).

4.2.4 Bicycle Network Development

An extensive effort has been undertaken by TRANS to develop a comprehensive cycle network in the model. Similar to the roadway network, the bicycle network is comprised of various facility types, and its attractiveness from a user perspective is somewhat dependent on a number of factors which influence the level of comfort and quality of service that can be provided for cyclists. Link attributes are therefore defined with the following information:

- Facility Type
- Pavement Condition (1 Good, 2 Bad, 3 Worse)
- Adjacent Parking (yes/no; parking width)
- Bike Lane Blockage (yes/no)
- Driveways (yes/no)
- Median (yes/no)
- Bicycle Facility Width
- Vehicle Lane Width = 3.5m default
- Curb Lane Width = 3.5m default
- Terrain (Flat, Hilly or Mountainous)
- Sight (Unrestricted site distance)

Facility types have also been expanded to include provisions for the following elements:

- Multi-use pathway – asphalt;
- Multi-use pathway – stone dust;
- Exclusive bike or separated bike lane;
- Bike lane allowed in mixed traffic;
- Paved shoulder;
- Sidewalks;
- Sharrows.

Multi-Use Pathways and/or exclusive bike lanes or separated bike lanes are coded as distinct elements separate from link provisions for motorized vehicles (road type 9 = non-motorized). This approach ensures bicycle links are not influenced by potential automobile congestion. In addition, coding practices also ensure that these links provide for interaction with the automobile network at intersections. In this respect development of key elements of a bicycle network also required attention to how cyclists operate through nodes (roadway intersections). These considerations need to reflect the potential for various levels of interaction between roadway users; vehicles and bicycles. In this respect, the network parameters were defined to identify additional information including provisions:

- Signalized intersections
- Allowable Turn Movements
- Curb to Curb Cross Street Width
- Left Turn lane (& Length)
- Right Turn Pocket
- Right Turn Lane (& Length)

Table 4-3 presents in tabular form the total number of links for each of the roadway types including the non-motorized links. The table includes the total lane-km of each link type and for each interference level presented according to the three digit link convention described in Section 4.2.2.

Table 4-3 | TRANS link type numbering system

Road Type	Level of Flow		LINK TYPE (LANE-KM)									
			Posted Speed Limit									Total
#	#		20	30	40	50	60	70	80	90	100	Lane-km
1	**Freeway (Autoroute)**											
	0	Rural / no interference									100 (482)	482
	1	Low interference						17 (3)			10 (233)	237
	2	Medium interference				25 (5)		27 (7)			20 (121)	133
	3	High interference						37 (12)			30 (8)	20
	5	Ramp			54 (25)	55 (2)	56 (135)	57 (1)				163
	Subtotal											**1,035**
2	**Expressway (Route Express)**											
	0	Rural / no interference							208 (25)			25
	Subtotal											**25**
3	**Arterial (Artère majeure)**											
	0	Rural / no interference				305 (123)	306 (265)	307 (222)	308 (1592)	309 (168)		2,370
	1	Low interference	12 (2)			15 (64)	16 (139)	17 (71)	18 (74)	19 (22)	10 (0)	373
	2	Medium interference		23 (3)	24 (1)	25 (242)	26 (273)	27 (48)	28 (3)			570
	3	High interference			34 (3)	35 (250)	36 (138)					391
	5	Ramp			54 (4)	55 (11)	56 (15)					30
	6	Bridge			64 (1)	65 (14)	66 (19)	67 (7)	68 (4)			45
	Subtotal											**3,779**
4	**Major Collector (Artère mineure)**											
	0	Rural / no interference			404 (25)	405 (137)	406 (267)	407 (183)	408 (1975)	409 (162)		2,748
	1	Low interference			14 (11)	15 (102)	16 (27)	17 (15)				155
	2	Medium interference		23 (3)	24 (25)	25 (111)	26 (10)	27 (22)			20 (0)	171
	3	High interference		33 (1)	34 (24)	35 (62)	36 (11)					98
	Subtotal											**3,171**
5	**Minor Collector (Collectrice)**											
	0	Rural / no interference			504 (1)	505 (90)		507 (102)	508 (28)			221
	1	Low interference			14 (218)	15 (214)	16 (14)	17 (11)	18 (12)			469
	2	Medium interference			24 (49)	25 (95)						145
	3	High interference		33 (4)	34 (71)	35 (193)	36 (4)					272
	Subtotal											**1,107**
6	**Local (rue locale)**											
	0	Rural / no interference				605 (8)		607 (4)	608 (1)			12
	1	Low interference			14 (1)	15 (0)						1
	2	Medium interference		23 (1)		25 (1)						2
	3	High interference			34 (467)	35 (1250)	36 (12)	37 (4)	38 (16)			1,750
	Subtotal											**1,765**
7	**Centroid Connector**											
	0	Rural / no interference				705 (1)					700 (1951)	1,952
	Subtotal											**1,952**
8	**Transit**											
	1	Transitway / Bus Only				815 (2)		817 (81)				84
	2	Rail Transit									20 (114)	114
	Subtotal											**198**
9	**Non-Motorized**											
	1	Multi-use / Bike	912 (1075)								910 (15)	1,090
	2	Pedestrian Only									20 (32)	32
	3	Transfer									30 (1)	1
	Subtotal											**1,122**
Grand Total												**14,155**

4.2.5 Updating Transit Network Functions

The transit route structure and associated transit itineraries are updated periodically based on existing transit services provided on each side of the Ottawa River. As noted in Table 4-3, transit only lanes are coded using ‘8’ with 2 sub-categories to distinguish between the technology used; Transitway and bus only lanes (bus operation) and rail transit (LRT operation).

It is also noted that the former TRANS Model had identified a number of transit travel time functions (TTF) for application based on different transit operating environments (i.e. Transitway links, Bus only Queensway lanes and O-Train line etc.). Transit Time Functions are mathematical relationships that relate the travel time along a particular transit segment as a function of characteristics of the transit vehicle, line and segment itself. The use of transit time functions in the TRANS Model varies by facility; functions describing operations along OC Transpo’s Transitway and other bus-only facilities are based primarily on segment length and running speed, while other functions describing transit routes operating in mixed traffic include the auto mode level of service as a measure of congestion as it affects travel speed. The 2013 TRANS Model Update included an update of the TTFs using data provided by OC Transpo. GPS running time data was provided for the routes listed below in Table 4-4, comprising a mix of Transitway and mixed traffic operations, conventional and express service, and local and long-haul routes.

Table 4-4 | OC Transpo Routes Examined for Calibration of Transit Time Functions

1	2	8	9	12	22	60
77	85	93	94	95	96	97
98	99	101	111	116	118	232

The selected routes were divided into segments with common speed and operational characteristics. Transit travel times along these segments forecast by the TRANS Model were compared to GPS travel times provided by OC Transpo, as well as forecast auto travel times from the model. This comparison showed that transit travel speeds generally fell within the hierarchy proposed as part of the 2013 Ottawa Transportation Master Plan, as summarized below in Table 4-5.

Table 4-5 | Ottawa TMP 2013 - Heirarchy of Transit Travel Speeds

Running Way	Segment Speed
Mixed Traffic Operation	1.3 * Auto Speed
Curbside Transit Lanes in Downtown	20 km/h
Curbside and Median Transit Lanes (outside of downtown)	40 km/h
Grade-separated transit rights-of-way	50 km/h
Hunt Club – Fallowfield SW Transitway	70 km/h
East and West Transitways through Greenbelt	90 km/h

In addition, as noted in the previous section transit skims were used to identify the percentage of total trip length which occurred on an exclusive right of way (i.e. the Transitway / bus lanes etc).

4.3 Volume Delay Functions

Volume delay functions (VDF) are mathematical relationships which define the sensitivity of both changes in roadway traffic volume and the overall travel time spent to travel on the roadway under prevailing conditions. For example, as roadway congestion increases with increasing traffic volume on a specific roadway with a defined roadway capacity the amount of travel delay accrued to roadway users increases accordingly. Consequently different VDF's are used for various roadway types such as a local, collector, arterial or freeway. As noted in the previous section the modelled road network had adopted a road type classification system which could be used to define VDF's based on a roadway lane capacity, free flow travel speeds as well as additional roadway features such as the level of interference.

Considerable research has focused on the precise formulation and shape of functions used to explain increases in delays based on increasing roadway congestion. The application of various mathematical formulations has resulted in a number of different shapes of the curve defined by the volume delay function. The most predominate and commonly applied mathematical formulations include:

- **S shapes** (adopted in Montreal) have typically been applied in regions where roadway congestion is experienced for lengthy periods during the commuter rush hours. The S shape function tends to dampen the impact of increasing travel times typically resulting from congested networks.
- **Conical curves** have typically responded well in carrying out travel time assessment and analysis but have not typically enjoyed the same level of success with respect to traffic assignment as poorer results are noted regarding traffic volume distribution across competing paths.
- **BPR equations** (Bureau of Public Roads) are designed to give reasonable volumes on links but in some cases travel times appear to be less reliable.

The previous modelling framework had applied VDF's based on the BPR formulation and consequently the work undertaken as part of this project built on these previous efforts with a redefined road classification system and updated lane capacities with a view of improving the BPR VDF's application within the model framework.

It is important to note that the BPR formula assumes that "coded capacity" (also called "practical capacity") is entered as the flow rate that corresponds to Level of Service "C" traffic conditions. Practical capacity is defined in this equation as 80% of the capacity. However, traffic engineers commonly define "capacity" as that service volume (e.g. flow rate) corresponding to Level of Service "E". Over the years, there has been considerable confusion about which to use and apply in the context of long range planning models. Some advocate sticking with the LOS "C" definition, while others favour adjusting the BPR equation to accommodate the LOS "E" definition.

Regardless of the approach used in defining capacity, particularly for future planning horizons it is noted that the link volumes may still exceed capacity, either during an early assignment iteration or as the final volume. The model does not actually limit the maximum volume assigned to a link based on the roadway's capacity value. Rather as the volume grows for any particular assignment iteration, the V/C ratio increases, and this reduces the link speed for the next iteration, making it less attractive as a viable route serving two specific O-D pairs, which ultimately reduces the volume assigned to the link thereby also reducing the resulting V/C ratio (this is the basic definition of "capacity restraint"). Nevertheless, in oversaturated conditions, the final V/C ratios may still exceed 1.0. In the real world, this condition is generally not achievable, as significant queuing results in reducing the volume that can be served (which is not currently simulated in most regional models). The standard BPR equation is as follows:

$$s = \frac{s_f}{1 + a \times \left(\frac{v}{c}\right)^b} \qquad \text{Equation 151}$$

where:

s	=	predicted mean speed,
s_f	=	free-flow speed,
v	=	volume,
c	=	practical capacity,
a	=	ratio of the free flow speed to the speed at capacity
b	=	parameter that determines how abruptly the curve drops

4.3.1 Lane Capacities

A review of the typical lane capacities for various roadway types is presented in Table 4-6. The lane capacities represent the range of capacities applied within each roadway classification as well as for specific location elements such as CBD. Lane capacities noted for Toronto (GTA) suggest that the GTA model makes use of the practical capacity based on a comparison of the freeway capacity of approximately 1800 pcplph with 2100 for the US data.

The NCHRP also references the FHWA as a primary source in the development of the capacities tabulated above for use with the BPR equation. Consequently both the GTA and the NCHRP appear to support the application and use of the practical capacities in defining lane capacity for various roadway types in long range planning models.

Table 4-6 | Typical Lane Capacity Values from Literature Review

US FHA[1]		GTA [2] (Toronto)	
Roadway Classification	Lane Capacity (pcphpl)	Roadway Classification	Lane Capacity (pcphpl)
Freeway	2,100 - 2,100 - 2,100	Freeway (basic - ramps)	1,800 – 1,400
		Controlled Access or Rural Hwy & Art	1,500 – 1,200
Major Arterial	1,003 - 878 - 673	Major Urban Arterial	900
Minor Arterial	920 - 805 - 617	Medium Urban Arterial	700
Major Collector	836 - 732 - 560	CBD Arterial	500
Minor Collector	669 - 585 - 448	Collector & Local	400
Local	502 - 439 - 336		

National Cooperative Highway Research Program [3]			
Roadway Classification	Lane Capacities (pcphpl)		
	CBD	Outer CBD	Rural/Residential
Freeway	1,750 (2,200)	1,750 (2,200)	1,750 (2,200)
Expressway	800 (1,000)	1,000 (1,250)	1,100 (1,375)
Two-Way Arterial (no parking)	600 (750)	800 (1,000)	800 (1,000)
One-Way Arterial (+parking)	700 (875)	650 (812)	900 (1,125)
Two-Way Arterial (+parking)	600 (750)	550 (687)	550 (687)

1 *Sample Methodologies for Regional Emissions Analysis in Small Urban and Rural Areas,* US Department of Transportation, Federal Highway Administration: The hourly lane capacity values indicated are for Rural / Small Urban / Urban area types. Several adjustment factors were used in this study to determined those capacities (lane width, heavy vehicle, approach grade, parking lane, bus blocking, area type, right turn and left turn adjustment factors)

2 *GTA AM Peak Hour Network Coding Standard*, University of Toronto, May 1998: The lane capacities indicated are AM peak hour capacities in auto vehicles per hour per lane.

3 *Predicting Air Quality Effect of Traffic-Flow Improvements: Final Report and User's Guide*, National Cooperative Highway Research Program, 2005. The lane capacities indicated are "practical capacities" which is defined as 80% of the capacity. The number in brackets (calculated by us and are included to allow for comparison with the FHA data) shows 100% of the capacity.

In addition, past work carried out by TRANS and its member agencies identified and documented a number of typical capacity values based on detailed review of observed traffic count data. The background report prepared in support of the TRANS 1995 Model Update provided typical lane capacities for a number of roadways within the National Capital Region. A review of the nominal lane capacities identified in Table 4-7 compare well with the capacity values identified through the literature review however it is noted that the freeway values appear to be more reflective of those values generally cited for freeway sections where weaving operations impact the overall available capacity. In addition the higher end of the capacity range for arterial roadways stands out as being high when compared with the data presented in Table 4-6.

Table 4-7 | TRANS Lane Capacities 1995 TRANS Model Update

Link Capacities for Selected NCR Roads[4]		
Roadway Classification	Lane Capacities (pcphpl)	Comments and Roadway Examples
Highway 417	1,800- 1,600 -1,200	little weaving-weaving-ramps
Highway	1,600 - (1,200-1,000) - 800	Rural - (Hwy 16) - Hwy 31
Parkway	1,200 -1,000 - 800	Airport Pkwy- Ottawa R & Isl Pky- Q. E. & C By Dr.
Arterials	1,200 - 1,000 – 800 - 600	Hunt Club- Merivale@Baseline- Parkdale-Wellington@Parkdale
CBD Arterials	800 – 600 - 400	Bank & Slater - Queen Street - Elgin
Collector	600 – 400	Jockvale Rd. - Percy
Local	400	
Transitway	1,400	

[4] *TRANS 1995 Model Calibration Report,* Exhibit 2.1 - Guidelines to Assign Link Nominal Capacities to NCR Roads

More recently the City of Ottawa's 2003 Official Plan Review also updated lane capacities based on a review of observed data for various roadway types. The background report which documented various lane capacities "Strategic Analysis of Travel Demand" was undertaken as part of the Transportation Master Plan. A comparison with the lane capacity data in Table 4-7 with the data presented and documented in the 2003 TMP indicates that the per lane capacities fall more in line with the ranges associated with each roadway type.

Table 4-8 | City of Ottawa Lane Capacities 2003 TMP

City of Ottawa Transportation Master Plan Background Report[5]		
Roadway Classification	Lane Capacities (pcplph)	
	1995 Ottawa TMP	Ottawa Observed
Freeway (basic - weaving)	2,200 – 1,750	n/a
Parkway (free flow-at grade)	1,200 – 600	1,700 - 1,100 – 725
CBD Arterial	900 – 600	800 – 600
Major Urban Arterial	1,000 - 900	1,300 - 800
Rural Arterial	1,000	1,500 - 1,100
Major Collector	800 - 700	1,100 - 800
Minor Collector	n/a	1,000 - 600
Local	n/a	300

[5] *City of Ottawa – Transportation Master Plan Support Projects,* Assignment 2 – Strategic Analysis of Travel Demand,

From the review of this data, lane capacities in vphpl were recommended for the National Capital Region as detailed in Table 4-9. The shading of the blocks was an attempt to indicate where the largest lane km ought to lie in an ideal system. For example, under the freeway road type it would be expected that the most lane kilometers ought to lie in the "no and Low interference groupings" (dark blue). Conversely for the minor arterial road type it would be expected that a large majority of the inventory would lie in the "low to medium interference" groupings areas indicate that there would not likely be many roadways that would qualify for these roadway types as well as the indicated level of interference. The lane capacities used in the TRANS Model for various roadway types are highlighted in Table 4-9.

Table 4-9 | Lane Capacities TRANS NCR Roadways

Level of Interference

	ROAD TYPE	1 Rural / no interference	2 Low inteference	3 Medium interference	4 High interference	5 Ramp	6 Bridge
1	Freeway (Autoroute)	2200	2000	1850	1700	1400	
2	Expressway (Route Express)	1400	1300	1200	900		
3	Arterial (Artère majeure)	1100	1000	800	600		700
4	Minor Arterial (Artère mineure)	800	700	600	500		
5	Collector (Collectrice)	700	600	550	450		
6	Local (rue locale)	600	550	450	350		
7	Centroid Connector	9999					

	ROAD TYPE	1 Transitway / Bus Only	2 Rail Transit
8	Transit	n/a	n/a

	ROAD TYPE	1 Multi-Use / Bike	2 Pedestrian Only	3 Transfer
9	Non motorized	n/a	n/a	n/a

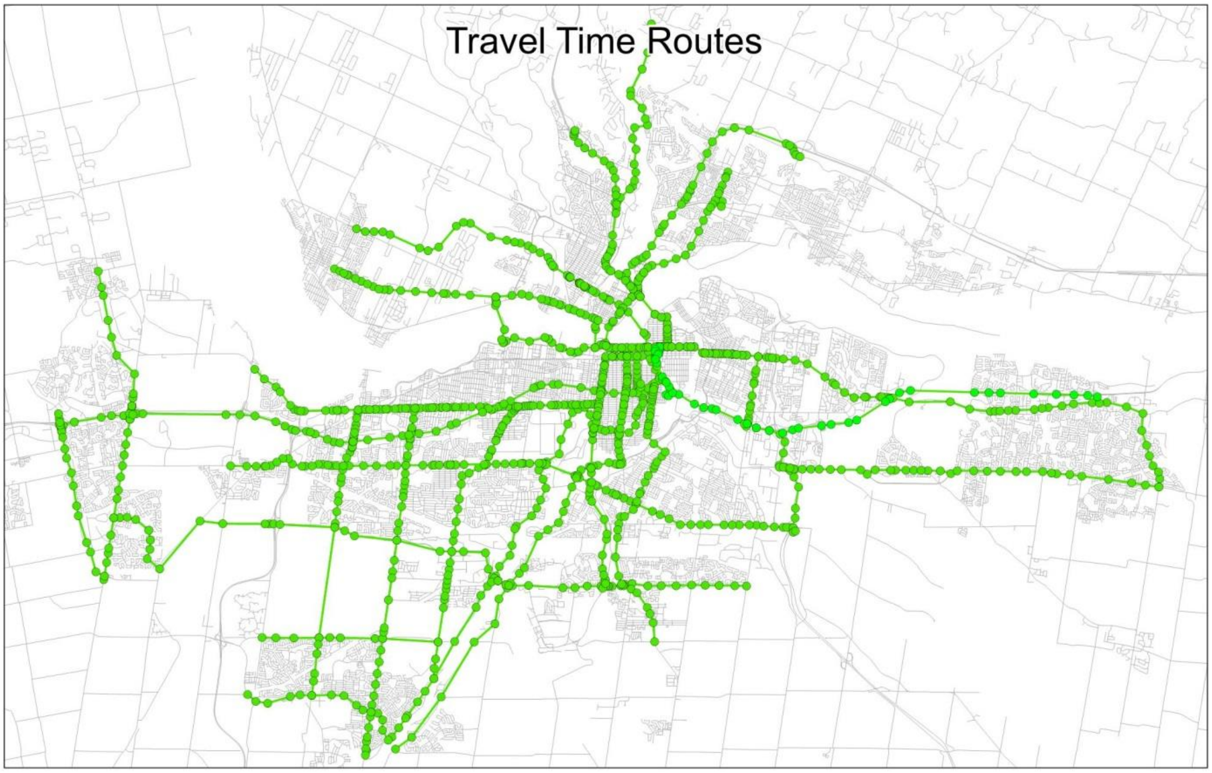
Low # → Highest #

Increasing level of Occurrence (ln-km) within Road Type

4.3.2 Travel Time & VDF Validation

The TRANS Committee commissioned a travel time survey during the fall of 2011, with a view of obtaining the existing typical peak period travel times between key origin-destination pairs. The survey identified and recorded travel times along 22 major travel itineraries and sub-itineraries in Ottawa and Gatineau, illustrated in Exhibit 4-6 below; 10 runs per itinerary were performed spanning the 2.5 hour morning and afternoon peak periods at 15 minute intervals. The results of this survey were recorded using GPS, and returned position, distance covered and running speed at one second intervals during all runs.

Exhibit 4-6 | National Capital Region Travel Time Survey Itineraries



The results of the 2011 TRANS Travel Time Survey were reviewed, analyzed and served as a good basis for carrying out a detailed validation of TRANS Model roadway link VDF functions as part of the 2013 TRANS Model update. Each of the travel time runs recorded during the survey were plotted and compared with modelled values (base year travel times) along the individual links making up the various routes surveyed and from the 2011 TRANS Model.

An example of the comparison carried out can be seen in Exhibit 4-7, Exhibit 4-8 and Exhibit 4-9 below. The figures show the survey travel times along Carling Avenue in Ottawa during the AM peak period as well as the travel time along the same corridor as modelled within the 2011 TRANS Model (bolded black line represent the modelled conditions). The travel time graphs also incorporated the assigned modelled link traffic volumes as a bar chart in the background to highlight specific areas of relatively heavier traffic along the travel itineraries that could contribute to slowdowns in either the observed traffic time runs or the modelled conditions.

Exhibit 4-7 | Example Travel Time Itinerary - Carling Avenue (Route 9)

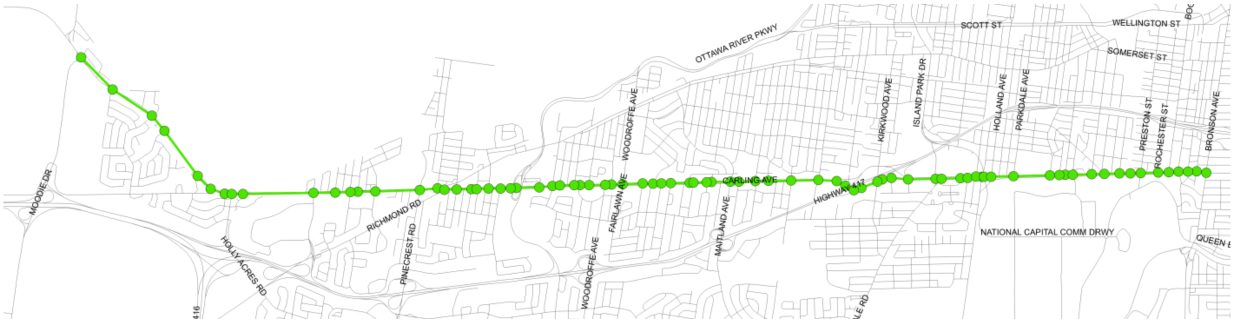


Exhibit 4-8 | Comparison of TRANS Model Forecast Travel Time versus Survey Observations (Carling Ave Inbound)

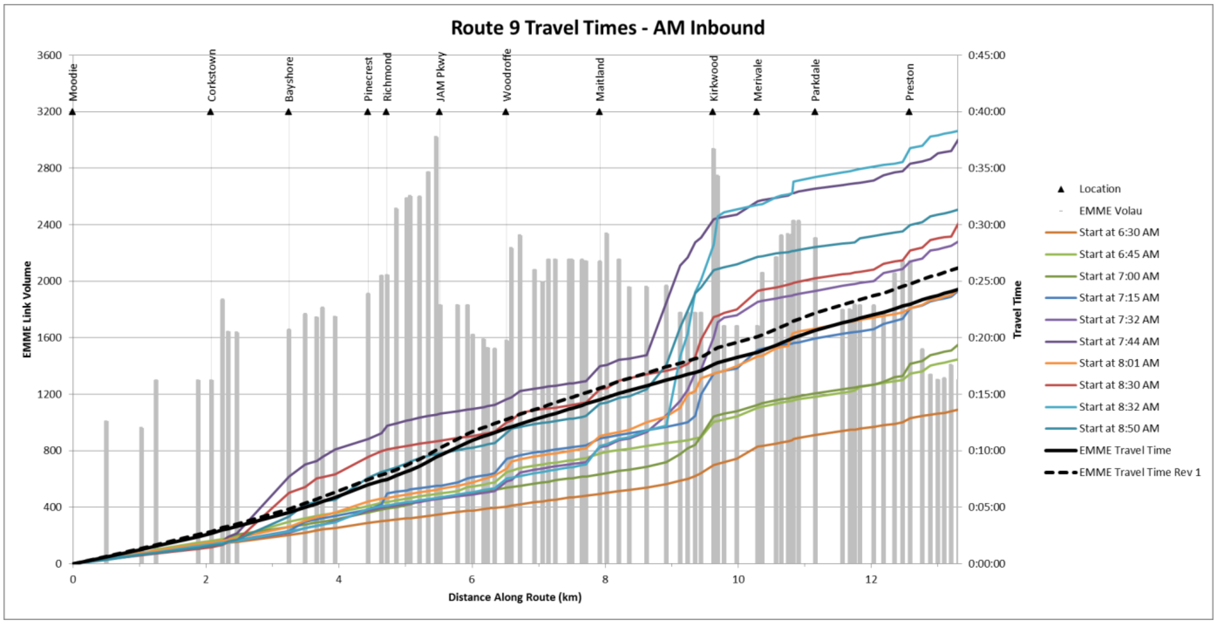
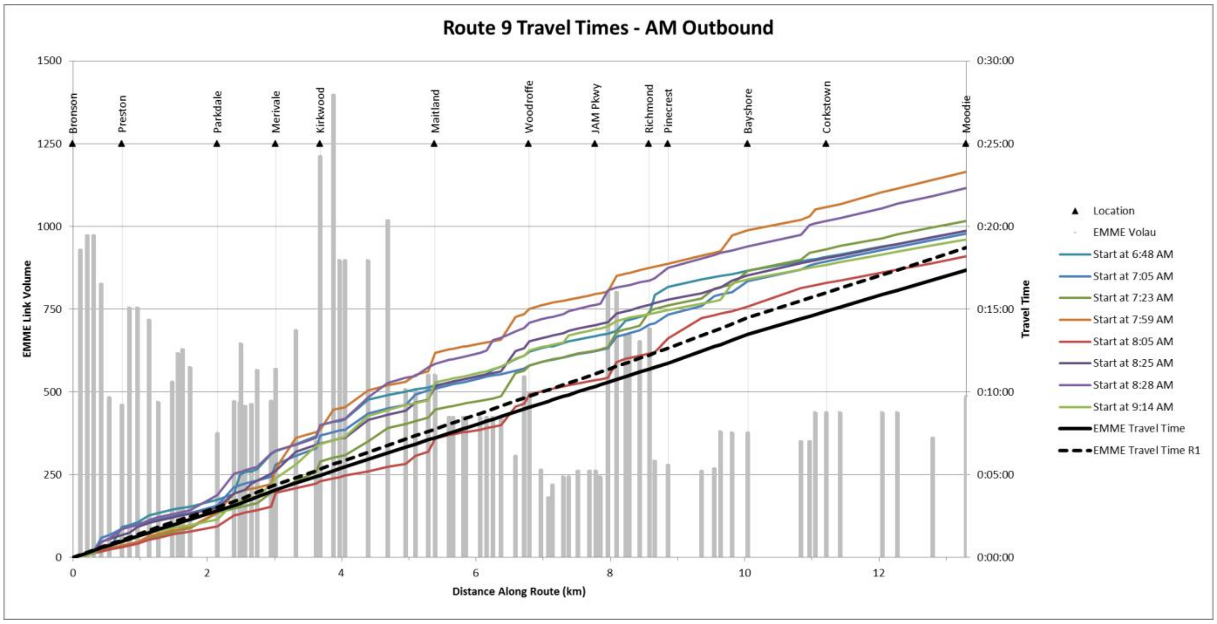


Exhibit 4-9 | Comparison of TRANS Model Forecast Travel Time versus Survey Observations (Carling Ave Outbound)



The graph indicates that moderate or significant delays are observed in reported travel times as one approaches Kirkwood Avenue, highlighting localized congestion at this location during the morning peak. Much smaller jumps in travel time can be observed in most of the survey runs on approaches to other arterial intersections. However due to the nature of the replication of the overall roadway network within the TRANS Model (links and nodes) the model reports travel time on an individual link by link basis and as such, the reported TRANS Model travel time has a more even slope as it does not reflect the variability in travel speed when approaching major intersections. The TRANS Model results are averaged across the length of the link while the survey captures and reports travel time each and every second. Despite these differences in the data stratification, this example shows the TRANS Model results (as averaged across the length of the roadway links) as having a slightly lower travel speed from the beginning of the route to Kirkwood Avenue, and a similar travel speed when compared with survey observations after that point.

Adjustments to the model were then incorporated to attempt to better represent the observed travel times. An adjustment to the length coefficient was applied (approximately 7% to 9% increase), which was equivalent to approximately a 10% reduction in the overall modelled travel speed along these specific links. The travel times resulting from this revised network were added to the graphs in Exhibit 4-8 to assess if the model better represents the observed conditions (dashed bolded line). The graphs for each trip itinerary, including the original and revised TRANS Model forecast travel times, are included as **Appendix B.1** for both the peak and non-peak direction during the AM peak period (inbound & outbound trips).

In general, the comparison between the observed and preliminary forecast travel times drew the following conclusions:

- **For AM inbound traffic** (peak direction), the travel times forecast using the TRANS Model generally represented slower operations than travel times observed in the travel survey. The modelled link travel times (i.e. VDFs as constructed) are often higher than observed because the current model framework is not constructed to reflect intersection delays and the delays are reflected in the slower average speed along the entire link. The slower travel speed was also notable on travel times inbound on all major regional Highways (417, 174, 5 and 50) and several suburban arterials.
- **For AM outbound traffic** (non-peak direction), the TRANS Model forecast travel times were more variable compared to observed travel times. The modelled travel times fell within the range of observed times on most arterial routes, although several radial routes from downtown Ottawa (via Main Street, Bronson/Airport Parkway, Carling, Greenbank and Woodroffe) were slower than those observed. As with inbound trips, forecast model travel times on the area's major highways were generally slower than those observed. It is important to note that the network and associated assignment of VDFs is carried out based on the roadway classification and consequently the VDF typically remains the same for each direction of travel and during various time of day periods.
- The visual presentation of travel times (plots) also indicated several links in the TRANS Model network where the specific VDF functions introduced significant travel time delays into the network, which were not necessarily observed in the travel time runs.

Given the above observations, adjustments to the TRANS Model network and VDF in particular, were carried out where the modelled travel time for a link was not reflective of the observed survey travel times. The adjustment to the length coefficient (approximately a 7% to 9% increase) resulted in a slight increase in the modelled travel times for those specific routes that were typically being reported by the TRANS Model as having lower travel times (faster speeds) than observed reported conditions from the survey runs. This slight adjustment resulted in the forecast modelled travel times reflecting an acceptable range of the observed travel time surveys. TRANS Modelled travel times that were initially in the high range or higher than observed travel times, however have remained high with these adjustments but can be considered a conservative approach for travel time forecasts.

Overall the adjustments were considered appropriate and aimed at ensuring the modelled travel time results are reflective of the existing conditions, despite a fairly wide range of observed travel times as reported by the survey and in general reflective of when the travel time run was made within the peak hour. Also it is recognized the modelling constraints associated with the application of a VDF to reflect intersection operations. In future, TRANS should consider the additional network modelling enhancements that can be leveraged when intersection modelling is incorporated within the overall modelling framework. The introduction of intersection network modelling may initially be advanced for key intersections that historically exhibit high levels of volume to capacity ratios and where consequently improvements to overall travel time modelling can be identified beyond what the current application of VDFs for various links.

As described previously, the assignment of VDF is based on the type of roadway and its specific attributes including link capacity and posted speed. The link capacity is a function of the roadway type (arterial, major collector…) as well as the level of interference. The naming convention for the VDF attribute in the network consists of two digits as follows:

- Link Capacity = 200 x 1st digit
- Posted Speed = 10 x 2nd digit

For example, a link with a capacity of 400 vph and 50 kph would be assigned with a VDF # of 25. The model uses these values in the BPR equation to estimate the predicted mean speed.

In addition, a review of the performance of the various VDF’s as assigned by TRANS member agencies to individual network elements does not suggest any changes to the current practices being applied by member agencies. In other words, continued collaboration and discussion among TRANS agencies is encouraged as it relates to ongoing network coding practices, as this approach has appeared to result in good results from a network coding perspective.

5.0 MODEL ESTIMATION

5.1 Accessibility Measures

A simplified mode choice model was defined to calculate the mode choice logsums for accessibility calculations. The starting LOS model coefficients are adopted based on estimated mode choice model and calibrated to produce reasonable results (and sensitivities) in the TRANS Model. The final coefficients are shown in Table 5-1. For this model, 5 modes were defined – SOV, HOV, Walk to transit, Drive to Transit and Walk, and 4 purposes (1-Work, 2-Univ, 3-School and 4- Other which includes maintenance and discretionary).

Table 5-1 | Simplified Mode Choice Coefficients for Accessibility Calculation

Utility Variables	1- Work	2- University	3- School	4- Other
SOV and HOV Modes				
Auto Congested Time (min)	-0.09	-0.10	-0.12	-0.15
SOV Cost (Distance x 0.16 $/km)	-0.60	-1.20	-1.50	-1.60
HOV Cost (Distance x 0.16 $/km)	-0.40	-0.80	-1.00	-1.00
Transit Modes				
Transit In-Vehicle Time (min)	-0.09	-0.10	-0.12	-0.15
Transit Wait time (min)	-0.18	-0.18	-0.30	-0.30
Transit -Walk Time (min)	-0.12	-0.12	-0.20	-0.25
Number of Boardings	-0.30	-0.30	-0.50	-0.30
Transit Fare ($)	-0.60	-1.20	-1.50	-1.60
Walk				
Distance (km)	-2.0	-2.0	-2.0	-2.0
Distance > 5 km	-999	-999	-999	-999

In addition to LOS coefficients, additional coefficients are defined by 3 car sufficiency types (zero cars, low sufficiency and high sufficiency). Table 5-2 shows the mode specific constants by car sufficiency types, modes and purpose.

Table 5-2 | Car Sufficiency Coefficients for Auto dependent modes

Utility Variables	1- Work	2- University	3- School	4- Other
SOV				
Zero Cars	-999	-999	-999	-999
Low Car Sufficiency	-1.5	-1.5	-1.5	-1.5
High Car Sufficiency	0	0	0	0

Utility Variables	1- Work	2- University	3- School	4- Other
HOV				
Zero Cars	-3.0	-2.0	-1.0	-3.0
Low Car Sufficiency	-2.0	-1.0	0	-2.0
High Car Sufficiency	-2.5	-1.5	-0.5	-2.5
Drive to Transit				
Zero Cars			-5.0	-5.0
Low Car Sufficiency			-5.0	-5.0
High Car Sufficiency			-5.0	-5.0
Walk				
Zero Cars			2.0	
Low Car Sufficiency			2.0	
High Car Sufficiency			2.0	

The mode choice utilities are computed for three time periods – Early (EA), AM peak and Midday (MD). A number of mode and time period choice logsums are computed during various combinations of modes and time periods as discussed in Subsection 3.2.1.

For the destination choice accessibility measures, the size variables were calculated as a linear combination of household and zone land-use variables multiplied by respective coefficients. The coefficient values are shown in Table 5-3 and Table 5-4.

Table 5-3 | Production Size variables

Variables	Regression coefficients by travel purpose				
	Work	University	School	Maintenance	Discretionary
Household Variables					
Income Less than $30,000	-0.0584	0.0683		-0.2148	0.1670
Income between $30,000 and $59,999	-0.0412	0.0205		-0.0838	0.2848
Income between $60,000 and $89,999					0.3539
Income $90,000 and more	0.0801				0.4306
1st worker in HH dummy	0.6925		-0.0807	0.2651	-0.1632
2nd worker in HH dummy	0.7106	0.0244	0.1116	0.0749	0.0261
3rd and further workers in HH (#)	0.6545	0.0665	-0.0748	0.0680	0.1201
1st non-worker in 0-worker HH dummy		-0.0523		0.6348	
2nd and further non-workers (#) in	0.0339	0.1374	0.2228	0.2662	0.0913
Non-workers (#) in 1-worker HH	0.0362	0.0910	0.3459	0.2709	0.1120
Non-workers (#) in 2-worker+ HH	0.0277	0.1087	0.5420	0.2193	0.1128
Detached Home		-0.0296	-0.0935	0.1224	

Variables	Regression coefficients by travel purpose				
	Work	University	School	Maintenance	Discretionary
Zonal Characteristics					
Population Density	0.0008				
Rental Apartments		0.00002			
District Characteristics					
Population Density		0.0006		0.0031	0.0027

The values of coefficients in the table have been estimated by means of an auxiliary regression model that used the LU variables as independent variables and expanded trip ends by travel purpose as dependent variables. These models were estimated in the same fashion as the tour production and attraction models.

Table 5-4 | Attraction Size Variables

Variables	Regression coefficients by travel purpose				
	Work	University	School	Maintenance	Discretionary
Zonal Characteristics					
Total employment	0.4228400				
Major Shops Employment in Ontario				3.1905820	
Street Shops Employment in Ontario				1.4711260	
Retail employment in Quebec	0.3252600				0.3613000
Restaurant Employmentin Ontario	0.3252600				1.0750000
Theatre Employment in Ontario	0.3252600				2.3470000
Service employment in Ontario					0.0876200
Service employment in Quebec					0.3754000
Employment in Banks in Ontario				3.3576560	
Hospital Employment in Ontario	0.4753000			0.3572630	
Health employment in Ontario				0.6944750	
Health employment in Quebec	0.3118100			0.3291050	
Office (public) employment	0.3557400			0.0352420	
Education employment	0.5024700	0.4952100	0.1526970	0.2024770	0.1592000
Total population			0.0251120	0.0315510	0.0461500
University enrollment		0.4899000			
Secondary school enrollment			0.7925740	0.1288330	0.0984600
Elementary school enrollment			0.5293050	0.2128130	
Sporting Leasable Area					0.0000832

The set of accessibility measures created for TRANS Model are summarized in Subsection 3.2.2.

5.2 Car Ownership Model

The car ownership model has been estimated as a choice model based on disaggregate household data from the OD Survey and according to specifications noted in Subsection 3.3 previously. The model estimation results are summarized in Table 5-5 below. Zero-car alternative served as the reference case with all coefficients equal to zero except for the car-sufficiency (cars vs. workers) constants. To enhance the mode analysis the car-sufficiency constants were set in such a way that the zero reference case for each household group corresponded to the number of cars equal to number of workers.

Table 5-5 | Estimation results for car ownership model

Parameters	Utility Coefficients by alternative							
	0 cars		1 car		2 car		3 car	
	Coeff	T-Stat	Coeff	T-Stat	Coeff	T-Stat	Coeff	T-Stat
Constant								
0 Worker	0.000		2.397	10.5	-3.005	-9.7	-6.329	-14.9
1 Worker	-2.141	-8.8	0.000		-3.702	-17.7	-6.640	-21.3
2 Workers	-1.049	-3.3	1.010	4.8	0.000		-2.511	-9.9
3+ Workers	-0.899	-1.5	1.101	3.4	0.213	0.8	0.000	
Number of Non-Workers								
0 Worker	0.000		0.949	9.4	2.034	17.6	2.227	16.3
1 Worker	0.000		0.551	6.7	1.250	14.3	1.411	15.1
2+ Workers	0.000		0.443	3.2	0.717	5.2	0.899	6.4
Household Income								
Less than $30,000	0.000		-3.193	-20.7	-4.380	-23.2	-4.380	-23.2
$30,000 to $59,999	0.000		-1.018	-6.8	-1.603	-9.7	-1.622	-8.6
$60,000 to $89,999	0.000		0.000		0.000		0.000	
$90,000 or more	0.000		0.465	2.5	1.237	6.5	1.397	6.9
Dwelling Type								
Detached Home	0.000		1.847	20.0	2.877	24.6	3.135	18.2
Auto Dependancy/Accessibility								
To Work Locations	0.000		4.104	9.0	4.559	9.6	4.963	9.6
To Non-Mandatory Locations	0.000		0.000		1.082	5.4	2.090	7.2
Transit Accessibilities to Non-Mandatory Locations								
Cars Less than Workers	0.202	11.7	0.202	11.7	0.202	11.7	0.202	11.7
Cars More than Workers	-0.072	-5.1	-0.072	-5.1	-0.072	-5.1	-0.072	-5.1
Zonal Densities								
Population Density	0.000		-0.0024	-2.3	-0.0023	-1.4	-0.0035	-1.4
% Detached Dwelling Units	0.000		0.000		1.133	9.0	0.822	4.5
District Densities								
Population Density	0.000		-0.0359	-9.9	-0.0544	-12.4	-0.0519	-9.5
Nesting Coefficient								
0 car vs. 1+ cars				0.900				
1 car vs. 2+ cars				0.650				

The estimation results showed that the number of cars available to the household is strongly correlated with the number of workers in the household and household income. As the number of the workers in the household increases, the likeliness of having more cars in the household also increases. The strong impact of income on car ownership is very logical. For example, in a household with income less than $30,000 a year, the likelihood of zero cars is the highest, and the probability of choosing 1 (-3.193) or more cars (-4.380) is significantly reduced due to strong negative constants. Similarly, for a high income household ($90,000+), the likelihood of having more cars is higher because of positive (increasing) constants by car ownership levels.

Other variables that further helped predict the number of cars available to a household are: the remaining number of (non-working) members of the household, whether the home is detached or not, accessibility to work and non-work locations, transit accessibility, population density of the area and the percentage of detached dwelling units in the traffic zone. Accessibilities play an important role in car ownership model. The auto dependency to work location significantly increases the probability of having at least one car in the household (4.104). However, the auto dependency does not affect the choices as strongly between 1 (4,104) and 2+ (4.559) cars. On the other hand, the auto dependency to non-work location increases the chances for the household to have 2 or more cars. Better transit accessibility to non-work locations reduces the probability of having more cars than workers in the household.

5.3 Daily Tour Generation Models

In this section, we provide summaries for the daily tour production and attraction models. It should be noted that the reported statistical fit is much better for tour attraction than for tour production since the attraction model was estimated based on 672 TAZs while the production model was based on 25,374 individual households. However, it should also be understood that in the model application, individual household productions are aggregated within each zone, and eventually the production and attraction tour totals are balanced for the region.

5.3.1 Household Daily Tour Production Model

The household daily tour production model has been estimated as a linear regression model based on disaggregate household data from the OD Survey and according to the specifications noted previously in Subsection 3.4.1 Household Daily Tour Production Model. The model estimation results for 7 travel purposes are summarized in Table 5-6 below. The regression models were estimated without intercept, i.e. no default household tour generation rate was assumed. In terms of car-sufficiency impacts, the balance car sufficiency (cars equal to workers) served as the reference case with a zero coefficient. The most significant coefficients that explain the household tour generation rate are highlighted.

The data showed that the presence of workers in the household is a very strong explanatory variable for the number of work-related tours. Also, stronger coefficients for higher income households as compared to lower income households show that higher income households generate more work tours per worker (particularly 1st worker and 2nd worker) than lower income households. Low income households probably comprises of more part-time workers which explains fewer work tours per worker in the household. University students are not explicitly defined as household members, and so, in addition to the number of non-workers in the household in relation to the number of workers, other variables are required to explain university tours: the number of cars in relation to the number of workers, and variables relating to population and employment density. The latter are used to further identify the probability of university students' location.

Table 5-6 | Estimation results for household tour production model

	Regression coefficients by travel purpose						
Variables	**Work-Low**	**Work-Med**	**Work-High**	**University**	**School**	**Maintenance**	**Discretionary**
Household Variables							
Zero Car Household	-0.0362			0.0435		-0.1812	-0.0646
Cars fewer than workers							-0.0743
Cars greater than workers						0.0641	0.1553
Income Less than $30,000				0.0567	0.0391	-0.1509	-0.1134
Income $30,000 to $59,999				0.0181		-0.0734	-0.0524
Income $60,000 to $89,999							
Income $90,000 or more							0.0696
1st worker in HH dummy	0.5729	0.7127	0.7179	-0.0540	-0.1316	-0.1024	
2nd worker in HH dummy	0.7117	0.6987	0.7425	0.0326	0.0931	0.0743	0.0444
3rd and further workers in HH (#)	0.7965	0.7352	0.6975	0.0669	-0.0777	0.0676	0.1356
1st non-worker in 0-worker HH				-0.1019		0.2379	
2nd and further non-workers (#) in 0-worker HH	0.0188	0.0215		0.1403	0.1820	0.2464	0.0990
Non-workers (#) in 1-worker HH	0.0371	0.0242	0.0493	0.0946	0.3372	0.2568	0.0781
Non-workers (#) in 2-worker+ HH	0.0402		0.0352	0.1087	0.5371	0.2125	0.1053
Detached Home				-0.0154		0.0984	
Zonal Characterictics							
Population Density		0.0007	0.0007				
Rental Apartments				0.00001			
Accessibility to Purpose Specific Location	0.0049		0.0049	0.0080		0.0646	0.0321
District Characteristics							
Population Density							0.0022
R Square	0.6135	0.7333	0.8116	0.1630	0.5531	0.4030	0.2359
Adjusted R Square	0.6121	0.7332	0.8227	0.1625	0.5530	0.4026	0.2355

Note: The most significant coefficients that explain the household tour generation rate are highlighted in red. The negative coefficients are to off-set the school tours generated because of non-worker adult in the household.

School tours are best predicted by the number of non-workers in households with one or two workers. In such households, non-workers would presumably be children, whereas non-workers in households that have no worker would most frequently be adults. For school purpose, it is important to note that children and adults are not distinguished among non-workers. The negative coefficients on worker dummy is trying to off-set the school tours generated because of non-worker adult in the household.

Maintenance and discretionary tours are also well explained by the household composition, primarily presence of workers and non-workers. It should be noted that non-workers and especially in households with no workers, are characterized by the highest generation rate for maintenance and discretionary tours. Of particular importance here is the fact that in addition to population forecast, application results of the tour generation model would be sensitive to accessibilities particularly for maintenance and discretionary tours.

5.3.2 Zonal Daily Tour Attraction Model for Primary Destination

The zonal daily tour attraction model has been estimated as a linear regression model based on the aggregated-by-TAZ tour ends (primary destinations) from the OD Survey and according to the specifications in Subsection 3.4.2 above. The regression model estimation results for 5 travel purposes are summarized in Table 5-7 below. The regression models were estimated without intercept, i.e. no default zonal tour attraction rate was assumed. The most significant coefficients that explain the zonal tour attraction rate are highlighted. All variables relate to the TAZ itself except for last two variables that relate to the district-level density.

Table 5-7 | Estimation results for zonal tour attraction model

Variables	Regression coefficients by travel purpose				
	Work	University	School	Maintenance	Discretionary
Zonal Characterictics					
Total employment	0.5986				
Major Shops Employment in Ontario				3.2893	0.3261
Street Shops Employment in Ontario				1.6259	0.5448
Other Retail employment in Ontario					
Retail employment in Quebec				2.9560	0.4549
Restaurant Employment in Ontario					1.0434
Theatre Employment in Ontario					2.3437
Other Service employment in Ontario					0.0744
Service employment in Quebec					0.3759
Service employment (restaurants, theatres and other services)				0.0463	
Employment in Banks and Post Offices in Ontario				0.0463	
Hospital Employment in Ontario				0.3512	
Health employment in Ontario				0.7310	
Health employment in Quebec				0.3263	
Office (public) employment	0.1765				
Office (private) employment					
Education employment	0.3242	0.4952	0.1527	0.2051	0.1592
High Tech Employment in Ontario					
Warehousing Employment in Ontario					
Hotel Employment in Ontario					
University enrolment		0.4899			
Secondary School enrolment			0.7926	0.1305	0.1000
Elementary School enrolment			0.5293	0.2039	
Total population	0.0136		0.0251	0.0329	0.0456
Sports Gross Area (hectares)					0.8288
Total employment x Accessibility by Purpose	0.00023				
Total Retail employment x Accessibility by Purpose				0.00018	0.000006
R Square	**0.8828**	**0.9758**	**0.8353**	**0.8365**	**0.6596**
Adjusted R Square	**0.8826**	**0.9758**	**0.8343**	**0.8363**	**0.6591**

Note: The most significant coefficients that explain the zonal tour attraction rate are highlighted in red

The data showed very robust relationships between the variables and the tour attractions, for all travel purposes except for discretionary trips (lower R square value). Work tours are very well explained by employment, with some addition of the population effect (work from home, telecommuting, etc.). The coefficient on total employment is nearly 0.6 which means that every job attracts 0.6 work tours. It might seem low at first, but the additional attraction factors on public and education employment should also be counted in an additive fashion. Since, modeling area is part of the National Capital Region, it is expected that a significant number of jobs are held in public offices which are major attractors for work tours in the region. Every public office job will attract 0.77 (0.6+0.17) work tours. University tours are very well explained by university enrolment numbers (which suggests these are very reliable and are in agreement with the observed university tours in the OD Survey) and education employment. School tours are very well explained by secondary and elementary school enrolments.

Maintenance tours are well explained by various types of employment and primarily by retail employment. As a travel attraction factor, retail employment on the Ontario side was disaggregated by major shopping and street shopping. The results show that major shopping centers attract more tours per employed person compared to street shopping locations. Maintenance tours are also explained by health employment (assuming visiting doctor or dentist that is classified as a maintenance purpose) and by school enrollment (assuming drop off / pick up children at school that is classified as a maintenance purpose). Discretionary tours are explained by retail and service employment, school enrollment (as a proxy for parks or extra-curricular activities, for instance), gross sports area (sport areas have very low employment but still attract a large number of discretionary tours) and by population: discretionary tours (which include visiting friends and family) are attracted to residential locations.

Accessibilities interacted by employment did not show significant impact on tour attractions. However, they were retained to make the model sensitive to change in accessibilities.

The total work attractions are split by income groups (low, medium and high) based on logit model. The results of the work attraction split model are summarized in Table 5-8.

Table 5-8 | Estimation results for Work Attraction Split Model

Variables	Coefficients (t-stat)		
	Work- Low	Work- Med	Work- High
Constants	-2.2417 (-11.6)		-0.0911 (-1.0)
Zonal Characteristics			
Average Income by Place of Work (in 1000s)	-0.0050 (-1.7)		0.0037 (2.8)
% Retail Employment	0.9688 (3.9)		-0.3765 (-3.2)
% Service Employment	0.7276 (3.0)		
% Education Employment	0.6251 (3.0)		
% Health Employment	0.5604 (2.7)		
% Office Public Employment			0.2651 (4.2)
% Warehousing Employment			-3.6419 (-1.5)
% Industry Employment			-0.3298 (-2.6)
% High Tech Employment	-1.3338 (-2.2)		0.9428 (6.3)
% Office Private Employment	1.1817 (2.9)		

Variables	Coefficients (t-stat)		
	Work- Low	Work- Med	Work- High
Accessibility of Total Employment	-0.0169 (-0.5)		0.0424 (3.2)
Employment Density	-0.0004 (-3.1)		0.0001 (3.9)
Population Density	0.0021 (2.0)		
Number of Observations	18,021		
Likelihood with Constants only	-14617.7322		
Final likelihood	-14347.1796		

Work medium income was used as a reference case. The data shows that the percentage of higher income work attraction in a zone increases with increase in average income by place of work. Retail, service, education and health employment tend to create more low income jobs; whereas, public office and high tech employment tends to create more high income jobs. Also, warehousing and industry employment tends to reduce high income jobs in the zone. Better accessibility to total employment and high employment density (which are proxies for CBD and more urban areas) tend to have higher percentage of higher income employment.

5.4 Pre-Mode Choice Models (Non-Walk vs. Walk)

In this section, we provide summaries for the tour pre-mode choice (non-walk (motorized and bicycle) vs. walk) models for tour productions and attractions.

5.4.1 Binary Pre-mode Choice for Tour Productions

The pre-mode choice model for tour productions has been estimated as a binary logit choice model based on the observed tour records from the OD Survey and according to the specifications in Subsection 3.5.2 above. The model estimation results for 7 travel purposes are summarized in Table 5-9 below. All variables relate to the walk utility while non-walk utility was set to zero as the reference case. This way, the coefficient values correspond to positive or negative impact on probability for the tour to be walk only. The large negative constant for walk shows that overall the share of walk tours is small compared to non-walk tours. The household variables were limited to car-sufficiency dummies since the model is applied in the TRANS Model system in aggregate fashion by household segments. The balanced car-sufficiency (number of cars equal to the number of workers) was used as the reference case (with zero coefficients) amongst car-sufficiency categories.

Table 5-9 | Estimation results for binary pre-mode choice model for tour productions

Variables	Work Low	Work Med	Work High	University	School	Maintenance	Discretionary
Walk constant	-3.7863	-5.2017	-6.5773	-4.9182	-3.8406	-3.5824	-2.9835
Household Variables							
Zero Car Household	1.0447	0.9588	0.7863		0.1771	1.2774	0.9205
Cars fewer than Workers		0.7423	0.4849		0.1771	0.2316	0.5403
Cars more than Workers	-0.1641	-0.0916	-0.4787	-0.1957	-0.1582	-0.3282	-0.1617
Zonal Characteristics							

Variables	Work Low	Work Med	Work High	University	School	Maintenance	Discretionary
Proportion of Age >= 45 yrs in population			-1.1116				
Population Density						0.0021	0.0018
Retail and Service Density						0.0100	0.0098
Elementary School Enrollments					0.0007		
Walk Accessibility	0.1697	0.3635	0.5618	0.5667	0.3707	0.2577	0.2224
Superzone Characteristics							
Product of population and employment densities		0.0150	0.1417				
Population Density		0.0062			0.0044	0.0039	
Retail and Service Density	0.0117			0.0145			
% Low Income in Ontario							0.9244
% Detached Homes		-0.5939	-0.7254		-0.6650	-0.6561	-0.7111
University enrollments				0.00001			
Secondary School Enrollments					0.0002		
Number of Observations	774	6,501	10,747	2,830	8,074	18,552	9,700
Likelihood with Constants only	-234.950	-1458.791	-1798.916	-606.572	-3767.366	-5852.770	-3425.51
Final likelihood	-217.931	-1200.607	-1263.042	-496.982	-3509.667	-5106.882	-3102.298

The walk constants are strong and negative representing lower share of walk trips compared to non-walk trips. The share of walk tours is also explained by variables such as car sufficiency (the lower is car sufficiency the higher is the walk travel probability), population age (people of age of 45 and older are less inclined to walk), densities of population, retail employment (higher densities produce more walk travel), percentage of low-income population (more inclined to walk travel) and percentage of detached houses (logical negative effect). The walk accessibilities proved to be very strong as expected. The accessibilities are a measure of access from given production zone to all attractions zones within walk distance and are scaled by tour (purpose specific) attractions in the attraction zones. A larger accessibility value shows that the given production zone has a lot of tour attractions within walking distance which will make the probability of walking to attraction zone more likely.

The share of walk school (secondary) and university tours proved, as expected, to be better explained by variables at the superzone level than at the TAZ level. On the other hand, the share of walk tours for elementary school children proved to be better explained at TAZ level. Presence of university / school in the superzone logically creates more walk travel produced by the residents. For university tours, it is also a manifestation of the residential self-choices of students living in rent apartments.

5.4.2 Binary Pre-mode Choice for Tour Attractions

The pre-mode choice model for tour attractions has been estimated as a binary logit choice model based on the observed tour records from the OD Survey and according to the specifications in Subsection 3.5.3 above. The model estimation results for 7 travel purposes are summarized in Table 5-10 below. As for the pre-mode choice model for tour production described in the previous subsection, all variables relate to the walk utility while motorized utility was set to zero as the reference case. Individual household variables cannot be used in this model since it is applied at the tour attraction end.

Table 5-10 | Estimation results for binary pre-mode choice model for tour attractions

	Walk utility coefficients by travel purpose						
Variables	Work Low	Work Med	Work High	University	School	Maintenance	Discretionary
Walk constant	-3.6806	-3.9972	-7.1522	-3.6830	-3.5129	-3.7122	-2.6799
Zonal Characteristics							
Population Density						0.0119	0.0063
Retail and Service Density						0.0019	
Walk Accessibility	0.1877	0.2154	0.5876	0.2148	0.2630	0.2011	0.1265
Superzone Characteristics							
Population Density	0.0054	0.0024	0.0021	-0.0013	0.0038	0.0015	0.0030
Retail and Service Density		0.0002		0.00250			0.0011
% Detached Homes	-0.1370	-0.4843	-0.2585			-0.4124	-0.6034
Number of Observations	773	6,501	10,747	2,830	8,074	18,561	9,696
Likelihood with Constants only	-218.310	-1458.791	-1798.916	-606.572	-3767.367	-5864.902	-3422.971
Final likelihood	-213.326	-1414.549	-1685.078	-602.394	-3685.474	-5433.920	-3271.192

Share of walk tours is explained by variables such densities of population, retail and service density (higher densities produce more walk travel at both TAZ and superzone levels of spatial aggregation), as well as percentage of detached houses (logical negative effect).

The share of walk tours proved, as expected, to be affected by walk accessibilities. The accessibilities are a measure of access to given zone from all production zones for walk mode only and are also dependent on tour productions in the production zones.

5.5 Time-of-Day and Stop-Frequency Choice Models

In this section, summaries for the time-of-day and stop frequency choice models for tour productions and attractions are provided.

5.5.1 Joint Choice of Time-of-Day and Stop Frequency for Tour Productions

The joint choice model of time of day and stop frequency for tour productions has been estimated as a multinomial logit choice model based on the observed tour records from the OD Survey and according to the specifications in Subsection 3.6.1 above. The model has 60 alternatives combined of 15 time-of-day choice alternatives (feasible combinations of 5 outbound and 5 inbound time-of-day periods) and 4 stop-frequency alternatives. The model estimation results (utility coefficients) for 7 travel purposes are summarized in

Table 5-11 through Table 5-17 below. The t-stat values are summarized in parenthesis next to the estimated coefficients.

Table 5-11 | Estimation results for TOD & stop-frequency choice for low income work tour productions

Variables	TOD Outbound					TOD Inbound					Duration			Stops	
	Early	AM	MD	PM	NT	Early	AM	MD	PM	NT	Short	Med	Long	Outbound	Inbound
Constants- No Stop	-2.3741 (-4.9)	0 (0)	0.7781 (1.8)	1.6487 (1.5)	1.4809 (1.1)	-4 (0)	-2.1416 (-1.9)	0.7651 (1.7)	0 (0)	-1.6553 (-3.5)	1.3798 (3.1)	2.8791 (3.4)	2.8648 (2.2)		
Constants- With Stop	-6.01 (-7.6)	-2.5386 (-8.6)	-1.8304 (-3.4)	-1.6655 (-1.3)	-0.647 (-0.4)	-5 (0)	-5 (0)	-0.008 (0)	-0.8828 (-2.1)	-2.7187 (-4.1)					
Constants- Both Stop														1.3324 (4.9)	
Household Variables															
Zero Car HH	0.6101 (2)							-0.5026 (-2)						-0.9114 (-2.1)	
Car Sufficiency Low							0.6496 (0.5)								
Car Sufficiency High	0.406 (1.2)		-0.325 (-1.2)	0.4449 (1)	0.7686 (1.2)		1.3922 (1.4)			0.2524 (0.9)					
Zonal Characteristics															
Population Density	0.0072 (1.4)									0.0106 (2.3)				0.0076 (1.3)	-0.0045 (-0.9)
Retail Density	-0.0432 (-1.2)				-0.4372 (-1.6)			-0.041 (-1.6)		-0.0534 (-2)				-0.0621 (-1.4)	0.019 (1.4)
% Low Income HH in Ontario				-2.1685 (-1.1)						-1.2417 (-1.2)					
% Low Income HH in Quebec				-2.6048 (-1.1)	6.3125 (3.1)		5.1573 (2.2)	-0.9743 (-1.1)		-1.8738 (-1.6)					-1.8758 (-1.8)
% Detached HH				-1.0312 (-1.4)											-0.6907 (-1.6)

The t-stat values are summarized in parenthesis next to the estimated coefficients

Table 5-12 | Estimation results for TOD & stop-frequency choice for medium income work tour productions

Variables	TOD Outbound					TOD Inbound					Duration			Stops	
	Early	AM	MD	PM	NT	Early	AM	MD	PM	NT	Short	Med	Long	Outbound	Inbound
Constants- No Stop	-2.6669 (-9.3)	0 (0)	0.2788 (1.9)	1.6492 (6.4)	2.0539 (4.5)	6.741 (0)	6.5887 (0)	8.6905 (0)	8.3912 (0)	5.9638 (0)	1.8996 (12.4)	3.8276 (13.7)	4.0495 (9.7)		
Constants- With Stop	-5.5832 (-14.1)	-1.8838 (-10.2)	-1.1085 (-5.2)	0 (0)	0.4552 (0.8)	-5 (0)	4.4717 (0)	6.8998 (0)	6.4114 (0)	4.1663 (0)					
Constants- Both Stop														1.466 (15.9)	
Household Variables															
Zero Car HH				-1.5566 (-2.6)				-0.2765 (-1.8)		0.2241 (1.5)				-0.9274 (-3.6)	0.122 (0.9)
Car Sufficiency Low										0.1802 (2.1)					-0.3978 (-4.4)
Car Sufficiency High			0.3267 (3.8)	0.3846 (2.1)	0.2875 (0.9)			0.2831 (3.3)		0.1132 (1.1)				-0.2622 (-2.1)	-0.2722 (-2.8)
Zonal Characteristics															
Population Density	-0.0065 (-3.2)													-0.0058 (-2.7)	0.002 (1.5)
Retail Density	0.0112 (1.8)		0.0085 (2.1)							-0.014 (-2.4)					
% Low Income HH in Ontario	0.836 (1.4)			-3.157 (-3.2)	1.7029 (1.6)					1.1862 (3.2)				-1.1962 (-2.2)	0.6858 (1.7)
% Low Income HH in Quebec	2.0286 (3.4)		-0.6948 (-1.7)	-1.7923 (-1.7)											
% Detached HH	0.6459 (2.8)			-1.0931 (-3.7)			0.6515 (0.8)							-0.537 (-2.9)	0.2811 (1.8)
Accessibility	0.0117 (0.2)	0.0117 (0.2)	0.0117 (0.2)	0.0117 (0.2)	0.0117 (0.2)	0.0117 (0.2)	0.0117 (0.2)	0.0117 (0.2)	0.0117 (0.2)	0.0117 (0.2)					

The t-stat values are summarized in parenthesis next to the estimated coefficients

Table 5-13 | Estimation results for TOD & stop-frequency choice for high income work tour productions

Variables	TOD Outbound					TOD Inbound					Duration			Stops	
	Early	AM	MD	PM	NT	Early	AM	MD	PM	NT	Short	Med	Long	Outbound	Inbound
Constants- No Stop	-3.092 (-12)	0 (0)	-0.7661 (-3.8)	-1.2207 (-3.2)	0.7943 (1.9)	-3.2464 (-6.5)	-3.2464 (-6.5)	-0.2829 (-2)	0 (0)	-2.0642 (-14.6)	1.3382 (8.9)	2.8642 (10.2)	2.7136 (6.5)		
Constants- With Stop	-6.7549 (-22.1)	-2.2706 (-47.8)	-2.7605 (-13.2)	-4.6273 (-9.7)	-1.7983 (-3.5)	-3.026 (-2.6)	-3.8217 (-6.4)	-1.0602 (-5.2)	-1.1002 (-7.9)	-2.9724 (-14.7)					
Constants- Both Stop														1.5449 (25.2)	
Household Variables															
Zero Car HH		0 (0)	0.2777 (1.2)					-0.3417 (-1.2)	0 (0)	0.4081 (1.8)				-1.7808 (-3.5)	
Car Sufficiency Low								-0.0522 (-0.8)							-0.1842 (-3.1)
Car Sufficiency High		0 (0)	0.2978 (4.4)	0.4814 (3.3)		1.1572 (1)	1.1987 (2.7)	0.2031 (2.9)	0 (0)	0.2572 (3.6)				-0.266 (-3.3)	-0.2064 (-3.1)
Zonal Characteristics															
Population Density	-0.0029 (-1.4)						-0.0215 (-2)								-0.0041 (-3.3)
Retail Density							0.0585 (3.4)								0.0122 (3)
% Low Income HH in Ontario			1.4542 (3.6)												
% Low Income HH in Quebec	3.7219 (6.4)						3.925 (1.5)			-1.5105 (-2.5)				0.8163 (1.5)	-2.1054 (-4)
% Detached HH	0.9379 (4.4)	0 (0)	0.262 (1.7)	0.6511 (2.1)											-0.3811 (-2.9)

The t-stat values are summarized in parenthesis next to the estimated coefficients

Table 5-14 | Estimation results for TOD & stop-frequency choice for university tour productions

Variables	TOD Outbound					TOD Inbound					Duration			Stops	
	Early	AM	MD	PM	NT	Early	AM	MD	PM	NT	Short	Med	Long	Outbound	Inbound
Constants- No Stop	2.7676 (-10.7)	0 (0)	-0.8557 (-2.9)	-2.6082 (-4.4)	-3.5094 (-4)	3.8475 (-3.1)	-3.8983 (-6.2)	-0.7159 (-2.4)	0 (0)	0.3727 (1.3)	0.1814 (0.6)	-0.455 (-0.8)	-1.7941 (-2.1)		
Constants- With Stop	-5 (0)	-3.6532 (-18.9)	-3.428 (-10)	-6.0028 (-8.5)	-7.6862 (-5.7)	-5 (0)	-5.8291 (-4.6)	-1.8598 (-2.9)	-1.209 (-2.1)	-0.5911 (-0.9)					
Constants- Both Stop														1.1085 (5.8)	
Household Variables															
Zero Car HH					-1.0965 (-1.5)			0.2251 (1.4)						-0.5651 (-1.5)	0.4318 (1.9)
Car Sufficiency Low							-0.0382 (-0.1)							-0.5556 (-1.9)	
Car Sufficiency High				0.0686 (0.4)						-0.0922 (-1)					
Zonal Characteristics															
Population Density								0.0032 (1.8)						0.0055 (1.9)	-0.0067 (-2.1)
Employment Density															0.0062 (2.1)
% Low Income HH in Ontario			1.0243 (2.3)	1.2781 (1.6)	4.1487 (3.5)										
% Low Income HH in Quebec			-1.5017 (-2.3)												
Super Zonal Characteristics															
% Low Income HH in Ontario															-2.0506 (-1.5)
% Low Income HH in Quebec															-3.4323 (-2)

The t-stat values are summarized in parenthesis next to the estimated coefficients

Table 5-15 | Estimation results for TOD & stop-frequency choice for school tour productions

Variables	TOD Outbound					TOD Inbound					Duration			Stops	
	Early	AM	MD	PM	NT	Early	AM	MD	PM	NT	Short	Med	Long	Outbound	Inbound
Constants- No Stop	-5.317 (-7.7)	0 (0)	-2.7904 (-4.5)	-4.8203 (-3.9)	-4.8226 (-2.5)	-9 (0)	-8.6179 (-5.7)	-2.082 (-3)	0 (0)	-4.0003 (-3.7)	0.81 (1.3)	0.32 (0.3)	-1.3613 (-0.7)		
Constants- With Stop	-9 (0)	-4.4992 (-9.6)	-5.7001 (-7)	-7.7091 (-5.2)	-9 (0)	-9 (0)	-9 (0)	-3.3619 (-4.1)	-0.6711 (-1.5)	-3.062 (-2.7)					
Constants- Both Stop														1.6796 (7)	
Household Variables															
Zero Car HH		0 (0)	0.7618 (2.7)				3.424 (2.6)	0.4111 (2.7)	0 (0)					-1.0759 (-1.1)	-0.608 (-1.8)
Car Sufficiency Low								-0.1471 (-1.9)							
Car Sufficiency High	-0.953 (-1.3)	0 (0)	0.4224 (3.7)				1.5293 (1.4)	0.1874 (2.9)	0 (0)						
Zonal Characteristics															
School Enrollments	0.0004 (1.2)	0 (0)	0.0002 (3.4)												
Super Zonal Characteristics															
Population Density			0.0074 (1.9)	0.0058 (0.6)				0.0019 (0.9)	0 (0)	0.0069 (1.1)					
% Low Income HH in Ontario		0 (0)	-4.6967 (-4.5)					2.8957 (3.9)	0 (0)	3.4721 (1.6)					-3.1096 (-2.5)
% Low Income HH in Quebec	8.1594 (3.4)	0 (0)	-5.3301 (-4.3)				4.8139 (0.8)	-0.1203 (-0.1)	0 (0)	4.8888 (2.1)				-3.5381 (-1.4)	-6.6234 (-4.2)
% Detached HH							1.6224 (0.9)	1.4358 (4.9)	0 (0)	2.1173 (2.5)				-0.3206 (-0.6)	-1.5841 (-3.6)

The t-stat values are summarized in parenthesis next to the estimated coefficients

Table 5-16 | Estimation results for TOD & stop-frequency choice for maintenance tour productions

Variables	TOD Outbound					TOD Inbound					Duration			Stops	
	Early	AM	MD	PM	NT	Early	AM	MD	PM	NT	Short	Med	Long	Outbound	Inbound
Constants- No Stop	-1.9503 (-1.8)	-0.2409 (-0.5)	0 (0)	-0.6186 (-1.3)	-0.6846 (-0.8)	-2.7285 (-2.9)	-0.8364 (-1.8)	0 (0)	0.2398 (0.5)	0.3005 (0.3)	1.0569 (-2.4)	-3.4369 (-3.8)	-5.0045 (-3.5)		
Constants- With Stop	-5.7912 (-4.5)	-1.9043 (-3.9)	-1.0441 (-8.1)	-2.3891 (-4.9)	-2.6916 (-3)	-9 (0)	-3.1539 (-6.7)	-1.3418 (-17.1)	-1.2965 (-2.8)	-1.4496 (-1.6)					
Constants- Both Stop														0.595 (12.6)	
Household Variables															
Zero Car HH		-0.6196 (-3.9)		-1.3627 (-10.9)	-2.0344 (-11.3)	-0.6791 (-1.1)	-2.5169 (-4.8)							-0.2471 (-2.2)	-0.36 (-3.2)
Car Sufficiency Low				0.1833 (2.8)	0.3163 (4.7)		0.3753 (3.7)							-0.1507 (-2.1)	
Car Sufficiency High	-0.6815 (-2.9)	-0.7407 (-11.2)		-0.9438 (-15.5)	-0.9803 (-11.2)	0.775 (-1.8)	-0.5492 (-5.5)		-0.2859 (-5.9)	-0.6106 (-8.1)				-0.092 (-1.9)	0.0836 (2)
Zonal Characteristics															
Population Density	-0.0195 (-3.1)			0.0016 (1.8)		0.0216 (2.6)	0.0042 (2.8)			0.0031 (3.5)					
Employment Density															
Retail Density	0.0194 (2.5)	-0.011 (-1.9)		-0.0053 (-1.3)	-0.0275 (-3.7)	-0.0146 (-0.8)			0.0025 (0.8)	0.0077 (1.8)					
% Low Income HH in Ontario	2.3944 (1.7)						-1.2551 (-2.7)							-0.4871 (-1.4)	
% Low Income HH in Quebec	3.4174 (2.6)													-1.5218 (-3.6)	-1.4957 (-4.7)
% Detached HH	0.4598 (0.8)	0.1511 (1.3)		0.279 (2.8)						0.3812 (4)				-0.216 (-1.8)	0.0442 (0.5)
Accessibilities by Time Period	0.1505 (1.6)														

The t-stat values are summarized in parenthesis next to the estimated coefficients

Table 5-17 | Estimation results for TOD & stop-frequency choice for discretionary tour productions

Variables	TOD Outbound					TOD Inbound					Duration			Stops	
	Early	AM	MD	PM	NT	Early	AM	MD	PM	NT	Very Short	Short	Med	Outbound	Inbound
Constants- No Stop	-6.2346 (-4.3)	-3.1534 (-4.2)	0 (0)	2.5448 (3.3)	5.104 (3.5)	1.0914 (0.7)	1.755 (2.3)	0 (0)	-2.5629 (-3.4)	-3.6632 (-2.5)	2.441 (3.3)	2.3132 (1.6)	4.0715 (1.8)		
Constants- With Stop	-8.4527 (-5.4)	-4.8089 (-6.1)	-1.2221 (-5.7)	0.8847 (1.1)	3.2215 (2.2)	-9 (0)	-1.3529 (-1.6)	-1.8235 (-23.9)	-4.3946 (-5.8)	-6.2683 (-4.3)					
Constants- Both Stop														1.3216 (14.8)	
Household Variables															
Zero Car HH		-0.1228 (-0.5)		-1.255 (-8.1)	-1.3298 (-8.3)		-1.9652 (-2.7)								
Car Sufficiency Low					0.2854 (3.7)										
Car Sufficiency High	-0.5006 (-1.9)	0.117 (1)		-1.038 (-11.5)	-1.0606 (-10.5)		-0.9773 (-4.5)		-0.1477 (-1.7)	-0.4362 (-4.3)					
Zonal Characteristics															
Population Density															0.0022 (1.8)
Retail Density															-0.0112 (-1.7)
% Low Income HH in Ontario	-4.2831 (-2.4)	-2.7923 (-4.4)		-0.7087 (-1.5)	-1.4666 (-3.5)	5.2052 (1.1)	3.5942 (2.8)		0.2571 (0.6)					-2.0425 (-3.2)	
% Low Income HH in Quebec				-1.2778 (-1.9)	-1.7838 (-2.7)	-5.7886 (-0.5)			1.4449 (2.6)	1.3764 (2.2)				-3.5811 (-4.2)	-1.2344 (-2.1)
% Detached HH				0.3978 (2.5)										-0.9258 (-4.6)	
Accessibility	0.5225 (3.4)	0.5225 (3.4)	0.5225 (3.4)	0.5225 (3.4)	0.5225 (3.4)	0.5225 (3.4)	0.5225 (3.4)	0.5225 (3.4)	0.5225 (3.4)	0.5225 (3.4)					
Super Zonal Characteristics															
Population Density	0.0112 (1.2)			0.0071 (2.5)	0.0092 (3)	-0.0006 (0)	-0.0059 (-0.9)		-0.0063 (-2.9)	-0.0087 (-3.1)					
Retail Density	-0.023 (-1)			-0.0085 (-1.8)	-0.0178 (-3.3)	-0.036 (-0.3)	0.0098 (0.9)			0.0156 (3.3)					

The t-stat values are summarized in parenthesis next to the estimated coefficients

The model is essentially tour-based, making AM and PM periods dependent on each other in a consistent way. For example, majority of people going to work during AM go back home during PM and any factor affecting the outbound TOD for them would have a reflection on the inbound TOD. It should be noted, however, that despite the fact that each tour is perfectly symmetric (one outbound and one inbound half-tour) the AM and PM periods are not totally symmetric since each of them have a unique blend of outbound and inbound half-tours by purpose. For example, there are more maintenance and discretionary trips during PM compared to AM.

A large portion of the observed variation by TOD periods is explained by a set of outbound and inbound constants that form baseline timing profiles for each purpose. In additional to that, the data showed expected relationship between the probabilities of directional half-tours being produced in particular TOD periods (AM and PM are currently of the highest importance) and certain variables, of which the strongest effects are:

- Positive effect of percentage of low-income population and detached houses on outbound Early choice for medium and high income work tours,
- Relatively higher probability of later outbound school tours in the midday period in dense urban areas,
- Higher propensity of zero-car households to engage in maintenance tours that end in the midday or PM period versus AM,
- Higher probability of households with high car sufficiency to start discretionary tours earlier (in AM and midday periods.

With respect to the stop-making propensity, the configuration of constants stratified by TOD period and stop vs. no-stop for each half-tour directions allows to capture the observed stop-frequency patterns by TOD periods. In particularly, for all work commute, there is a lower propensity to have an outbound stop for early period compared to AM and midday while there is approximately the same stop-making probability for both most frequent inbound periods (midday and PM). Another interesting observation is that across all purposes, the dummy for both stops (outbound and inbound) on the same tour proved to be positive. This is different from some other metropolitan areas where rather substitution effects were observed.

Accessibilities did not prove to be significant for work and university purposes. However, the positive values were retained in the model. It is known that mandatory activities are more restrictive in time of day choice. For maintenance and discretionary activities, the accessibility impacts proved to be significant and strong, as expected. It shows that people are more likely to change time period for their non-mandatory travel as compared to mandatory travel.

5.5.2 Time-of-Day Choice for Tour Attractions

The time-of-day choice model for tour productions has been estimated as a multinomial logit choice model based on the observed tour records from the OD Survey and according to the specifications in Subsection 3.6.2 above. The model has 15 alternatives as feasible combinations of 5 outbound and 5 inbound time-of-day periods. The model estimation results for 7 travel purposes are summarized in

Table 5-18 through Table 5-24 below. The time period specific constants represent the relative share of travel occurring in each time periods compared to the reference case (e.g., AM peak in outbound direction and PM peak in inbound direction.

Table 5-18 | Estimation results for time-of-day choice model for low income work tour attractions

Variables	TOD Outbound					TOD Inbound					Duration			
	Early	AM	MD	PM	NT	Early	AM	MD	PM	NT	Very Short	Short	Med	Long
Constants	-1.7916 (-2.7)	0 (0)	1.3324 (2)	1.4989 (1.2)	3.3383 (1.8)	-0.6654 (-0.4)	-0.6654 (-0.4)	0.6554 (1)	0 (0)	-3.2261 (-4.3)		2.1598 (3.5)	4.3605 (3.6)	5.1415 (2.8)
Zonal Characteristics														
% Public Offices		0 (0)	-0.7641 (-1.9)							1.1084 (1.9)				
% Private Offices			-1.2337 (-1.3)					-2.3897 (-2.2)	0 (0)	0.9576 (0.8)				
% Retail	-1.0311 (-1.5)					3.9811 (1.8)	3.9811 (1.8)			1.0887 (1.6)				
% Service	-1.1019 (-1.3)	0 (0)	1.0686 (1.9)	2.2157 (2.3)				0.5996 (1)	0 (0)	1.4901 (2)				
% Warehousing														
% Industry														
% Health	-1.3942 (-2.1)							0.7813 (1.7)	0 (0)	0.8498 (1.3)				
% Education	-2.8769 (-2.6)	0 (0)	0.5965 (1.4)			3.3018 (1.9)	3.3018 (1.9)		0 (0)	1.1145 (1.8)				
Accessibility (Destination)	0.0233 (0.1)	0.023 3 (0.1)	0.0233 (0.1)	0.0233 (0.1)	0.0233 (0.1)	0.0233 (0.1)	0.0233 (0.1)	0.0233 (0.1)	0.0233 (0.1)	0.0233 (0.1)				
Super Zonal Characteristics														
Population Density	-0.0065 (-1.1)				0.0166 (2.3)	0.0753 (1.5)	0.0753 (1.5)							
Retail Density	-0.0027 (-1.1)					-0.8509 (-1.7)	-0.8509 (-1.7)	0.0015 (0.8)						
% Detached HH								0.9993 (2.8)						

Table 5-19 | Estimation results for time-of-day choice model for medium income work tour attractions

Variables	TOD Outbound					TOD Inbound					Duration			
	Early	AM	MD	PM	NT	Early	AM	MD	PM	NT	Very Short	Short	Med	Long
Constants	-1.1849 (-6.2)	0 (0)	-0.15 (-0.8)	-0.8934 (-2.2)	0.2121 (0.4)	-3.1101 (-2.9)	-2.4888 (-3.7)	-0.3891 (-2.2)	0 (0)	-2.0038 (-11.7)		1.4779 (9.1)	2.9802 (10.1)	2.8144 (6.4)
CBD				0.4015 (1.1)			1.0617 (1.1)			0.1748 (1.4)				
Zonal Characteristics														
% Public Offices	-0.6728 (-3.8)	0 (0)	-0.8359 (-5.2)	-0.5651 (-1.2)			-3.12 (-2.3)			-0.5285 (-3.2)				
% Private Offices	-2.0839 (-4.4)	0 (0)	-1.283 (-3.3)	-0.0588 (-0.1)	-3.6085 (-2)									
% Retail	-0.6842 (-2.4)	0 (0)	0.5842 (2.7)	2.3753 (5.4)			-3.0211 (-1.6)	0.8772 (3.9)	0 (0)	1.0396 (4.6)				
% Service	-0.4511 (-1.7)	0 (0)	0.4392 (2.1)	1.7248 (3.5)	1.4744 (2.1)			0.4638 (2.2)						
% Health	-1.1408 (-4.7)				0.6372 (1.2)			0.2542 (1.4)	0 (0)	0.3634 (2)				
% Education	-1.9269 (-6.5)	0 (0)	0.0506 (0.3)	1.3824 (3)	0.6778 (1)			1.0323 (6)						
Super Zonal Characteristics														
Population Density	-0.0039 (-2.4)	0 (0)	0.0058 (4)							-0.0043 (-2.7)				
Employment Density				-0.0008 (-1.5)				-0.0003 (-2.5)						
% Low Income HH in Ontario	0.8543 (2)	0 (0)	-0.8169 (-2)	-1.732 (-2.1)						1.175 (2.9)				
% Detached HH			0.3092 (2.5)		1.1063 (2.7)		1.5497 (2)	0.0913 (0.7)	0 (0)					

Table 5-20 | Estimation results for time-of-day choice model for high income work tour attractions

Variables	TOD Outbound					TOD Inbound					Duration			
	Early	AM	MD	PM	NT	Early	AM	MD	PM	NT	Very Short	Short	Med	Long
Constants	-2.0639 (-12.8)	0 (0)	-0.2491 (-1.5)	-1.2601 (-3.7)	0.3958 (0.8)	-2.1244 (-4.5)	-2.1244 (-4.5)	-0.6032 (-4)	0 (0)	-2.1716 (-13.2)		1.3923 (9.5)	2.9078 (10.7)	2.8004 (6.9)
CBD	0.1249 (0.8)	0 (0)	-0.2524 (-1.7)	-0.1117 (-0.3)	0.424 (0.8)	-2.383 (-2.3)	-2.383 (-2.3)	-0.0274 (-0.2)	0 (0)	0.1632 (1.2)				
Zonal Employment Categories														
% Public Offices	-0.2585 (-2.1)	0 (0)	-0.5322 (-4.1)	-0.9916 (-2.7)	-1.318 (-2.2)	0 (0)	0 (0)			-0.2009 (-1.6)				
% Private Offices	-0.5718 (-1.4)	0 (0)	-0.432 (-1.3)											
% Retail			0.5243 (2.8)	2.4699 (7.5)		-5.5923 (-1.5)	-5.5923 (-1.5)	0.6862 (3.6)	0 (0)	0.9131 (4.8)				
% Service			0.6442 (3.6)	1.3931 (3.4)	1.5003 (2.5)	1.9742 (2.4)	1.9742 (2.4)	0.6907 (4.2)	0 (0)	0.5184 (2.7)				
% Health								0.2651 (1.9)	0 (0)	0.4997 (3.4)				
% Education	-0.9517 (-3.8)	0 (0)	0.6155 (4)	1.4315 (4.4)	1.2717 (2.6)			0.7502 (5.2)						
Zonal Characteristics														
% Detached HH	-0.4499 (-4.1)	0 (0)	0.0638 (0.8)	0.3633 (2.1)	0.4895 (1.7)	-2.0486 (-2.3)	-2.0486 (-2.3)	0.4232 (5.1)	0 (0)					
Super Zonal Characteristics														
Population Density	-0.002 (-1.7)				0.0082 (1.9)	-0.0183 (-1.5)	-0.0183 (-1.5)							
Employment Density	-0.0003 (-2.1)	0 (0)	-0.0001 (-0.9)	-0.0005 (-1.2)	-0.0005 (-0.8)			-0.0002 (-1.4)	0 (0)	-0.0002 (-1.2)				
% Low Income HH in Ontario			-0.6678 (-2)		-2.2032 (-1.7)									
% Low Income HH in Quebec			-0.8814 (-3.7)							-0.5796 (-2.7)				

Table 5-21 | Estimation results for time-of-day choice model for university tour attractions

Variables	TOD Outbound					TOD Inbound					Duration			
	Early	AM	MD	PM	NT	Early	AM	MD	PM	NT	Very Short	Short	Med	Long
Constants	-2.8019 (-9)	0 (0)	-0.4037 (-1.1)	-2.5959 (-3.5)	-2.8553 (-2.6)	-3.5861 (-2.5)	-3.9993 (-5.2)	-0.2915 (-0.8)	0 (0)	0.4185 (1.1)		0.2418 (0.6)	-0.3489 (-0.5)	-1.6043 (-1.4)
CBD			-0.7409 (-1.9)					0.1891 (0.5)						
Accessibility	1.0012 (4.3)	1.0012 (4.3)	1.0012 (4.3)	1.0012 (4.3)	1.0012 (4.3)	1.0012 (4.3)	1.0012 (4.3)	1.0012 (4.3)	1.0012 (4.3)	1.0012 (4.3)				

Table 5-22 | Estimation results for time-of-day choice model for school tour attractions

Variables	TOD Outbound					TOD Inbound					Duration			
	Early	AM	MD	PM	NT	Early	AM	MD	PM	NT	Very Short	Short	Med	Long
Constants	-3.6748 (-7.3)	0 (0)	-3.5962 (-6.2)	-7.9653 (-6.7)	-9.214 (-5.2)		-10.3716 (-7.5)	-10.3716 (-7.5)	0 (0)	-0.5375 (-0.9)		-0.705 (-1.2)	-2.6547 (-2.3)	-5.7718 (-3.3)
Zonal Characteristics														
Employment Density								0.0025 (2.9)	0 (0)	0.0027 (2.7)				
% Low Income HH in Ontario			-6.5644 (-6.8)											
% Low Income HH in Quebec			-3.6109 (-7.4)				2.1035 (4.8)							
School Enrollments			-0.0001 (-1.8)					0.0003 (8.2)	0 (0)	0.0004 (4.4)				
Super Zonal Characteristics														
Population Density			0.0038 (1)	0.0155 (1.9)						0.0123 (3.1)				
% Detached HH								1.2911 (11.5)						

Table 5-23 | Estimation results for time-of-day choice model for maintenance tour attractions

Variables	TOD Outbound					TOD Inbound					Duration			
	Early	AM	MD	PM	NT	Early	AM	MD	PM	NT	Very Short	Short	Med	Long
Constants	-3.3717 (-3.3)	0 (0)	2.6463 (2.6)	3.1559 (1.5)	4.6508 (1.5)	2.7936 (0.9)	2.0603 (1)	1.8933 (1.9)	0 (0)	-1.0371 (-1)		0.7801 (0.8)	0.1966 (0.1)	0.4337 (0.1)
CBD				-0.5548 (-3.5)				-0.6367 (-5.6)	0 (0)					
Zonal Characteristics														
Population Density				0.0062 (6.6)	0.007 (4.3)		0.0123 (9.6)			-0.0061 (-4.7)				
Retail Density			0.0021 (2.8)	0.0027 (2.6)				0.0025 (3.5)						
% Low Income HH in Ontario			-0.702 (-2.4)	-2.2942 (-6.3)	-2.2077 (-5.8)		-3.4145 (-6.3)							
% Low Income HH in Quebec			-0.7146 (-6.2)	-0.8253 (-5.8)	-1.2659 (-7.1)		-0.2802 (-1.8)							
% Detached HH				0.5454 (9.1)	0.7406 (7.8)		0.6456 (6.8)			-0.4879 (-6.2)				

Table 5-24 | Estimation results for time-of-day choice model for discretionary tour attractions

Variables	TOD Outbound					TOD Inbound					Duration			
	Early	AM	MD	PM	NT	Early	AM	MD	PM	NT	Very Short	Short	Med	Long
Constants	-2.7777 (-3.8)	0 (0)	3.5279 (4.7)	4.9914 (3.4)	7.4133 (3.3)	4.284 (1.9)	3.3214 (2.3)	2.7747 (3.7)	0 (0)	-0.5961 (-0.8)		2.2688 (3.1)	1.9434 (1.3)	3.2599 (1.4)
% Detached HH			-0.355 (-4.2)			-0.7814 (-0.8)				-0.218 (-2.7)				
Accessibility	0.0477 (0.4)	0.0477 (0.4)	0.0477 (0.4)	0.0477 (0.4)	0.0477 (0.4)	0.0477 (0.4)	0.0477 (0.4)	0.0477 (0.4)	0.0477 (0.4)	0.0477 (0.4)				
Super Zonal Characteristics														
% Low Income HH in Ontario			1.9641 (3.5)	2.8109 (4)	2.4796 (3.7)		2.9956 (2.8)	1.2577 (3.1)						
% Low Income HH in Quebec						-4.1162 (-0.9)								

In general, the data showed expected relationships between the probability of tours being attracted to a zone in a particular TOD period and certain variables, primarily different employment types. Attracted tours with and without stops were collapsed together in this sub-model. Specifically for work tours, public and private offices proved to attract more outbound travel in the conventional periods (AM peak) while retail and service employees tend to leave workplaces earlier (in Midday rather than PM). High income employees in CBD in general have a strong shift towards early starts (in Early period rather than AM). For Medium income workers going to CBD, there is a slight shift to later outbound travel and early inbound travel. Accessibilities did not come out significant and strong in most of the model for attraction end time of day choice.

5.5.3 Zonal Stop Attraction Model

The zonal daily stop attraction model has been estimated as a linear regression model based on the aggregated-by-TAZ intermediate tour stops from the OD Survey and according to the specifications in Subsection 3.6.4 above. The model estimation results for 7 travel purposes with additional subdivision by half-tour direction are summarized in

Table 5-25 below. The regression models were estimated without intercept, i.e. no default zonal tour attraction rate was assumed. The most significant coefficients that explain the zonal stop attraction rate are highlighted. All variables relate to the TAZ itself.

The strongest stop-attraction variables across all tour purposes and half-tour directions proved to be retail employment categories – major shop, street shop and other retail (as expected and in line with the tour-based models developed elsewhere). There is however, a significant and logical difference between the impacts of this variable on outbound and inbound half tours for work, university, and school. The inbound stop attraction is by-order-of-magnitude stronger than outbound reflecting the general stop-frequency pattern for commuters. It is primarily explained by time constraints that are much more restrictive for outbound (presumably morning) commuting leg. Additionally, bank employment generates stops in both directions (inbound being stronger) and restaurant employment generates inbound stops for the medium and high income commuters. Additionally school and university enrolment produced a significant number of stops on work, university, and school tours associated with dropping-off students at schools. For maintenance and discretionary tours, various categories of retail, service and health employment produces attractions for stops. For maintenance, shopping and theatre gross land area also proved to be significant and strong.

Table 5-25 | Estimation results for zonal stop attraction model

Variables	Work - Low		Work - Med		Work - High		University		School		Maintenance	Discretionary
	Outbound	Inbound	Outbound	Inbound	Outbound	Inbound	Outbound	Inbound	Outbound	Inbound		
Zonal Employment by category												
Major Shops in Ontario	0.0121	0.0268	0.0279	0.2261	0.0727	0.2911		0.1162		0.0757	0.9018	0.1909
Street Shops in Ontario		0.0303		0.1161	0.0837	0.2242					0.8758	0.1314
Retail in Quebec	0.0116	0.0378	0.0446	0.2129	0.0732	0.1569		0.0307		0.0597	0.6781	0.1384
Restaurant in Ontario		0.0339	0.0561	0.2120		0.2525	0.0278			0.0517	0.4086	0.2118
Theatre in Ontario		0.0941				0.2049						0.2763
Bank in Ontario	0.0892		0.1573	0.2969	0.2488	0.4140					1.1792	
Post Office in Ontario			0.0197									
Service in Quebec							0.0097					0.0453
Office (public)	0.0017		0.0041	0.0082	0.0180	0.0228	0.0035	0.0053			0.0103	
Hospital in Ontario			0.0121			0.0205					0.0715	
Other Health in Ontario			0.0486	0.0897	0.0541	0.1440		0.0331	0.0113	0.0308	0.3615	0.1153
Office (private)							0.0136					
Education	0.0148		0.0305	0.0352	0.0721	0.0725					0.0627	0.0463
Other Zonal Characteristics												
Elementary School enrollment			0.0186		0.0598	0.0592			0.0046	0.0120		0.0203
Secondary School enrollment			0.0095		0.0272		0.0053				0.0914	
University enrollment							0.0031	0.0100				
Shopping GLA (hectares)											23.4146	
Parks Gross Area (hectares)							0.0319					
Theatre GLA (hectares)		9.2232		28.325				44.860			70.4284	
Total population	0.0010	0.0016	0.0025	0.0068	0.0047	0.0066		0.0020	0.0011	0.0041	0.0259	0.0061
R Square	0.1437	0.1984	0.4427	0.6400	0.6209	0.7311	0.3125	0.5420	0.1643	0.3670	0.7775	0.6322
Adjusted R Square	0.1360	0.1900	0.4325	0.6345	0.6152	0.7262	0.3052	0.5372	0.1605	0.3613	0.7732	0.6267

Note: The most significant coefficients that explain the zonal stop attraction rate are highlighted in red.

5.6 Tour and Trip Distribution

5.6.1 Aggregate Calibration Strategy

The tour and trip distribution models are not estimated with the disaggregate data. These models are calibrated to match the observed aggregate statistics. The reason for a different approach compared to the TOD and mode choice models is that the tour/trip distribution models have only a limited number of parameters (dispersion coefficients) that makes it more effective to directly calibrate the model. The calibration procedure involves multiple runs of the model with successive adjustments of the model parameters until a good match to the observed data has been achieved. For all purposes (5 or 7), the purpose specific mode choice logsums are used for gravity component. In additional to mode choice logsum, distance based impedance (dispersion coefficient * distance) and impedance for river crossings (between Ottawa and Gatineau) were also introduced.

The following components of the tour/trip distribution require calibration:

- Dispersion coefficients used in the auxiliary gravity component in the smoothing procedure for seed matrices (explained in **Subsection 3.7.1** above),
- Dispersion coefficients used in the gravity component of the hybrid gravity-balancing model for construction of tour end matrices (explained in **Subsection 3.7.2** above),
- River Crossing penalty coefficients in the gravity component of the hybrid gravity-balancing model for construction of tour end matrices (explained in **Subsection 3.7.2** above),
- Dispersion coefficients used to regulate route deviation from the shortest path for stop location on chained half-tours (explained in **Subsection 3.8.3** above).

5.6.2 Dispersion Coefficients for Gravity Model Components

Dispersion coefficients used in both gravity model components (for the smoothing procedure and for the hybrid gravity-balancing model) are of the same nature and relate to the spatial distribution of tour ends (home origins and primary destinations) as function of travel impedance. The dispersion coefficients for smoothing were calibrated to match the observed average tour length in term of free-flow time (from the origin to primary destination) for each travel purpose. The gravity dispersion coefficients for work, university and school are set to zero because the mode choice logsums for these purposes were able to match the tour length frequencies, and additional calibration was not required. The target values of average tour length and the corresponding values of dispersion coefficients are shown in **Error! Reference source not found.** below (including both direct and chained tours). In a logical way, the shorter is the average tour length the stronger is the dispersion coefficient reflecting the growing disutility of longer travel for the corresponding purpose.

Table 5-26 | Targets and calibrated dispersion coefficients for the gravity model components

Travel purpose	Average tour length (min of free-flow auto time)	Dispersion coefficient for Smoothing	Dispersion coefficient for Gravity	River Crossing Penalty coefficients
Work	13.5	-0.105	0	-0.03 to -0.05
University	12.9	-0.105	0	-0.05
School	5.9	-0.105	0	-0.10
Maintenance	7.5	-0.105	-0.15	-0.12
Discretionary	9.2	-0.105	-0.08	-0.12

During the calibration phase, it was found that too many trips were crossing the Ottawa River. To restrict this movement, a river crossing penalty was introduced at the tour distribution stage.

5.6.3 Calibration of Stop Location on Chained Half-tours

Dispersion coefficients used to regulate route deviation from the shortest path for stop location on chained half-tours are of different nature compared to the gravity coefficients though they also reflect the trip distribution effect as function of travel impedance. The primary difference is that these coefficients also capture the relative stop location versus the home and primary-destination ends of the tour. The dispersion coefficients were calibrated to match the observed average route deviation from the shortest path, i.e. ratio of the actual path including stop to the shortest path between the origin and primary destination with no stop. The targets were calculated for each travel purpose and direction (outbound and inbound). The target values of average deviations and corresponding values of dispersion coefficients are shown in **Error! Reference source not found.** below (relate to chained tours only).

In addition to replication of the average route deviation, a set of secondary structural controls was used in order to better capture a differential (non-symmetric) choice of stop locations with respect to the tour ends. In fact, as the OD-Survey data has shown (and in line with the data from other metropolitan areas) very rarely stop location is chosen in the mid-point of the half-tour. Most frequently it is chosen in the vicinity of the home end. This behavioural phenomenon can be explained by familiarity with the area near home as well as by location of schools that induce many of the stops.

Table 5-27 | Targets and calibrated dispersion coefficients for the stop-location model

Travel purpose	Average tour length (min of free-flow auto time)	Observed route deviation for stops		Dispersion Coefficient			
				Outbound		Inbound	
		Outbound	Inbound	Home end	Destin end	Home end	Destin end
Work	13.5	1.60	1.68	-0.200	-0.080	-0.190	-0.070
University	12.9	1.71	1.81	-0.140	-0.070	-0.130	-0.060
School	5.9	1.67	1.85	-0.220	-0.140	-0.170	-0.090
Maintenance	7.5	1.89	1.74	-0.250	-0.150	-0.250	-0.150
Discretionary	9.2	1.64	1.67	-0.250	-0.150	-0.250	-0.150

In general, in a logical way, outbound direction is characterized by a relatively smaller deviation from the shortest path for mandatory purposes (work, university, and school) because of time constraints in the outbound (most frequently AM) commute that results in stronger coefficients. Also the home-end coefficient is logically significantly stronger than destination-end coefficient reflecting on the asymmetry of stop locations.

5.7 Mode Choice for Motorized and Bicycle Trips

In this section, we provide summaries for the trip mode choice model estimated for AM and PM periods and by 7 travel purposes. The first three purposes (1-3) represent work for different income groups. Since, the purpose is the same (i.e. Work), the mode choice model for the work purposes (1-3) was estimated together with segmentation by income groups (using additional constants by mode by income group) to differentiate between the three travel purposes. The three work purposes share the same coefficients for all variables except the income groups since only specific income group is applicable for each work purpose. . The coefficients on income groups help in defining different mode shares across the three income groups or the three work travel purposes. The model has been estimated as a nested logit model based on the observed trip records from the OD Survey and according to the specifications noted previously in Subsection 3.9.1. The model has 15 alternatives that correspond to the modelled motorized modes and bicycle grouped into 4 upper level nests and 9 lower level nests.

5.7.1 Summary of Coefficients for Level-of-Service Variables

The model estimation results. with respect to the Level-of-Service (LOS) variables like travel time and cost for all the travel purposes, are summarized in Table 5-28 (unscaled coefficients before nesting) and Table 5-29 (scaled coefficients after nesting) below. The coefficients for the first three purposes (i.e. work purposes) are the same and are shown only once. LOS variables are of primary importance when different network alternatives / projects are compared. The coefficient values for LOS variables predefine the model response to network improvements, in particularly predicted shift to transit as the result of transit improvements and growing congestion.

Un-scaled coefficients correspond to the elemental alternatives (15 modes) before nesting. They reflect on the elasticities of lower-level choices between 8 transit modes in the transit nest and 5 auto modes in the auto nest (all other nests have one mode each). Scaled coefficients correspond to composite utilities of 4 Nests (Auto, Transit, Bicycle and School Bus). They reflect on the elasticities of upper level choices between the nests. When compared to other models estimated elsewhere, the scaled coefficients have to be used, especially if the nested logit models are compared to multinomial logit models.

In general, the OD survey and related datasets indicated a high level of consistency and robustness of the estimated mode preferences. The base year datasets was also extremely helpful for a subsequent aggregate validation of the results for both TOD periods. Similar to other disaggregate mode choice models estimated with synthetic (EMME produced) LOS skims, some coefficients required constraining or enforcement (highlighted in yellow in the tables) if their original values (or ratios between the original coefficient values) fell beyond the acceptable range. Some other coefficients were linked together (highlighted in blue in the tables) in the estimation process (either by specifying the same value or by specifying a predetermined ratio between them) in order to enhance the statistical significance. For example and in line with the most mode choice models estimated elsewhere, cost coefficients for auto and transit were mostly specified in a generic way.

All LOS variables in the final estimated model specification have obtained logical values in the reasonable range comparable with the other mode choice models developed elsewhere. The three innovative variables introduced in the model that relate to travel time reliability (congestion delay separated from the free-flow time for auto, the transit time components by stop density and share on Transitway/rail time and bike time by facility type proved to have a very strong and logical impact with the reasonable coefficient estimates.

The mode choice utility coefficients are estimated for LOS (time and cost) variables. There are several derived ratios calculated between these coefficients that are useful for analysis and control of the model logic. The following derived model parameters are of primary importance (bold in the tables; these parameters are independent of scaling, thus they are identical in both tables):

- Auto Value of Time (VOT), calculated as a ratio of the free-flow auto time coefficient to auto cost coefficient; the usual range for auto VOT is between 5$/h and $20/h with the school purpose exhibiting the lowest VOT and work purpose exhibiting the highest VOT, VOT represents willingness to pay in order to reduce travel time. For example, if there is a toll road which offers faster route compared to a non-tolled road, then it is expected that road users with higher VOT are more likely to use the toll road as compared to users with lower VOT.
- Auto Value of Reliability (VOR), calculated as a ratio of the congestion auto delay coefficient to auto cost coefficient (congestion auto delay was calculated as the difference between congestion auto time and free-flow time); the expected values for VOR are somewhat higher than for VOT,
- Transit wait time weight, calculated as a ratio of the wait time coefficient to in-vehicle time coefficient; the acceptable range for wait time weight is between 2.0 and 3.5,
- Transit walk time weight, calculated as a ratio of the walk time coefficient to in-vehicle time coefficient; the acceptable range for walk time weight is between 1.5 and 2.5,
- Transfer penalty, calculated as a ratio of the coefficient for number of boardings to in-vehicle time coefficient; the acceptable range for transfer penalty is between 3 min and 15 min depending on the transfer condition.,
- Transit VOT, calculated as a ratio of the transit in-vehicle time coefficient to transit fare coefficient; the expected values for transit VOT is somewhat lower than for the auto VOT.

Table 5-28 | Summary of estimated coefficients for LOS variables (unscaled –lower level choices)

Variables	Work	Univ	Scho	Main	Disc
Highway Free Flow Time (min)	-0.0308	-0.0132	-0.0169	-0.0283	-0.0257
Highway Delay (min)	-0.0562	-0.0264	-0.0169	-0.0566	-0.0514
Auto & Parking Cost ($)	-0.1200	-0.1500	-0.1787	-0.2500	-0.1910
Auto VOT $/hr	**15.4**	**5.3**	**5.7**	**6.8**	**8.1**
Auto VOR $/hr	**28.1**	**10.6**	**5.7**	**13.6**	**16.1**
Transit In-Vehicle Time	-0.0228	-0.0202	-0.0169	-0.0294	-0.0219
IVTT transit Way	0.0128	0.0080		0.0100	0.0100
IVTT low Stop Density	0.0011	0.0030		0.0030	0.0030
IVTT High Stop Density	-0.0050	-0.0030		-0.0050	-0.0050
Transit Fare & Access/Egress Cost	-0.1200	-0.1500	-0.1787	-0.2500	-0.1910
Wait Time	-0.0685	-0.0605	-0.0507	-0.0882	-0.0502
Walk Time	-0.0530	-0.0302	-0.0338	-0.0735	-0.0527
Number of Boardings	-0.1142	-0.0829	-0.0845	-0.1470	-0.1096
Drive Access Time	-0.0308	-0.0132	-0.0169	-0.0283	-0.0257
Walk Time Weight	**2.3**	**1.5**	**2.0**	**2.5**	**2.4**
Wait Time Weight	**3.0**	**3.0**	**3.0**	**3.0**	**2.3**
Transfer Penalty, min	**5.0**	**4.1**	**5.0**	**5.0**	**5.0**
Transit VOT $/hr	**11.4**	**8.1**	**5.7**	**7.1**	**6.9**
Bike Time- Mixed Traffic	-0.0618	-0.0660	-0.0734	-0.1391	-0.1148
Bike Time -Sharrow Bike Lane	-0.0573	-0.0594	-0.0734	-0.1251	-0.1034
Bike Time - Paved Shoulders	-0.0525	-0.0528	-0.0734	-0.1112	-0.0919
Bike Time - Bike Lane with Traffic	-0.0309	-0.0440	-0.0734	-0.0927	-0.0766
Bike Time - Multi Use - Stone Dust	-0.0340	-0.0440	-0.0734	-0.0695	-0.0766
Bike Time - Multi Use - Asphalt	-0.0247	-0.0264	-0.0734	-0.0463	-0.0574
Bike Time - Exclusive Bike Lane	-0.0155	-0.0220	-0.0734	-0.0232	-0.0306
Nesting (Upper)	0.9000	0.9000	0.9000	0.6766	0.9000
Nesting (Lower)	0.8702	0.9000	0.7911	0.9000	0.9000

Table 5-29 | Summary of estimated coefficients for LOS variables (scaled)

Variables	Work	Univ	Scho	Main	Disc
Highway Free Flow Time	-0.0241	-0.0107	-0.0120	-0.0172	-0.0208
Highway Delay	-0.0440	-0.0214	-0.0120	-0.0345	-0.0416
Auto & Parking Cost	-0.0940	-0.1215	-0.1273	-0.1522	-0.1547
Auto VOT $/hr	**15.4**	**5.3**	**5.7**	**6.8**	**8.1**
Auto VOR $/hr	**28.1**	**10.6**	**5.7**	**13.6**	**16.1**
Transit In-Vehicle Time	-0.0179	-0.0163	-0.0120	-0.0179	-0.0178
IVTT transit way	0.0100	0.0065		0.0061	0.0081
IVTT low Stop Density	0.0009	0.0024		0.0018	0.0024
IVTT High Stop Density	-0.0039	-0.0024		-0.0030	-0.0041
Transit Fare & Access/Egress Cost	-0.0940	-0.1215	-0.1273	-0.1522	-0.1547
Wait Time	-0.0537	-0.0490	-0.0361	-0.0537	-0.0407
Walk Time	-0.0415	-0.0245	-0.0241	-0.0448	-0.0427
Number of Boardings	-0.0895	-0.0671	-0.0601	-0.0895	-0.0888
Drive Access Time	-0.0241	-0.0107	-0.0120	-0.0172	-0.0208
Walk Time Weight	**2.3**	**1.5**	**2.0**	**2.5**	**2.4**
Wait Time Weight	**3.0**	**3.0**	**3.0**	**3.0**	**2.3**
Transfer Penalty, min	**5.0**	**4.1**	**5.0**	**5.0**	**5.0**
Transit VOT $/hr	**11.4**	**8.1**	**5.7**	**7.1**	**6.9**
Bike Time- Mixed Traffic	-0.0484	-0.0534	-0.0522	-0.0847	-0.0930
Bike Time -Sharrow Bike Lane	-0.0411	-0.0428	-0.0522	-0.0677	-0.0744

Bike Time - Paved Shoulders	-0.0242	-0.0356	-0.0522	-0.0564	-0.0620
Bike Time - Bike Lane with Traffic	-0.0266	-0.0356	-0.0522	-0.0423	-0.0620
Bike Time - Multi Use - Stone Dust	-0.0194	-0.0214	-0.0522	-0.0282	-0.0465
Bike Time - Multi Use - Asphalt	-0.0121	-0.0178	-0.0522	-0.0141	-0.0248
Bike Time - Exclusive Bike Lane	-0.0448	-0.0481	-0.0522	-0.0762	-0.0837
Nesting (Upper)	0.9000	0.9000	0.9000	0.6766	0.9000
Nesting (Lower)	0.8702	0.9000	0.7911	0.9000	0.9000

Coefficients and values for auto LOS are shared between auto driver and passenger modes. Cost variables (operating and parking) for the HOV modes are scaled down based on square root of occupancy ($\sqrt{2}$ for HOV2 and $\sqrt{3}$ for HOV3+). This approach of partially scaling the HOV costs is in line with latest research and new generation of mode choice models developed in US. A large number of HOVs are intra-household car sharing where cost is not perceived as equally divided among all the passengers (children in a lot of cases) but most of it is absorbed by the adult in household (or driver of the vehicle). But, sharing a car has cost benefits as compared to no-sharing which is reflected by scaling of costs. Coefficients and values for most transit LOS variables are shared between 8 transit modes.

The data shows that the probability of trips being made by auto is differentially sensitive to the free-flow travel time and congestion delays. For example, for work purpose, every minute of travel delay is being perceived as twice as long as a minute of free flow travel time. This generally reflects travelers' preferences towards more reliable travel options since the nature of delay is in being not stable and making the travel time less predictable. Likewise, the proportion of a transit trip made on the Transitway (or on a semi-exclusive right-of-way) proves to be a strong positive factor favouring choice of transit as the mode. Similarly, the travel time on low stop density route is less onerous than high stop density route.

The relative weights for walk and wait times for transit trips (i.e. their perception by users) as well as perceived transfer penalty, match well the values commonly used in modelling practices:

- 1 minute of walk time is perceived as 1.5-2.5 minutes of in-vehicle time depending on travel purpose,
- 1 minute of wait time is perceived as 2.3-3.0 minutes of in-vehicle time depending on travel purpose,
- 1 transfer adds 4.0-5.0 minutes of perceived extra penalty to the calculated transit time.

Overall, the choice of auto modes (SOV, HOVs, driver and passenger) is more sensitive to travel time changes than that of transit since the auto time coefficient (e.g., -0.0308 for work) is large (in absolute terms) than the transit in-vehicle time coefficient (e.g., -0.0228 for work) for all purposes. This means that the same improvement (e.g. time saving) would attract fewer auto users to transit if it were applied to transit travel than it would attract transit users to auto if it were applied to auto travel. Similarly, the same extra time (e.g. delay) would attract more auto users to transit if it were applied to auto travel than it would attract transit users to auto if it were applied to transit travel. This is a manifestation of a "Modal Transfer Conservatism" that helps simulate user behaviour in a realistic way. This is different from the prevailing US practices where 1 min saved on highway and 1 min saved on transit are constrained to have the same generic coefficient that is a legal requirement of the Federal Transit Administration to obtain federal funding for transit projects.

The bicycle travel time coefficients were estimated by travel time spend on facility type. However, it was not possible to estimate all coefficients in a consistent way. So, in many cases the bicycle time on various facilities were linked to the bicycle time on one of the facility in order to estimate. Overall, the results look good. Bicycle mode choice between OD pairs is sensitive to the type of routes (bicycle friendly) available between the OD pair.

The value of cost-related coefficients proved difficult to estimate because of a limited variation in travel costs across the travel services provided in the region. Often in addition to an OD survey, stated preference survey is necessary to adequately estimate cots coefficients and the derived VOT. Nevertheless, in order to complete the model estimation task, the basic auto VOT was enforced (by linking the cost coefficient to time coefficient) to be around 15$/h (VOT being assumed to range between 1/3 and 2/3 of the wage rate, the hourly wage corresponding for the NCR to $30-35/h) for work purpose and lower VOT was assumes for other purposes.

One of the important positive features of the proposed mode choice model that proved itself in the estimation is that there was no need to introduce “flat” mode choice constants by geographic location like CBD destination dummy for transit that most of the regional mode choice models have. The combination of such estimated variables as auto delays, transit right-of-way attractiveness (guided transit not subject to congestion), and population/employment density explains the observed mode shares variation across the different geographic areas. This increases the strength of the model forecasting ability under changing conditions and for new network or land-use scenarios.

Estimated models for school and maintenance purposes have a stronger nesting coefficient close to 0.68-0.79. A nesting coefficient of 1 indicates MNL structure which means that no nesting exists. A smaller value shows strong nest behavior which indicates that the mode considerations of transit sub-modes are different from the preferences between transit and other modes. It means, that if a new transit mode is introduced (for example, LRT) the expected ridership for this new mode for these purposes will mostly come from the existing transit modes. Contrary to that, we may expect a stronger switch to transit from private modes for work, university and discretionary purposes.

5.7.2 Mode Choice Estimation Results for AM and PM period

The model estimation results with all mode utility coefficients for all travel purposes for AM and PM period are summarized in Table 5-30 through Table 5-34 below. The mode specific constants are fully segmented by time period, but all other variables have generic coefficients across AM and PM periods. All coefficients except constants for AM and PM are generic across the 3 work purposes. Table 5-30 shows the estimation results for work purpose. The constants for each work purpose (low income, medium income and high income) are the sum of mode specific constants (by time period) and the coefficient for specific income group by each mode. The mode specific constants are estimated such that they match the aggregate mode shares.

In addition to the LOS variables discussed in Subsection 5.7.1 above, for work trips, a strong car-sufficiency and income impact should be mentioned. Zero-car households strongly favor transit and bicycling, while high-car-sufficiency households do not favor bicycling. Additionally, low-income households logically favor walk-to-transit mode but not bicycling. Low-density residential areas (with a high percentage of detached houses) favor auto driver modes and do not favor walk to transit modes. Higher employment density at the destination (workplace) end logically has a positive impact on propensity to use all transit modes compared to the auto modes.

For university trips, the LOS variables are discussed in Subsection 5.7.1 above. In addition to those, a strong car-sufficiency impact should be mentioned. Zero-car households cannot use auto driver and park-and-ride modes. Low-car-sufficiency households favor transit and high-car-sufficiency favor park-n-ride modes. Low-density residential areas (with a high percentage of detached houses) strongly favor Park-and-Ride and kiss-and-ride, and makes bicycling unattractive. Higher population density at the trip origin (residential) end and the size of the university at the trip destination end positively enhance propensity to use walk-to-transit and bicycling modes. Logically, travel behaviour of university students is not dependent on the household income.

In addition to the LOS variables discussed in Subsection 5.7.1 above, for school trips, the following main impacts should be mentioned. School trips constitute the only segment where school bus is considered as additional mode while some modes (like Park-and-Ride and bike-and-ride) are not really observed and hence get excluded (very high negative constants). Low-car-sufficiency households disfavor auto driver modes while high-car-sufficiency households strongly favor auto driver modes and school bus. Residential population density has a certain negative impact on use of the auto driver mode; Logically, households living in detached houses (presumably in low-density areas) strongly rely on school bus. School enrolments have positive impact on transit, school bus and bicycling.

In addition to the LOS variables discussed in Subsection 5.7.1 above, for maintenance trips, a strong car-sufficiency impact should be mentioned. Zero-car households cannot use auto driver and park-and-ride modes. They strongly favour transit modes and bicycling. High-car-sufficiency households favour auto driver modes (SOV, HOV2 and HOV3+). Higher employment density at the trip destination enhances propensity to use transit modes. In general, there is very low frequency of using Park-and-Ride, Kiss-and-Ride and Bike-and-Ride modes because of comparatively short trip distances and other factors common for shopping and escorting trips in all metropolitan regions.

In addition to the LOS variables discussed in Subsection 5.7.1 above, for discretionary trips, a strong car-sufficiency impact should be mentioned. Zero-car households cannot use auto driver and park-and-ride modes. They strongly favour transit modes. High-car-sufficiency households strongly disfavour transit modes and favour auto driver modes. There is a certain positive impact of employment density at the trip destination end on use of all transit modes. Densely populated areas tend to favour bicycling and no favour auto modes. Similar to maintenance trips, there is a low observed frequency of using Park-and-Ride and Kiss-and-Ride options in general.

Table 5-30 | Estimation results for mode choice model for work trips

Variables	SOV	HOV 2	HOV2	HOV 3+	HOV3+	Conventional				Premium				
		Driver	Pass	Driver	Pass	Walk	PNR	KNR	BNR	Walk	PNR	KNR	BNR	Bicycle
Constants - AM	2.0945	0.0121	0.0000	-1.1164	-0.8040	2.1806	-1.9185	-3.0607	-5.0000	2.2440	-1.1452	-2.9609	-5.0000	0.1841
Constants - PM	2.1985	0.1578	0.0000	-1.1062	-0.9544	2.2724	-1.7277	-3.6140	-5.0000	2.2403	-1.3633	-2.2894	-5.0000	0.0822
Level of Service Variables														
Auto Free Flow Time			-0.0308											
Auto Delay			-0.0562											
Auto & Parking Cost			-0.1200											
Transit IVTT										-0.0228				
IVTT transit Way										0.0128				
IVTT low stop density										0.0011				
IVTT high stop density										-0.0050				
Wait Time										-0.0684				
Walk Time										-0.0530				
Number of Boardings										-0.1140				
Drive Access Time										-0.0308				
Bicycle Time by Facility Type														
Mixed Traffic														-0.0618
Paved Shoulders														-0.0525
Bike Lane with Traffic														-0.0309
Multi Use - Stone Dust														-0.0340
Multi Use - Asphalt														-0.0247
Exclusive Bike Lane														-0.0155
Household Variables														
Low Income						1.7428	-0.0550	1.7428	1.7428	1.3425	0.8641	1.3425	1.3425	-0.0438
Medium Income						0.9319	0.4535	0.9319	0.9319	0.6940	0.2156	0.6940	0.6940	-0.0438
Zero Cars	-99.0000					0.4075	-99.0000	-0.8517	0.4075	0.4075	-99.0000	-0.8517	0.4075	1.0612
Car Sufficiency Low	-0.1110						-0.2668	-1.2592				-1.2592		
Car Sufficiency High														-0.1536
Zonal Characteristics														
Employment Density						0.0008	0.0008	0.0008	0.0008	0.0009	0.0009	0.0009	0.0009	0.0003
Super Zonal Characteristics														
Population Density						0.0018	-0.0087	-0.0087		0.0018	-0.0087	-0.0087		0.0034
% Detached HH	1.0117	1.0117		1.0117		-1.3042				-1.3042				-1.1682
Nesting Upper Level							0.90000							
Nesting Lower Level							0.87020							

Table 5-31 | Estimation results for mode choice model for university trips

Variables	SOV	HOV 2	HOV2	HOV 3+	HOV3+	Conventional				Premium				
		Driver	Pass	Driver	Pass	Walk	PNR	KNR	BNR	Walk	PNR	KNR	BNR	Bicycle
Constants - AM	1.747	0.238		-0.692	0.286	2.461	-3.535	-2.481	-3.539	1.935	-4.061	-3.007	-4.065	-0.662
Constants - PM	2.260	0.313		-0.506	0.029	2.561	-2.141	-2.474	-3.439	2.003	-2.699	-3.031	-3.997	-0.248
Level of Service Variables														
Auto Free Flow Time			-0.013											
Auto Delay			-0.026											
Auto & Parking Cost			-0.150											
Transit IVTT									-0.020					
IVTT transit Way									0.008					
IVTT low stop density									0.003					
IVTT high stop density									-0.003					
Wait Time									-0.061					
Walk Time									-0.030					
Number of Boardings									-0.083					
Drive Access Time									-0.013					
Bicycle Time by Facility Type														
Mixed Traffic														-0.066
Paved Shoulders														-0.053
Bike Lane with Traffic														-0.044
Multi Use - Stone Dust														-0.044
Multi Use - Asphalt														-0.031
Exclusive Bike Lane														-0.022
Household Variables														
Zero Cars	-99.000	-99.000		-99.000		0.184	-99.000			0.184	-99.000			
Car Sufficiency Low						0.184				0.184				
Car Sufficiency High							0.510				0.510			
Super Zonal Characteristics														
Population Density	-0.009	-0.009		-0.009		0.015				0.015				0.030
% Detached HH							2.051	2.020			2.051	2.020		-2.065
University Enrollment	0.00001													0.00002
Nesting - Upper							0.90000							
Nesting - Lower							0.90000							

Table 5-32 | Estimation results for mode choice model for school trips

Variables	SOV	HOV 2	HOV2	HOV 3+	HOV3+	Conventional				Premium					School Bus
		Driver	Pass	Driver	Pass	Walk	PNR	KNR	BNR	Walk	PNR	KNR	BNR	Bicycle	
Constants - AM	-2.852	-1.723		-1.934	0.847	2.540	-6.548	-4.705	-6.460	1.294	-7.793	-5.951	-7.706	-2.273	1.666
Constants - PM	-3.509	-2.406		-3.220	0.533	2.466	2.466	-4.779	-6.534	0.888	0.888	-6.357	-8.112	-2.981	0.485
Level of Service Variables															
Auto Congested Time	-0.017														
Auto & Parking Cost	-0.179														
Distance															-0.012
Transit IVTT						-0.017									
Wait Time						-0.050									
Walk Time						-0.034									
Number of Boardings						-0.084									
Drive Access Time						-0.017									
Bicycle Time														-0.073	
Household Variables															
Zero Cars	-99	-99		-99			-99				-99			0.801	
Car Sufficiency Low	-2.613	-1.207		-1.207											
Car Sufficiency High	0.233	0.081		0.081											0.196
Zonal Characteristics															
Population Density	-0.026	-0.026		-0.026										0.008	-0.009
% Detached HH	-0.855	-0.855		-0.855		-0.740				-0.740					0.388
Employment Density															-0.019
School Enrollments	0.0005					0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0006	0.0001
Nesting - Upper level	0.900														
Nesting - Lower level	0.791														

Table 5-33 | Estimation results for mode choice model for maintenance trips

Variables	SOV	HOV 2	HOV2	HOV 3+	HOV3+	Conventional				Premium				
		Driver	Pass	Driver	Pass	Walk	PNR	KNR	BNR	Walk	PNR	KNR	BNR	Bicycle
Constants - AM	1.858	1.370		0.026	-0.627	0.995	-4.590	-4.799	-4.005	-0.194	-5.780	-5.989	-5.194	-3.756
Constants - PM	1.170	0.611		-0.829	-0.779	0.264	-6.800	-6.596	-4.737	-0.876	-7.940	-7.736	-5.876	-3.425
Level of Service Variables														
Auto Free Flow Time	-0.028													
Auto Delay	-0.057													
Auto & Parking Cost	-0.250													
Transit IVTT						-0.029								
IVTT transit Way						0.010								
IVTT low stop density						0.003								
IVTT high stop density						-0.005								
Initial Wait Time						-0.088								
Xfer Wait Time						-0.103								
Walk Time						-0.074								
Number of Boardings						-0.059								
Drive Access Time						-0.028								
Bicycle Time by Facility Type														
Mixed Traffic														-0.139
Paved Shoulders														-0.111
Bike Lane with Traffic														-0.093
Multi Use - Stone Dust														-0.069
Multi Use - Asphalt														-0.046
Exclusive Bike Lane														-0.023
Household Variables														
Zero Cars	-99.000	-99.000		-99.000		1.993	-99.000	1.993	1.993	1.993	-99.000	1.993	1.993	1.817
Car Sufficiency Low														0.957
Car Sufficiency High	0.019	0.019		0.019										
Zonal Characteristics														
% Detached HH	0.310	0.310		0.310		-1.233				-1.233				-0.706
Employment Density						0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	
Super Zonal Characteristics														
Population Density	0.004	0.004		0.004		0.010	0.034			0.010	0.034			0.022
Nesting - Upper	0.677													
Nesting - Lower	0.900													

Table 5-34 | Estimation results for mode choice model for discretionary trips

Variables	SOV	HOV 2 Driver	HOV2 Pass	HOV 3+ Driver	HOV3+ Pass	Conventional Walk	Conventional PNR	Conventional KNR	Conventional BNR	Premium Walk	Premium PNR	Premium KNR	Premium BNR	Bicycle
Constants - AM	2.746	1.213		-0.208	0.060	2.034	-4.627	-4.966	-4.966	1.443	-5.218	-5.557	-5.557	0.563
Constants - PM	1.181	0.647		-0.445	-0.101	0.836	-5.825	-6.164	-6.164	0.289	-6.372	-6.711	-6.711	-0.903
Level of Service Variables														
Auto Free Flow Time	-0.0257													
Auto Delay	-0.0514													
Auto & Parking Cost	-0.1910													
Transit IVTT						-0.0219								
IVTT transit Way						0.0100								
IVTT low Stop Density						0.0030								
IVTT High Stop Density						-0.0050								
Wait Time						-0.0502								
Walk Time						-0.0527								
Number of Boardings						-0.0438								
Drive Access Time						-0.0257								
Bicycle Time by Facility Type														
Mixed Traffic														-0.1149
Paved Shoulders														-0.0919
Bike Lane with Traffic														-0.0766
Multi Use - Stone Dust														-0.0766
Multi Use - Asphalt														-0.0575
Exclusive Bike Lane														-0.0306
Household Variables														
Zero Cars	-99.000	-99.000		-99.000		0.8028	-99.000	0.8028	0.8028	0.8028	-99.000	0.8028	0.8028	0.1997
Car Sufficiency Low														-2.2294
Car Sufficiency High	0.1581	0.0435		0.0435		-0.1843	-0.1843	-0.1843	-0.1843	-0.1843	-0.1843	-0.1843	-0.1843	-0.3664
Zonal Characteristics														
% Detached HH	-0.7024	-0.7024		-0.7024		-1.9878				-1.9878				-1.0019
Employment Density						0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	-0.0066
Super Zonal Characteristics														
Population Density	-0.0045	-0.0045		-0.0045										0.0170
Nesting - Upper	0.9000													
Nesting - Lower	0.9000													

5.8 Trip Assignment

5.8.1 Auto Assignment

Auto assignment procedures used at different stages of the integrated “mode choice – assignment” model are described in Subsection 3.10.1 above. The auto assignment algorithm (“static user equilibrium”) is built-in in the EMME package and does not require many specific parameters except for specification of the volume-delay functions, value of time specification and stopping criteria: maximum number of iterations as well allowed relative and absolute gaps. The applied volume-delay functions are described in detail in the Section 4.3 previously. The value of time was defined as $10/hr (SOV and external), $15/hr (HOV 2), $20/hr (HOV 3+) and $20/hr (commercial) vehicles. This value of time is used in the generalized cost function to convert any tolls into equivalent of minutes in the decision to find the best cost route. In the 2011 networks, there are no links with tolls so this does not impact the model results.

The stopping criteria applied according to the strategy described in Subsection 3.10.1 above. Both gaps were set to a small value of 0.1 that corresponds to a very good level of convergence. The maximum number of iterations is set in a flexible incremental way. At the beginning of the mode choice procedure when trip matrices are still very crude, a limited number of assignment iterations is implemented (10, 20, 30…) since a crude estimation of auto travel times and volumes would suffice. As the result, the auto assignment normally stops by the maximum number iterations saving on the run time. Close to the end of the mode choice procedure when trip matrices are nearing the convergent state, a large number of assignment iterations is implemented (…, 60, 70, 80) in order to ensure an accurate estimation of auto travel times and volumes. As the result, the auto assignment normally stops by achieving the specified gaps.

5.8.2 Bicycle Assignment

The bicycle assignment and the iterative procedures between bicycles and autos are described in Subsection 3.10.2 above. The bicycles are assigned to the road network using the auto assignment algorithm in EMME. However, the volume-delay functions for bicycles are defined separately and are very different from the auto volume-delay functions. The volumes delay function parameters in bicycle assignment are calculated based on the auto assignment results to account for cross impacts between auto and bicycles.

The stopping criteria applied in a similar as in the auto assignment. Both gaps were set to a small value of 0.1 that corresponds to a very good level of convergence. The maximum number of iterations is set in a flexible incremental way. At the beginning of the mode choice procedure when trip matrices are still very crude, a limited number of assignment iterations is implemented (10, 20, 30…), however, the bicycle assignment converges very fast in 3-4 iterations.

5.8.3 Transit Assignment

Transit assignment procedures used at different stages of the integrated "mode choice – assignment" model are described in Subsection 3.10.4 above. The extended transit assignment algorithm ("strategies with variant") is built-in in the EMME package. It requires several transit service related attributes, path-building parameters (weights applied for walk and wait time as well as boarding/transit penalties) and sources for calculation of in-vehicle, walk, and wait times. The initial setting of transit path building parameters are summarized in Table 5-35 below. In the transit network, 3 stop types are defined: 1=pole, 2=shelter, 3=station which can be extended in future based on changes in the transit network. These stop types are used for defining wait convenience factor and base boarding times. The wait time convenience factor has a highest value (higher penalty on wait time) for pole stop type and lowest value for station stop type. The base boarding times are currently set as same for all these stop types but can be changed in future to account for bigger stations which require more time to make transfers between lines.

Transit assignments are distinguished between local-only assignment and premium transit assignment. In general, the applied transit assignment parameters are in agreement with the estimated mode choice parameters with regard to LOS variables and weights described in Subsection 5.7.1 above.

The transit assignment parameters can be re-estimated in future if new surveys are available. It may include bus speed surveys as well as special surveys of transit users (on-board surveys) that provide statistics about transit itineraries and, in particularly, number of transfers and riders' preferences regarding transfer points.

Table 5-35 | Transit Assignment Parameters

Path Component	Parameter	Weight
Wait time	Variable "spline function" computing wait time as a function of headway as discussed in Subsection **3.10.4**	Wait Convenience Factor by stop type: 2.5 for "pole", 2.25 for "shelter" and 2.00 for "station".
Boarding time	Boarding type was defined by station type: 0.5 (pole and shelter) and 1.0 (station).	2.5
Boarding Cost	Mode specific boarding fare (see	1.0
In-vehicle time	Weighted representation of in-vehicle time to account for more productive use of time in some of the modes. • Regular bus : 1.00 • Express bus : 0.95 • BRT : 0.95 • O-Train : 0.93 • LRT : 0.90	1+ crowding factor + productivity bonus *proportion of seated passengers. Crowding function parameters: • IVT weight for seating passenger ideal (1.0) • IVT weight for seating passenger at full capacity (1.2) • Curve for seating passenger (2.0) • IVT weight for standing passenger ideal (1.5)

Path Component	Parameter	Weight
		• IVT weight for standing passenger at full capacity (2.0) • Curve for standing passenger (3.0) Productivity Bonus: • Express buses : -0.1 • LRT /BRT : -0.1
Dwelling time	1.5 seconds per boarding, 0.5 seconds per alighting	
Auxiliary Time	Walking time	2.0

Table 5-36 shows the 2011 base fare by service type. For university students, a discounted fare was used based on the discounts available in Ottawa and Gatineau. For university students in Ottawa, the transit pass fee included in the tuition so their perceived transit fare cost was assumed as zero. For the Gatineau side, a per-ride cost was computed based on the student pass value. There are no transfer costs for transfers between non-express transit services. For express and interzonal bus services, a top up fare is paid. Due to limitations in EMME, the fares are not represented correctly at each transfer. However, the fare skims were corrected in the EMME script to remove duplicate fares (when a transfer is made) before the fares are used in the mode choice model.

Table 5-36 | Fare Classification by Mode

Service Type	Fare (cents)	University Student Discounted Fare (cents)	Transfer Fare to "transfer to" this Service
OCT Regular, BRT, LRT	260	0	None
OCT Express	390	0	130
O-Train	285	0	None
STO Regular	295	106	None
STO Express	345	106	50
STO Interzonal	590	106	250; 200 from STO Express

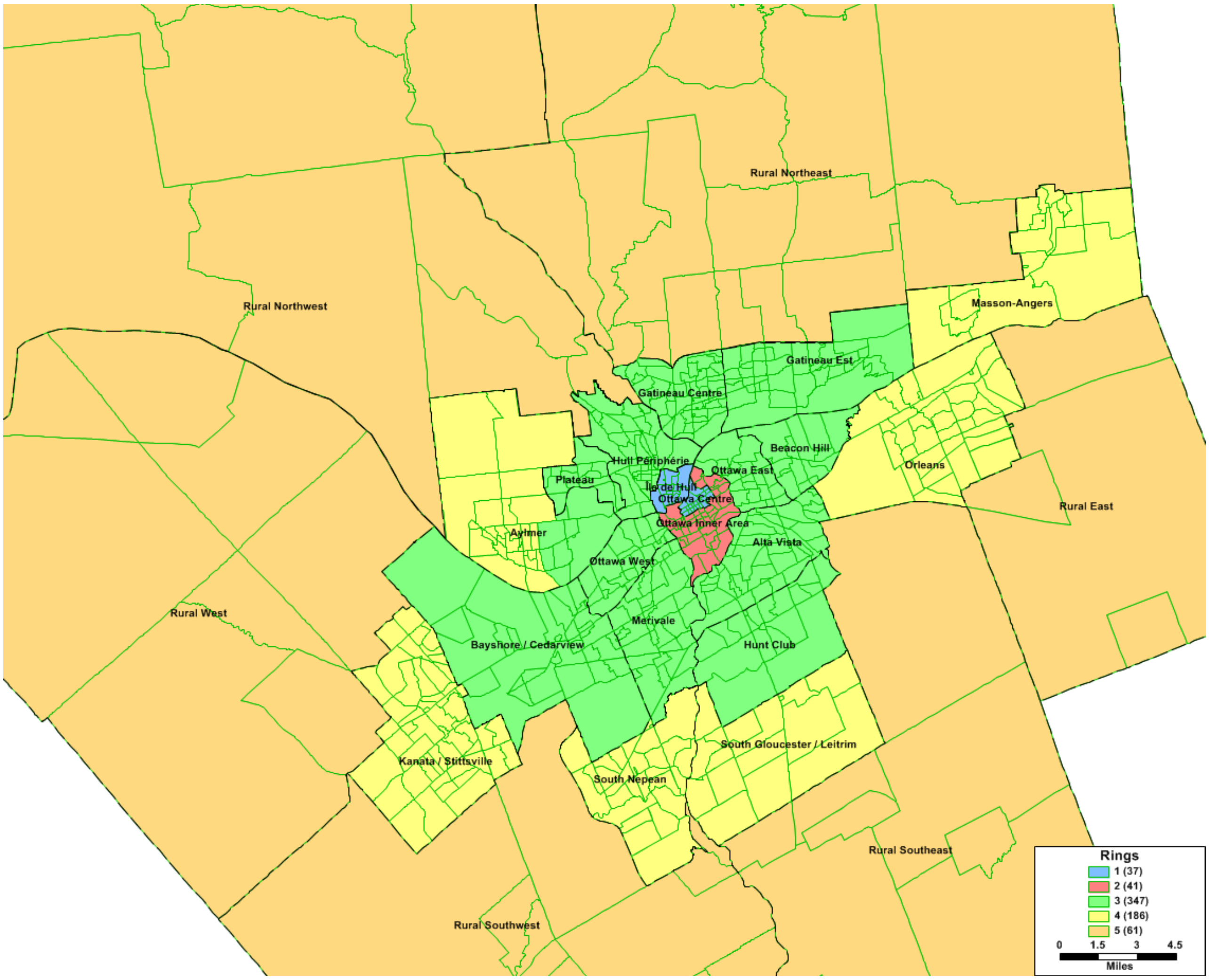
5.9 Validation of Model System

After implementation, each component of the model system has been validated against the observed statistics from the OD Survey across multiple relevant dimensions. The car ownership model was validated across number of workers in the households and number of autos in the household. Exhibit 5-1 shows the comparison between Model output and OD Survey. After a few rounds of calibrating, the distribution of households by auto ownership and number of workers closely match the OD survey distributions.

Exhibit 5-1 | Car Ownership Model Validation Results

Most of the tour level models were validated at the ring level by purpose. Exhibit 5-2 shows the definition of rings in the Ottawa-Gatineau region. The rings are defined as more or less concentric loops around the CBD area. Downtown Ottawa and Gatineau together is defined as the Ring 1 or CBD. Ring 2 is the urban neighborhood south of Ottawa downtown. This ring does not cover any area on the Gatineau side. Ring 3 is the area surrounding ring 1 and 2, but inside the Greenbelt. Ring 4 are the sub-urban areas outside of green belt and Ring 5 mostly covers the rural areas.

Exhibit 5-2 | Definition of Rings for Model Validation



The tour productions and attractions were validated and calibrated by tour purpose (7), province (Ottawa vs Gatineau) and rings (5). Table 5-37 and Table 5-38 below summarize final aggregate validation results for tour production and attractions. Overall, the results look very good and the calibration process helped to better match productions and attractions at ring level. The productions and attractions shown below in the Tables are unbalanced productions and attractions.

Table 5-37 | Tour Production Validation Results

Purpose	Ottawa - Modelled	Ottawa-Observed	Ottawa % Difference	Gatineau - Modelled	Gatineau-Observed	Gatineau % Difference
1- Work Low	15,453	17,098	-9.6%	10,466	10,867	-3.7%
2- Work Med	126,731	139,590	-9.2%	55,566	57,601	-3.5%
3- Work High	210,417	218,863	-3.9%	54,444	57,261	-4.9%
Subtotal - Work	**352,601**	**375,551**	**-6.1%**	**120,476**	**125,729**	**-4.2%**
4- University	54,196	52,097	4.0%	11,931	11,708	1.9%
5- School	117,415	115,767	1.4%	38,310	40,673	-5.8%
6- Maintenance	243,756	265,094	-8.0%	65,862	70,554	-6.7%
7- Discretionary	133,464	140,067	-4.7%	35,491	36,788	-3.5%
Total	**901,432**	**948,576**	**-5.0%**	**272,070**	**285,452**	**-4.7%**

Table 5-38 | Tour Attraction Validation Results

Purpose	Ottawa - Modelled	Ottawa-Observed	Ottawa % Difference	Gatineau - Modelled	Gatineau-Observed	Gatineau-% Difference
1- Work Low	19,206	19,072	0.7%	7,927	7,992	-0.8%
2- Work Med	150,361	148,879	1.0%	42,438	40,736	4.2%
3- Work High	227,960	225,832	0.9%	41,637	42,116	-1.1%
SubTotal - Work	**397,527**	**393,783**	**1.0%**	**92,002**	**90,844**	**1.3%**
4- University	57,776	55,150	4.8%	9,686	7,632	26.9%
5- School	117,084	114,677	2.1%	38,350	39,934	-4.0%
6- Maintenance	268,403	267,640	0.3%	69,390	64,328	7.9%
7- Discretionary	132,890	136,375	-2.6%	37,560	35,549	5.7%
Total	**973,680**	**967,625**	**0.6%**	**246,988**	**238,287**	**3.7%**

The pre-mode choice model was also calibrated and validated by purpose and rings. Rings 1 - 2, and Rings 4 - 5 were combined since they have very similar walk mode shares. Table 5-39 and Table 5-40 below summarize final validation results for pre-mode choice tour production and attractions.

Table 5-39 | Pre-Mode (Walk) Tour Production Validation Results

Ring	Purpose	Modelled	Observed	Difference (Model-Observed)
1,2	1- Work Low	20.7%	20.8%	-0.1%
	2- Work Med	27.2%	26.8%	0.4%
	3- Work High	27.6%	28.3%	-0.7%
	4- University	31.8%	32.1%	-0.3%
	5- School	42.3%	42.6%	-0.3%
	6- Maintenance	31.4%	32.1%	-0.8%
	7- Discretionary	40.3%	40.5%	-0.2%
	Subtotal	**31.9%**	**32.5%**	**-0.7%**
3	1- Work Low	6.8%	6.8%	0.0%
	2- Work Med	4.5%	4.4%	0.0%
	3- Work High	3.4%	3.4%	0.0%
	4- University	6.7%	6.7%	-0.1%
	5- School	23.3%	23.5%	-0.2%
	6- Maintenance	9.6%	9.9%	-0.3%
	7- Discretionary	11.7%	11.7%	0.0%
	Subtotal	**9.2%**	**9.3%**	**-0.1%**
4,5	1- Work Low	8.2%	8.2%	0.0%
	2- Work Med	2.6%	2.7%	-0.1%
	3- Work High	1.0%	1.0%	0.0%
	4- University	2.3%	2.4%	-0.1%
	5- School	19.4%	19.6%	-0.2%
	6- Maintenance	7.2%	7.3%	-0.2%
	7- Discretionary	7.7%	7.8%	0.0%
	Subtotal	**9.5%**	**9.3%**	**0.2%**
All Rings	**1- Work Low**	6.2%	6.2%	0.0%
	2- Work Med	4.3%	4.5%	-0.2%
	3- Work High	9.7%	10.4%	-0.7%
	4- University	22.5%	22.9%	-0.4%
	5- School	10.6%	11.2%	-0.6%
	6- Maintenance	13.3%	14.1%	-0.8%
	7- Discretionary	9.5%	9.3%	0.2%
Total		**6.2%**	**6.2%**	**0.0%**

Table 5-40 | Pre-Mode (Walk) Tour Attraction Validation Results

Ring	Purpose	Modelled	Observed	Difference (Model-Observed)
1,2	1- Work Low	13.1%	13.1%	0.0%
	2- Work Med	9.6%	9.6%	0.0%
	3- Work High	8.3%	8.2%	0.0%
	4- University	12.6%	12.8%	-0.1%
	5- School	30.4%	30.6%	-0.3%
	6- Maintenance	28.7%	28.9%	-0.2%
	7- Discretionary	29.0%	29.3%	-0.3%
	Subtotal	**15.4%**	**15.8%**	**-0.4%**
3	1- Work Low	7.7%	7.7%	0.0%
	2- Work Med	4.5%	4.7%	-0.2%
	3- Work High	2.7%	2.7%	0.0%
	4- University	6.4%	6.4%	0.0%
	5- School	21.3%	21.8%	-0.5%
	6- Maintenance	8.9%	9.0%	0.0%
	7- Discretionary	11.4%	11.4%	0.0%
	Subtotal	**8.6%**	**8.7%**	**-0.1%**
4,5	1- Work Low	5.9%	6.0%	-0.1%
	2- Work Med	4.0%	4.0%	0.0%
	3- Work High	2.5%	2.5%	0.0%
	4- University	5.0%	5.0%	0.0%
	5- School	21.8%	22.5%	-0.8%
	6- Maintenance	8.9%	9.0%	-0.1%
	7- Discretionary	8.9%	8.9%	0.0%
	Subtotal	**10.2%**	**10.5%**	**-0.4%**
All Rings	**1- Work Low**	8.9%	9.5%	-0.5%
	2- Work Med	6.0%	6.3%	-0.3%
	3- Work High	4.5%	4.6%	0.0%
	4- University	9.7%	10.3%	-0.6%
	5- School	22.3%	23.0%	-0.7%
	6- Maintenance	11.2%	11.3%	-0.1%
	7- Discretionary	13.8%	14.0%	-0.2%
Total		**11%**	**11%**	**0%**

The stop attraction model was validated by tour purpose and direction of tour (outbound vs. inbound). Table 5-41 below summarizes final validation results for stop attraction model.

Table 5-41 | Stop Attraction Validation Results

Purpose	Modelled	Observed	Difference (Model-Observed)	Modelled	Observed	Difference (Model-Observed)
Outbound						
1- Work Low	3,559	3,519		1.5%	1.4%	
2- Work Med	15,297	16,193	-896	6.3%	6.3%	0.0%
3- Work High	29,616	31,575	-1,959	12.3%	12.3%	-0.1%
4- University	3,408	3,610	-202	1.4%	1.4%	0.0%
5- School	2,241	2,049	192	0.9%	0.8%	0.1%
6- Maintenance	150,046	160,316	-10,270	62.1%	62.7%	-0.5%
7- Discretionary	37,346	38,597	-1,251	15.5%	15.1%	0.4%
SubTotal - Work	**48,472**	**51,288**	**-2,816**	**20.1%**	**20.0%**	**0.1%**
Total	**241,513**	**255,860**	**-14,347**			
Inbound						
1- Work Low	6,396	6,517	-121	2.6%	2.5%	0.1%
2- Work Med	36,434	38,399	-1,965	15.1%	15.0%	0.1%
3- Work High	54,161	57,573	-3,412	22.4%	22.5%	-0.1%
4- University	10,545	10,587	-41	4.4%	4.1%	0.3%
5- School	12,538	13,268	-730	5.2%	5.2%	0.0%
6- Maintenance	150,046	160,316	-10,270	62.1%	62.7%	-0.5%
7- Discretionary	37,346	38,597	-1,251	15.5%	15.1%	0.4%
SubTotal - Work	**96,991**	**102,489**	**-5,498**	**40.2%**	**40.1%**	**0.1%**
Total	**307,466**	**325,257**	**-17,791**			

The TOD production choice model results were validated by direction of tour and by stop frequency Table 5-42 to Table 5-48 below summarize final validation results for TOD and stop frequency choice model for tour productions. The model results are less than 0.5% difference from OD survey for most cases.

Table 5-42 | Low Income Work Productions - TOD and Stop Frequency Validation Results

Time Period		Modelled	Observed	Modelled	Observed	Difference (Model-Observed)
Outbound						
1	Early	2,766	2,950	11.50%	12.10%	-0.60%
2	AM Peak	12,668	12,929	52.68%	53.00%	-0.32%
3	Midday	6,707	6,671	27.89%	27.30%	0.59%
4	PM Peak	1,370	1,332	5.70%	5.50%	0.20%
5	Night	536	509	2.23%	2.10%	0.13%
Total		**24,047**	**24,391**	**100%**	**100%**	

Time Period		Modelled	Observed	Modelled	Observed	Difference (Model-Observed)
Inbound						
1	Early	1	-	0.00%	0.00%	0.00%
2	AM Peak	124	315	0.52%	1.30%	-0.78%
3	Midday	5111	5,120	21.26%	21.00%	0.26%
4	PM Peak	12591	13,160	52.36%	52.00%	0.36%
5	Night	6219	5,795	25.86%	25.70%	0.16%
Total		**24,046**	**24,391**	**100%**	**100%**	
Stop Frequency						
0	No Stop	17,411	17,770	72.40%	72.90%	-0.50%
1	Outbound Stop Only	1,132	1,505	5.50%	6.20%	-0.70%
2	Inbound Stop Only	4,351	3,931	18.09%	16.10%	1.99%
3	Both Stops	1,153	1,186	4.79%	4.90%	-0.11%
Total		**24,047**	**24,391**	**100%**	**100%**	

Table 5-43 | Medium Income Work Productions - TOD and Stop Frequency Validation Results

Time Period		Modelled	Observed	Modelled	Observed	Difference (Model-Observed)
Outbound						
1	Early	23,996	24,722	13.64%	13.79%	-0.15%
2	AM Peak	109,686	114,073	62.34%	62.00%	0.34%
3	Midday	34,053	33,505	19.35%	18.69%	0.67%
4	PM Peak	6,061	5,315	3.44%	2.96%	0.48%
5	Night	2148	1681.96	1.22%	0.94%	0.28%
Total		**175,944**	**179,297**	**100%**	**100%**	
Inbound						
1	Early	30	109.41	0.02%	0.06%	-0.04%
2	AM Peak	801	816.71	0.46%	0.46%	0.00%
3	Midday	31803	29730.53	18.08%	17.50%	0.58%
4	PM Peak	111839	116575.2	63.56%	63.50%	0.06%
5	Night	31472	32065.27	17.89%	18.50%	-0.61%
Total		**175,945**	**179,297**	**100%**	**100%**	
Stop Frequency						
0	No Stop	133,802	137,658	76.05%	76.78%	-0.73%
1	Outbound Stop Only	10,059	8,395	5.72%	4.68%	1.03%

Time Period		Modelled	Observed	Modelled	Observed	Difference (Model-Observed)
2	Inbound Stop Only	24,412	25,622	13.87%	14.29%	-0.42%
3	Both Stops	7,671	7,622	4.36%	4.25%	0.11%
Total		**175,944**	**179,297**	**100%**	**100%**	

Table 5-44 | High Income Work Productions - TOD and Stop Frequency Validation Results

Time Period		Modelled	Observed	Modelled	Observed	Difference (Model-Observed)
Outbound						
1	Early	25,139	25,333	9.84%	9.84%	0.01%
2	AM Peak	180,937	182,261	70.84%	70.76%	0.07%
3	Midday	40,398	41,290	15.82%	16.03%	-0.22%
4	PM Peak	6,421	6,167	2.51%	2.39%	0.12%
5	Night	2539	2519.47	0.99%	0.98%	0.02%
Total		**255,434**	**257,571**	**100%**	**100%**	
Inbound						
1	Early	57	9.73	0.02%	0.00%	0.02%
2	AM Peak	423	812.97	0.17%	0.32%	-0.15%
3	Midday	40676	40775.01	15.92%	15.83%	0.09%
4	PM Peak	175876	177294	68.85%	68.83%	0.02%
5	Night	38400	38679.28	15.03%	15.02%	0.02%
Total		**255,432**	**257,571**	**100%**	**100%**	
Stop Frequency						
0	No Stop	188,998	191,146	73.99%	74.21%	-0.22%
1	Outbound Stop Only	16,138	16,242	6.32%	6.31%	0.01%
2	Inbound Stop Only	38,070	36,176	14.90%	14.05%	0.86%
3	Both Stops	12,227	14,007	4.79%	5.44%	-0.65%
Total		**255,433**	**257,571**	**100%**	**100%**	

Table 5-45 | University Productions - TOD and Stop Frequency Validation Results

Time Period		Modelled	Observed	Modelled	Observed	Difference (Model-Observed)
Outbound						
1	Early	800	623	1.31%	1.15%	0.16%
2	AM Peak	28,806	25,493	47.33%	47.16%	0.17%

Time Period		Modelled	Observed	Modelled	Observed	Difference (Model-Observed)
3	Midday	25,564	22,797	42.00%	42.17%	-0.17%
4	PM Peak	4,476	3,906	7.35%	7.22%	0.13%
5	Night	1222	1242.89	2.01%	2.30%	-0.29%
Total		**60,868**	**54,062**	**100%**	**100%**	
Inbound						
1	Early	21	5.07	0.03%	0.01%	0.03%
2	AM Peak	368	234.07	0.60%	0.43%	0.17%
3	Midday	17892	15635.75	29.39%	29.42%	-0.03%
4	PM Peak	24685	22484.56	40.55%	40.10%	0.45%
5	Night	17902	15702.07	29.41%	29.54%	-0.13%
Total		**60,868**	**54,062**	**100%**	**100%**	
Stop Frequency						
0	No Stop	49,021	44,427	80.54%	82.18%	-1.64%
1	Outbound Stop Only	2,509	2,034	4.12%	3.76%	0.36%
2	Inbound Stop Only	8,121	6,740	13.34%	12.47%	0.87%
3	Both Stops	1,217	860	2.00%	1.59%	0.41%
Total		**60,868**	**54,062**	**100%**	**100%**	

Table 5-46 | School Productions - TOD and Stop Frequency Validation Results

Time Period		Modelled	Observed	Modelled	Observed	Difference (Model-Observed)
Outbound						
1	Early	212	321	0.18%	0.27%	-0.08%
2	AM Peak	106,326	110,362	92.33%	92.25%	0.08%
3	Midday	7,973	8,266	6.92%	6.91%	0.01%
4	PM Peak	573	633	0.50%	0.53%	-0.03%
5	Night	69	50.73	0.06%	0.04%	0.02%
Total		**115,153**	**119,632**	**100%**	**100%**	
Inbound						
1	Early	0	0	0.00%	0.00%	0.00%
2	AM Peak	73	46.96	0.06%	0.04%	0.02%
3	Midday	47994	49429.53	41.68%	41.32%	0.36%
4	PM Peak	63873	66427.17	55.47%	55.53%	-0.06%
5	Night	3214	3728.55	2.79%	3.12%	-0.33%

Time Period		Modelled	Observed	Modelled	Observed	Difference (Model-Observed)
Total		**115,154**	**119,632**	**100%**	**100%**	
Stop Frequency						
0	No Stop	103,374	109,392	89.77%	91.44%	-1.67%
1	Outbound Stop Only	1,079	1,165	0.94%	0.97%	-0.04%
2	Inbound Stop Only	10,062	8,591	8.74%	7.18%	1.56%
3	Both Stops	639	483	0.55%	0.40%	0.15%
Total		**115,154**	**119,632**	**100%**	**100%**	

Table 5-47 | Maintenance Productions - TOD and Stop Frequency Validation Results

Time Period		Modelled	Observed	Modelled	Observed	Difference (Model-Observed)
Outbound						
1	Early	2,315	2,613	0.84%	0.89%	-0.05%
2	AM Peak	32,553	34,314	11.77%	11.67%	0.11%
3	Midday	134,503	143,570	48.64%	48.81%	-0.17%
4	PM Peak	58,147	62,139	21.03%	21.12%	-0.10%
5	Night	49031	51516.74	17.73%	17.51%	0.22%
Total		**276,549**	**294,153**	**100%**	**100%**	
Inbound						
1	Early	764	843.79	0.28%	0.29%	-0.01%
2	AM Peak	15483	16558.88	5.60%	5.63%	-0.03%
3	Midday	113199	119978.3	40.93%	40.79%	0.15%
4	PM Peak	70887	75956	25.63%	25.82%	-0.19%
5	Night	76216	80816.17	27.56%	27.47%	0.09%
Total		**276,549**	**294,153**	**100%**	**100%**	
Stop Frequency						
0	No Stop	188,198	202,091	68.05%	68.70%	-0.65%
1	Outbound Stop Only	33,549	34,024	12.13%	11.57%	0.56%
2	Inbound Stop Only	40,887	43,258	14.78%	14.71%	0.08%
3	Both Stops	13,915	14,781	5.03%	5.02%	0.01%
Total		**276,549**	**294,153**	**100%**	**100%**	

Table 5-48 | Discretionary Productions - TOD and Stop Frequency Validation Results

Time Period		Modelled	Observed	Modelled	Observed	Difference (Model-Observed)
Outbound						
1	Early	1,666	1,837	1.14%	1.27%	-0.13%
2	AM Peak	8,877	8,182	6.06%	5.64%	0.42%
3	Midday	37,752	38,197	25.76%	26.32%	-0.56%
4	PM Peak	49,072	48,243	33.48%	33.24%	0.24%
5	Night	49208	48677.76	33.57%	33.54%	0.03%
Total		**146,575**	**145,137**	**100%**	**100%**	
Inbound						
1	Early	122	200.2	0.08%	0.14%	-0.05%
2	AM Peak	2896	2445.29	1.98%	1.68%	0.29%
3	Midday	29322	28763.11	20.00%	19.82%	0.19%
4	PM Peak	18541	19295.9	12.65%	12.30%	0.35%
5	Night	95694	94432.27	65.29%	66.06%	-0.78%
Total		**146,575**	**145,137**	**100%**	**100%**	
Stop Frequency						
0	No Stop	120,137	119,664	81.96%	82.45%	-0.49%
1	Outbound Stop Only	9,819	9,427	6.70%	6.50%	0.20%
2	Inbound Stop Only	12,527	11,911	8.55%	8.21%	0.34%
3	Both Stops	4,092	4,135	2.79%	2.85%	-0.06%
Total		**146,575**	**145,137**	**100%**	**100%**	

The TOD attraction choice model results were validated by direction of tour and purpose. Table 5-49 to Table 5-55 below summarize final validation results for TOD and stop frequency choice model for tour productions. The model results are less than 0.5% difference from OD survey for most cases.

Table 5-49 | Low Income Work Attractions - TOD Validation Results

Time Period		Modelled	Observed	Modelled	Observed	Difference (Model-Observed)
Outbound						
1	Early	2,915	3,148	12.2%	12.5%	-0.3%
2	AM Peak	12,498	13,343	52.3%	52.8%	-0.5%
3	Midday	6,548	6,888	27.4%	27.3%	0.2%
4	PM Peak	1,441	1,388	6.0%	5.5%	0.5%
5	Night	491	509	2.1%	2.0%	0.0%
Total		**23,893**	**25,275**	**100%**	**100%**	**0%**

Time Period		Modelled	Observed	Modelled	Observed	Difference (Model-Observed)
Inbound						
1	Early	10	-	0.0%	0.0%	0.0%
2	AM Peak	301	203	1.3%	0.8%	0.5%
3	Midday	5,111	5,391	21.4%	21.3%	0.1%
4	PM Peak	12,614	13,396	52.8%	53.0%	-0.2%
5	Night	5,858	6,286	24.5%	24.9%	-0.4%
Total		**23,894**	**25,275**	**100%**	**100%**	**0%**

Table 5-50 | Medium Income Work Attractions - TOD Validation Results

Time Period		Modelled	Observed	Modelled	Observed	Difference (Model-Observed)
Outbound						
1	Early	23,677	26,021	13.5%	14.0%	-0.5%
2	AM Peak	110,879	118,147	63.3%	63.6%	-0.3%
3	Midday	33,227	34,458	19.0%	18.6%	0.4%
4	PM Peak	5,509	5,334	3.1%	2.9%	0.3%
5	Night	1,784	1,697	1.0%	0.9%	0.1%
Total		**175,076**	**185,656**	**100%**	**100%**	**0%**
Inbound						
1	Early	30	109	0.0%	0.1%	0.0%
2	AM Peak	631	848	0.4%	0.5%	-0.1%
3	Midday	28,968	30,345	16.5%	16.3%	0.2%
4	PM Peak	113,879	120,841	65.0%	65.1%	0.0%
5	Night	31,569	33,513	18.0%	18.1%	0.0%
Total		**175,077**	**185,656**	**100%**	**100%**	**0%**

Table 5-51 | High Income Work Attractions - TOD Validation Results

Time Period		Modelled	Observed	Modelled	Observed	Difference (Model-Observed)
Outbound						
1	Early	24,077	26,331	9.5%	10.0%	-0.5%
2	AM Peak	178,368	186,407	70.2%	70.5%	-0.4%
3	Midday	42,868	42,664	16.9%	16.1%	0.7%
4	PM Peak	6,523	6,390	2.6%	2.4%	0.1%
5	Night	2,397	2,551	0.9%	1.0%	0.0%
Total		**254,233**	**264,343**	**100%**	**100%**	**0%**
Inbound						

Time Period		Modelled	Observed	Modelled	Observed	Difference (Model-Observed)
1	Early	38	10	0.0%	0.0%	0.0%
2	AM Peak	494	860	0.2%	0.3%	-0.1%
3	Midday	39,614	40,719	15.6%	15.4%	0.2%
4	PM Peak	173,924	181,735	68.4%	68.7%	-0.3%
5	Night	40,164	41,019	15.8%	15.5%	0.3%
Total		**254,234**	**264,343**	**100%**	**100%**	**0%**

Table 5-52 | University Attractions - TOD Validation Results

Time Period		Modelled	Observed	Modelled	Observed	Difference (Model-Observed)
Outbound						
1	Early	706	509	1.2%	0.9%	0.2%
2	AM Peak	28,145	25,991	46.3%	46.8%	-0.4%
3	Midday	24,761	23,839	40.8%	42.9%	-2.1%
4	PM Peak	5,693	3,925	9.4%	7.1%	2.3%
5	Night	1,434	1,294	2.4%	2.3%	0.0%
Total		**60,739**	**55,557**	**100%**	**100%**	**0%**
Inbound						
1	Early	19	5	0.0%	0.0%	0.0%
2	AM Peak	559	290	0.9%	0.5%	0.4%
3	Midday	16,241	15,692	26.7%	28.2%	-1.5%
4	PM Peak	24,872	23,046	40.9%	41.5%	-0.5%
5	Night	19,048	16,523	31.4%	29.7%	1.6%
Total		**60,739**	**55,557**	**100%**	**100%**	**0%**

Table 5-53 | School Attractions - TOD Validation Results

Time Period		Modelled	Observed	Modelled	Observed	Difference (Model-Observed)
Outbound						
1	Early	285	309	0.2%	0.2%	0.0%
2	AM Peak	105,248	118,955	91.4%	91.9%	-0.5%
3	Midday	8,910	9,365	7.7%	7.2%	0.5%
4	PM Peak	633	752	0.5%	0.6%	0.0%
5	Night	78	64	0.1%	0.0%	0.0%
Total		**115,154**	**129,445**	**100%**	**100%**	**0%**
Inbound						
1	Early	1	-	0.0%	0.0%	0.0%

Time Period		Modelled	Observed	Modelled	Observed	Difference (Model-Observed)
2	AM Peak	28	47	0.0%	0.0%	0.0%
3	Midday	45,946	51,575	39.9%	39.8%	0.1%
4	PM Peak	65,481	73,575	56.9%	56.8%	0.0%
5	Night	3,698	4,248	3.2%	3.3%	-0.1%
Total		**115,154**	**129,445**	**100%**	**100%**	**0%**

Table 5-54 | Maintenance Attractions - TOD Validation Results

Time Period		Modelled	Observed	Modelled	Observed	Difference (Model-Observed)
Outbound						
1	Early	2,132	2,710	0.7%	0.9%	-0.2%
2	AM Peak	32,794	36,686	11.4%	12.1%	-0.8%
3	Midday	141,819	147,683	49.1%	48.8%	0.3%
4	PM Peak	60,595	62,882	21.0%	20.8%	0.2%
5	Night	51,235	52,629	17.8%	17.4%	0.4%
Total		**288,575**	**302,589**	**100%**	**100%**	**0%**
Inbound						
1	Early	727	842	0.3%	0.3%	0.0%
2	AM Peak	14,093	16,582	4.9%	5.5%	-0.6%
3	Midday	119,224	124,260	41.3%	41.1%	0.2%
4	PM Peak	75,054	78,090	26.0%	25.8%	0.2%
5	Night	79,478	82,816	27.5%	27.4%	0.2%
Total		**288,576**	**302,589**	**100%**	**100%**	**0%**

Table 5-55 | Discretionary Attractions - TOD Validation Results

Time Period		Modelled	Observed	Modelled	Observed	Difference (Model-Observed)
Outbound						
1	Early	1,871	1,840	1.2%	1.2%	0.0%
2	AM Peak	8,423	8,215	5.5%	5.5%	0.1%
3	Midday	40,353	39,944	26.6%	26.7%	-0.1%
4	PM Peak	49,883	49,190	32.9%	32.8%	0.0%
5	Night	51,280	50,674	33.8%	33.8%	0.0%
Total		**151,810**	**149,863**	**100%**	**100%**	**0%**
Inbound						
1	Early	211	200	0.1%	0.1%	0.0%
2	AM Peak	2,585	2,421	1.7%	1.6%	0.1%

Time Period		Modelled	Observed	Modelled	Observed	Difference (Model-Observed)
3	Midday	30,008	29,564	19.8%	19.7%	0.0%
4	PM Peak	19,970	19,743	13.2%	13.2%	0.0%
5	Night	99,036	97,935	65.2%	65.3%	-0.1%
Total		**151,810**	**149,863**	**100%**	**100%**	**0%**

While the model results are compared at various steps in the model process. The final stages of the demand estimation occurs following mode split and provides the most comprehensive opportunity to compare base data both reported and observed travel with modelled results for the base year. Overall the model results were initially compared with reported travel as summarized form the OD survey at a regional level. This comparison is summarized in Table 5-56 below for modelled and reported travel components. It is noted that the modelled travel demand when compared against the reported OD Survey travel generally underestimated slightly both auto trips (-4 to -6%), transit trips (-4 to -5%) and bicycle trips (-6% to -9%) during each of the AM and PM peaks. However, following further analysis of the observed count data (traffic and transit) across strategic screenlines the modelled demands were generally slightly higher than the observed data. The model of course was estimated using the OD Survey dataset and therefore compares well against this data a several different levels of aggregation. However, during validation with count database, the model was re-calibrated to reduce total number of trips to better match the counts. The differences noted between the OD survey results and the identified observed traffic flows therefore serve to provide both a high and low estimate of the base year travel demands from which the model results can be compared and fully evaluated against.

Table 5-56 | Regional Travel Demand Comparisons for the AM and PM peak Periods

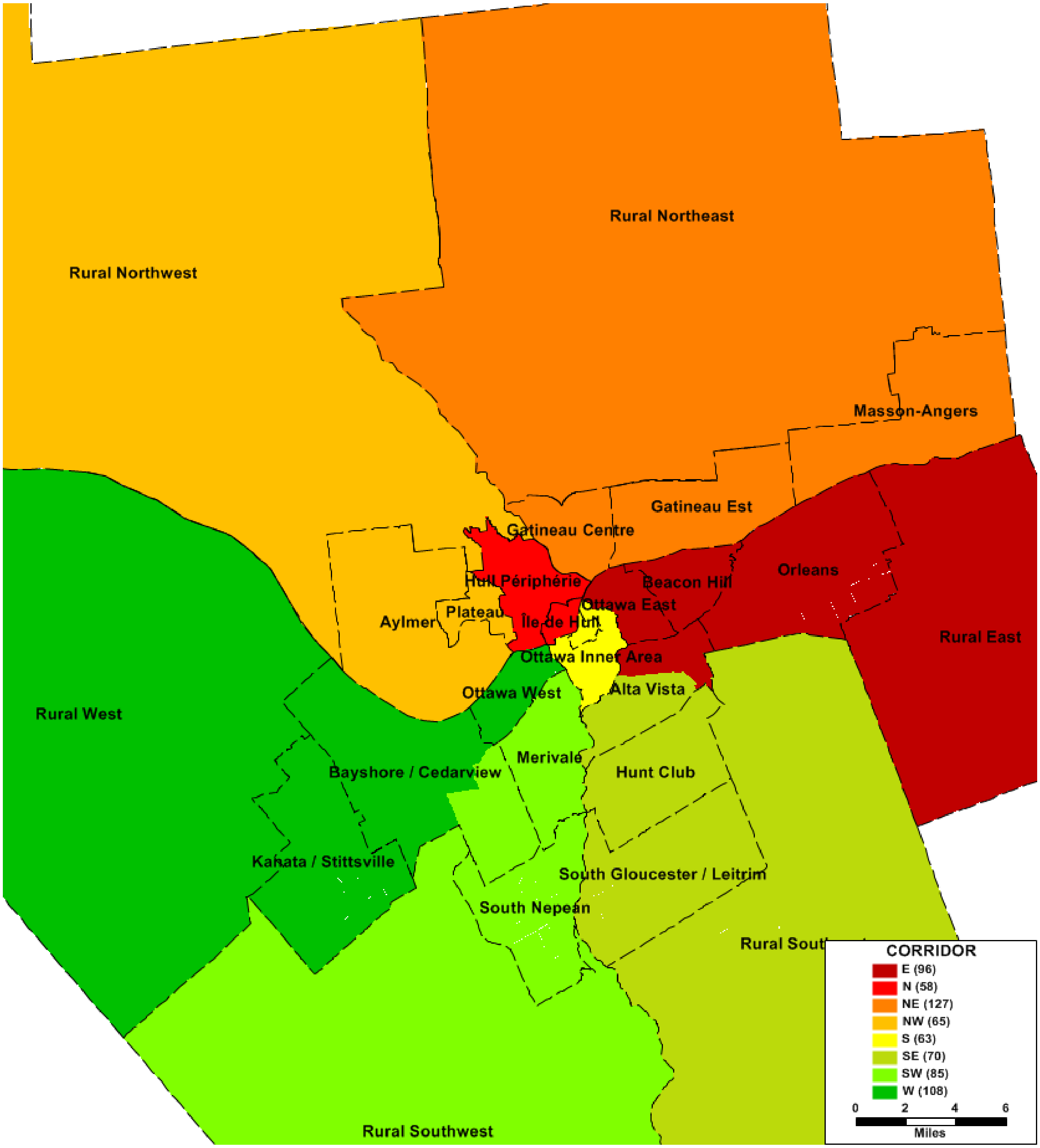
Region Wide Travel Demand	AM Period			PM Period		
	Model	OD Survey	% Difference	Model	OD Survey	% Difference
Total Auto Drivers	278,597	291,964	-4.6%	430,236	450,828	-4.6%
Total Auto Passengers	71,541	75,577	-5.3%	124,913	132,841	-6.0%
Average Occupancy	1.26	1.26		1.29	1.29	
Total Transit	103,552	109,531	-5.5%	113,856	119,031	-4.3%
Transit Mode Split	19.9%	19.2%		16.1%	16.0%	
Total Bicycle	12,933	13,839	-6.5%	16,144	17,750	-9.0%
Bicycle Mode Split	2.5%	2.4%		2.3%	2.4%	

Model results were also aggregated and scrutinized across a number of screenline and travel corridors. Eight travel corridors identified for the region were established to assess the model's ability to also reflect the reported travel by various modes of travel. Exhibit 5-3 shows the definition of eight corridors for the modelling region. For AM period, the directions are defined from all TAZs in the corridor to all TAZs within the corridor and to Ring 1 (CBD). For PM period, the direction is reversed. For example, “E” or East Corridor in the AM period means all trips originating with East Corridor and destined either within East Corridor or Downtown Ottawa/Gatineau (Ring 1). For PM period, it would be all trips originating in East Corridor and Downtown Ottawa/Gatineau and destined in East Corridor. These eight corridors cover all trips going in the specific direction. All the remaining traffic flows between the corridors are grouped in one group (EX) and the interprovincial flows not going to Downtown Ottawa/Gatineau are in one group (OG, GO). AM and PM mode choice models are calibrated separately. It requires the following steps:

1. Run Mode Choice model and generate validation statistics
2. Compare to OD Survey and calculate adjustment factors (applied as additional mode specific constants by corridor)
3. Adjustment factor = Old Adjustment Factor + Ln(Target Share/Modelled Share) , it’s calculated for each mode and corridor combination
4. Update EMME script to replace adjustment factors with new factors
5. Re-run mode choice model and repeat step 1-3

Table 5-57 and Table 5-58 show the validation results for mode choice model for AM and PM periods. The percentages differences are shown for differences greater than 0.5%. Overall, results show very good match of mode shares at the regional and corridor level.

Exhibit 5-3 | Definition of Corridor for Mode Choice Model Validation



As noted previously, the summary report compares modelled trips versus the OD survey reported trips by mode for each of the 8 corridors (defined in terms of Origin-Destination pairs) while the 0-EX and 9-GO categories refers to trips not defined within any of the eight predefined corridors. Overall the modelled mode shares remain within approximately 0.5% of reported mode shares for most of the corridors.

Table 5-57 | AM Mode Choice Validation Results

Survey

Corridor	Mode Distribution														
	SovDri	HOV2Dr	HOV2Pa	HOV3Dr	HOV3Pa	WkLoca	PNRLoc	KNRLoc	BkLoca	WkPrem	PNRPre	KNRPre	BkPrem	bicycl	schbus
0-EX	48.5%	9.3%	6.1%	2.8%	5.0%	10.3%	0.3%	0.3%	0.0%	9.0%	0.6%	0.5%	0.0%	2.2%	5.1%
1- E	33.3%	10.3%	6.4%	4.7%	7.6%	10.8%	0.1%	0.1%	0.0%	9.9%	1.0%	0.3%	0.0%	2.6%	12.8%
2-NE	37.1%	11.5%	8.3%	6.7%	8.4%	4.0%	0.6%	0.1%	0.0%	4.7%	0.7%	0.2%	0.0%	0.8%	17.0%
3- N	35.0%	9.8%	6.9%	4.1%	9.9%	26.0%	0.6%	0.2%	0.0%	2.5%	0.1%	0.0%	0.0%	2.1%	2.7%
4-NW	27.8%	13.0%	8.1%	6.8%	11.9%	12.0%	3.9%	0.6%	0.0%	0.0%	0.0%	0.1%	0.0%	1.8%	14.0%
5- W	33.3%	12.4%	6.1%	5.8%	8.0%	7.0%	0.2%	0.1%	0.0%	9.0%	1.5%	0.5%	0.0%	2.2%	13.9%
6-SW	31.0%	11.3%	6.4%	5.2%	7.7%	9.5%	0.2%	0.1%	0.0%	9.0%	1.7%	0.2%	0.0%	2.3%	15.3%
7- S	23.5%	10.0%	8.0%	2.4%	6.4%	22.8%	0.2%	0.2%	0.0%	4.0%	0.0%	0.0%	0.0%	15.3%	7.1%
8-SE	31.8%	10.7%	6.4%	5.3%	10.5%	10.8%	0.5%	0.2%	0.0%	7.3%	1.1%	0.1%	0.0%	1.4%	13.9%
9-GO	57.9%	9.2%	5.8%	2.5%	4.7%	8.2%	1.2%	0.5%	0.0%	5.1%	0.8%	0.6%	0.0%	2.4%	1.2%
Total	**40.6%**	**10.2%**	**6.3%**	**4.3%**	**6.9%**	**9.9%**	**0.4%**	**0.2%**	**0.0%**	**7.5%**	**0.8%**	**0.3%**	**0.1%**	**2.4%**	**10.1%**

Model

Corridor	Mode Distribution														
	SovDri	HOV2Dr	HOV2Pa	HOV3Dr	HOV3Pa	WkLoca	PNRLoc	KNRLoc	BkLoca	WkPrem	PNRPre	KNRPre	BkPrem	bicycl	schbus
0-EX	49.1%	9.6%	6.0%	2.9%	4.9%	10.1%	0.2%	0.1%	0.0%	9.0%	0.5%	0.6%	0.1%	2.1%	4.8%
1- E	33.4%	10.3%	6.4%	4.8%	7.7%	10.8%	0.1%	0.1%	0.0%	9.7%	1.0%	0.3%	0.0%	2.5%	12.8%
2-NE	37.2%	11.7%	8.0%	6.9%	8.2%	4.1%	0.7%	0.1%	0.0%	5.0%	0.5%	0.2%	0.0%	0.7%	16.7%
3- N	35.2%	10.0%	6.7%	4.2%	9.6%	26.3%	0.6%	0.2%	0.0%	2.6%	0.1%	0.0%	0.0%	1.9%	2.5%
4-NW	27.9%	13.1%	7.7%	6.9%	11.7%	12.1%	4.8%	0.7%	0.0%	0.0%	0.0%	0.1%	0.0%	1.6%	13.4%
5- W	33.2%	12.4%	6.0%	5.8%	8.2%	6.9%	0.2%	0.1%	0.0%	9.1%	1.5%	0.4%	0.1%	2.1%	14.1%
6-SW	31.0%	11.3%	6.4%	5.2%	7.8%	9.2%	0.2%	0.1%	0.0%	9.5%	1.6%	0.2%	0.0%	2.2%	15.3%
7- S	24.2%	10.3%	8.2%	2.6%	6.6%	22.0%	0.1%	0.1%	0.0%	4.2%	0.0%	0.0%	0.0%	14.7%	6.9%
8-SE	31.7%	10.7%	6.5%	5.2%	10.6%	10.7%	0.5%	0.2%	0.0%	7.3%	1.1%	0.1%	0.0%	1.1%	14.2%
9-GO	57.9%	9.1%	6.0%	2.6%	4.9%	8.7%	0.8%	0.4%	0.0%	5.3%	0.5%	0.4%	0.0%	2.0%	1.5%
Total	**38.3%**	**10.7%**	**6.5%**	**4.5%**	**7.2%**	**10.2%**	**0.5%**	**0.2%**	**0.0%**	**7.9%**	**0.8%**	**0.3%**	**0.1%**	**2.5%**	**10.4%**

Difference (Model-Survey)

Corridor	Mode Distribution														
	SovDri	HOV2Dr	HOV2Pa	HOV3Dr	HOV3Pa	WkLoca	PNRLoc	KNRLoc	BkLoca	WkPrem	PNRPre	KNRPre	BkPrem	bicycl	schbus
0-EX															
1- E															
2-NE															
3- N							0.9%								-0.6%
4-NW															
5- W															
6-SW	0.7%					-0.8%								-0.6%	
7- S															
8-SE															
9-GO	-2.3%	0.5%													
Total	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**

Table 5-58 | PM Mode Choice Validation Results

Survey

Corridor	Mode Distribution														
	SovDri	HOV2Dr	HOV2Pa	HOV3Dr	HOV3Pa	WkLoca	PNRLoc	KNRLoc	BkLoca	WkPrem	PNRPre	KNRPre	BkPrem	bicycl	schbus
0-EX	47.9%	11.6%	8.7%	4.3%	6.3%	8.8%	0.2%	0.1%	0.0%	7.4%	0.6%	0.2%	0.1%	1.9%	1.8%
1- E	38.6%	13.9%	10.7%	5.3%	9.1%	9.0%	0.0%	0.0%	0.0%	7.0%	0.7%	0.1%	0.0%	2.3%	3.1%
2-NE	38.8%	15.5%	10.0%	6.7%	9.7%	5.0%	0.5%	0.0%	0.0%	4.7%	0.7%	0.1%	0.0%	0.9%	7.5%
3- N	39.3%	12.3%	9.0%	4.0%	8.1%	20.0%	0.4%	0.1%	0.0%	2.2%	0.0%	0.0%	0.0%	3.7%	0.9%
4-NW	34.3%	13.3%	11.9%	7.0%	11.3%	10.0%	3.4%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	3.3%	5.1%
5- W	38.4%	15.8%	9.8%	6.8%	10.0%	5.0%	0.2%	0.0%	0.0%	6.0%	0.9%	0.2%	0.0%	2.3%	4.5%
6-SW	39.5%	15.7%	9.2%	5.4%	9.0%	7.0%	0.1%	0.1%	0.0%	6.9%	1.0%	0.2%	0.1%	1.4%	4.4%
7- S	26.4%	10.2%	8.8%	3.5%	10.1%	19.3%	0.2%	0.0%	0.0%	6.0%	0.0%	0.0%	0.0%	14.1%	1.5%
8-SE	42.1%	11.9%	8.8%	6.4%	9.1%	8.0%	0.5%	0.1%	0.0%	5.5%	0.8%	0.2%	0.0%	1.0%	5.5%
9-GO	42.5%	12.0%	10.0%	6.4%	9.1%	9.5%	0.6%	0.8%	0.0%	4.4%	1.2%	0.4%	0.1%	1.7%	1.3%
Total	**41.8%**	**13.3%**	**9.5%**	**5.3%**	**8.3%**	**8.3%**	**0.4%**	**0.1%**	**0.0%**	**6.2%**	**0.7%**	**0.2%**	**0.0%**	**2.4%**	**3.4%**

Model

Corridor	Mode Distribution														
	SovDri	HOV2Dr	HOV2Pa	HOV3Dr	HOV3Pa	WkLoca	PNRLoc	KNRLoc	BkLoca	WkPrem	PNRPre	KNRPre	BkPrem	bicycl	schbus
0-EX	48.3%	11.7%	8.7%	4.4%	6.1%	8.7%	0.2%	0.2%	0.0%	7.2%	0.6%	0.2%	0.1%	1.8%	1.7%
1- E	38.8%	14.0%	10.7%	5.4%	9.1%	8.9%	0.0%	0.0%	0.0%	6.8%	0.7%	0.2%	0.0%	2.2%	3.2%
2-NE	39.3%	15.7%	10.0%	6.8%	9.6%	4.8%	0.5%	0.0%	0.0%	4.6%	0.6%	0.1%	0.0%	0.7%	7.3%
3- N	39.6%	12.2%	8.8%	3.9%	7.8%	20.5%	0.5%	0.1%	0.0%	2.2%	0.0%	0.0%	0.0%	3.6%	0.9%
4-NW	34.9%	13.4%	11.8%	7.0%	11.0%	9.9%	3.3%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	3.2%	4.9%
5- W	38.5%	15.7%	9.7%	6.8%	10.0%	5.1%	0.2%	0.0%	0.0%	6.2%	0.9%	0.1%	0.0%	2.2%	4.6%
6-SW	39.6%	15.7%	9.3%	5.5%	8.9%	7.1%	0.1%	0.1%	0.0%	6.7%	0.9%	0.3%	0.0%	1.3%	4.5%
7- S	26.6%	10.3%	8.8%	3.4%	10.0%	19.3%	0.1%	0.1%	0.0%	6.1%	0.1%	0.0%	0.0%	13.6%	1.5%
8-SE	42.3%	11.9%	8.9%	6.5%	9.1%	7.8%	0.5%	0.1%	0.0%	5.4%	0.7%	0.2%	0.0%	0.8%	5.7%
9-GO	43.2%	12.1%	9.9%	6.4%	8.9%	9.5%	0.6%	0.7%	0.0%	4.5%	1.1%	0.2%	0.0%	1.6%	1.3%
Total	**42.1%**	**13.2%**	**9.4%**	**5.4%**	**8.2%**	**8.6%**	**0.4%**	**0.2%**	**0.0%**	**6.1%**	**0.7%**	**0.2%**	**0.0%**	**2.3%**	**3.3%**

Difference (Model-Survey)

Corridor	Mode Distribution														
	SovDri	HOV2Dr	HOV2Pa	HOV3Dr	HOV3Pa	WkLoca	PNRLoc	KNRLoc	BkLoca	WkPrem	PNRPre	KNRPre	BkPrem	bicycl	schbus
0-EX															
1- E	0.5%														
2-NE															
3- N	0.5%														
4-NW															
5- W															
6-SW															
7- S															
8-SE	0.7%														
9-GO															
Total	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**

Regional Cordon validation statistics were also compared based on an assessment of observed traffic count data as well as transit ridership statistics primarily from APC system (Automatic Passenger Counting system) which provided the base year 2011 travel demands for major facilitates crossing each of the cordons established. The final validation statistics for the AM and PM peak hours for each of the established regional cordons are summarized in Table 5-59 and Table 5-60 respectively. This summary focuses on the observed (from traffic and APC counts) vs. modelled trips for auto drivers (vehicle trips) and transit passengers crossing each of the six established regional cordons (Interprovincial, Greenbelt, Rideau River, Ottawa Inner Area, Gatineau Inner Area and Gatineau River). The auto volumes are compared for peak hour and the transit volumes are compared for peak period.

Table 5-59 | AM Validation against counts

Cordon	Auto (Peak Hour)			Transit (Peak Period)		
	Count	Volume	Ratio	Count	Volume	Ratio
Interprovincial	10,942	12,205	1.12	10,251	11,334	1.11
Greenbelt	38,739	37,686	0.97	22,428	22,714	1.01
Rideau River	21,345	21,809	1.02	26,175	25,857	0.99
Ottawa Inner Area	26,980	29,438	1.09	40,917	42,421	1.04
Gatineau Inner Area	10,468	11,127	1.06	13,570	13,768	1.01
Gatineau River	9,577	10,585	1.11	5,571	6,695	1.20

Table 5-60 | PM Validation against counts

Cordon	Auto (Peak Hour)			Transit (Peak Period)		
	Count	Volume	Ratio	Count	Volume	Ratio
Interprovincial	10,112	11,995	1.19	8,756	11,577	1.32
Greenbelt	36,384	32,496	0.89	19,229	21,558	1.12
Rideau River	21,030	23,582	1.12	25,182	25,553	1.01
Ottawa Inner Area	27,712	31,148	1.12	39,096	40,624	1.04
Gatineau Inner Area	9,511	11,162	1.17	11,438	12,737	1.11
Gatineau River	8,416	9,671	1.15	5,580	7,723	1.38

In general, the comparison of observed traffic volumes with the modelled results appear to be within acceptable ranges however, it is noted that the model produces more traffic for Gatineau River crossing and Interprovincial screenlines, particularly in PM period. Further review of the previous comparison of OD Survey results and reported mode splits confirmed that the modeled demands were generally not as high as the travel demands reported in the OD survey yet, significantly higher than the reported observed travel from the traffic counts and APC data sources. It is important to note that the observed travel demands are typically a single day “snapshot” of travel demands and in many cases variation would be expected by season and to a lesser extent by day of the week. The OD Survey, on the other hand, is based on reported travel (5% sample of residents) across a two month survey period and consequently would therefore tend to represent average conditions for the Fall period.

A more detailed screenline validation of the modelled travel demands was also carried out and is summarized in **Appendix C1 Screenline Demands**. In general, the AM Inbound travel demands for the AM peak hour across the vast majority of the regional screenlines represent the highest hourly travel demands. This is also representative of most urban centres of Ottawa-Gatineau size as the AM commuter peak tends to be more compressed. The AM non-peak direction (AM Outbound) is however significantly lower than its counterpart during the afternoon peak hour (PM Inbound). As a result the sum of travel demands (both directions of travel) across screenlines is higher for the PM than the AM despite the highest single direction of travel occurring during the AM peak hour.

In addition to screenline validation, modeled boarding and alighting volumes were compared to boarding and alighting counts for Transitway station as shown in Table 5-61. The counts and volumes are in similar ranges for most of the stations, particularly the one that carry large volumes. However, there are some stations (such as Billings Bridge Station) where the modeled boardings/alightings deviate significantly from the count data base.

Table 5-61 | Transitway Station Validation Report

Station #	Station	AM Period				PM Period			
		Boarding		Alighting		Boarding		Alighting	
		Count	Volume	Count	Volume	Count	Volume	Count	Volume
1	Barrhaven Centre	99	-	98	-	110	-	109	-
2	Baseline Station	1,893	2,054	3,318	2,582	2,103	1,784	3,687	1,624
3	Bayshore	959	1,128	776	520	1,065	776	862	968
4	Bayview Station	595	649	1,168	761	661	1,088	1,298	780
5	Billings Bridge Station	2,367	427	2,588	766	2,630	1,265	2,876	912
6	Blair Station	2,213	1,706	2,056	1,615	2,459	1,884	2,284	2,182
7	Campus Station	603	1,181	2,746	4,282	670	2,734	3,051	1,358
8	Cyrville Station	77	744	140	761	85	622	155	472
9	Dominion Station	285	445	138	248	317	174	153	334
10	Eagleson Park and Ride	1,269	1,221	315	2	1,410	148	350	5
11	Fallowfield Station	1,280	989	258	166	1,422	104	287	475
12	Greenboro Station								

Station #	Station	AM Period				PM Period			
		Boarding		Alighting		Boarding		Alighting	
		Count	Volume	Count	Volume	Count	Volume	Count	Volume
		878	1,836	786	1,582	975	2,016	873	2,643
13	Heron Station	447	734	608	1,069	497	1,030	676	731
14	Hurdman Station	7,479	8,322	7,563	7,963	8,310	9,039	8,403	10,453
15	Iris Station	386	235	139	348	429	350	154	592
16	Jeanne D'Arc	603	401	137	221	670	247	152	222
17	Laurier Station	766	1,298	2,318	1,581	851	3,787	2,575	1,344
18	Lebreton Station	1,858	1,216	1,993	1,205	2,064	1,697	2,214	890
19	Lees Station	1,006	654	575	436	1,118	364	639	727
20	Lincoln Fields Station	1,878	1,844	1,417	1,385	2,087	1,934	1,574	2,136
21	Longfields Station	99	46	28	61	110	47	31	100
22	Lycée Claudel	228	272	141	34	253	106	157	228
23	MacKenzie King Bridge	2,160	419	4,615	2,366	2,400	2,547	5,128	866
24	Marketplace Station	370	102	287	221	411	348	319	324
25	Millennium	44	45	82	4	49	13	91	66
26	Pinecrest Station	279	295	96	262	310	303	107	434
27	Place d'Orléans Station	1,354	1,985	1,031	796	1,504	652	1,146	1,213
28	Place d'Orléans P&R	688	383	40	8	764	6	44	1
29	Pleasant Park Station	149	675	55	152	166	310	61	284
30	Queensway Station	509	1,017	402	819	566	374	447	389
31	Riverside Station	55	380	143	136	61	183	159	246
32	Smyth Station	380	357	110	314	422	343	122	428
33	South Keys Station	938	299	827	19	1,042	187	919	275
34	Strandherd	447	974	67	651	497	526	74	656
35	St. Laurent Station	2,626	1,571	2,518	1,979	2,918	1,965	2,798	1,805
36	Terry Fox Station	525	386	208	346	583	274	231	481
37	Train Station	133	1,114	160	1,145	148	795	178	444
38	Trim Station	659	51	138	64	732	64	153	263
39	Tunney's Pasture								

Station #	Station	AM Period				PM Period			
		Boarding		Alighting		Boarding		Alighting	
		Count	Volume	Count	Volume	Count	Volume	Count	Volume
		1,637	1,182	3,075	2,463	1,819	2,815	3,417	1,019
40	Walkley Station	348	186	244	81	387	289	271	321
41	Westboro Station	888	1,090	446	394	987	601	496	698
	Total	41,457	39,913	43,850	39,808	46,062	43,791	48,721	39,389

6.0 PEER REVIEW

William Davidson, Senior Vice President, Parsons Brinckerhoff - June 9, 2014

The new TRANS Model (Ottawa-Gatineau), developed in 2014, represents an interesting hybrid construct where the basics of conventional trip-based models are enhanced by several components borrowed from the advanced Activity-Based Models (ABMs). In most respects, the developed model follows the best practices of classical trip-based models that have been intensively used in North America for the last two decades. The TRANS Model clearly separates travel generation, spatial distribution, mode choice, and assignment that is consistent with the trip-based modeling paradigm. All major steps are implemented in an aggregate fashion that made it possible to implement almost the entire system using EMME “macro” scripting language.

However, in design and implementation of every step, many advanced components were introduced that sets this model apart from most previously developed trip-based models and brings it closer to advanced ABMs. The model system includes a population synthesizer that is implemented at a fully disaggregate level. The travel generation and distribution steps are implemented in a tour-based fashion, although the tour structure is somewhat simplified (only one intermediate stop is considered in each tour direction). The mode system includes a detailed tour-based time-of-day choice model sensitive to the Level-of-Service (LOS) variables. This is a significant improvement over many trip-based models that operate with simplified “peak period factors” and cannot portray future peak spreading effects or congestion pricing impacts.

My specific area of interest relates to travel forecasting for transit. For many years, I have been leading the travel forecasting practice for numerous New Starts projects at Parsons Brinckerhoff. The United States Federal Transit Administration (FTA) has established a set of very rigid acceptance guidelines for travel models based upon many years of tracking the performance of travel models by comparison of the forecasts to the actual observed ridership for multiple transit services and projects. This has resulted in many improvements to mode choice models, regardless of in a trip-based or ABM framework. I’m pleased to see that the new TRANS Model incorporated many of the recent improvements recommended by PB and consistent with FTA guidelines. This includes consideration of transit capacity constraints and crowding, explicit modeling of station choice for Park-and-Ride and Kiss-and-Ride trips, and many others.

All models were statistically estimated with the recent Origin-Destination survey conducted in the Ottawa-Gatineau region. I find the coefficient values for time and cost components reasonable and generally consistent with the best-practice models developed in North America. The additional differentiation of in-vehicle time by stop frequency and crowding conditions is a very important improvement that is in line with the recent research sponsored by FTA and recently applied in Los Angeles and Chicago. In particular, this model properly differentiates between conventional transit services (such as local bus in a mixed traffic) and premium transit services (such as BRT or LRT).

Another very interesting and unique feature of this model relates to the inclusion of bicycle as a separate travel mode in the mode choice model as well as in highway assignment. Inclusion of bicycles in mode choice explicitly has become an important new feature already incorporated in several travel models in practice in the U.S. (Portland, San-Francisco, San Diego, and others). However, neither of them has yet incorporated bicycle in the traffic assignment. The approach implemented in the TRANS Model is probably the most advanced and comprehensive in travel modeling in practice today. The highway assignment and bicycle assignments are integrated though an iterative equilibration with the cross-impacts on each other. The bicycle assignment is sensitive to bicycle facility type (pathway, exclusive bike lanes, paved shoulders, mixed traffic, etc), auto congestion, bicycle congestion, and other parameters. This makes it possible to model specific projects that improve the bicycle infrastructure.

I also appreciate the effort made to comprehensively validate and calibrate this model for the base year against the observed traffic and transit counts by corridor, time-of-day, and direction. Even the bicycle volumes at several critical facilities were validated with promising results.

The entire model system is equilibrated with multiple level-of-service and accessibility measures fed back to all sub-models in a very detailed way. In this regard, the developed model system is more advanced that most of the travel models in practice. I find it very important from both theoretical and practical standpoint, that not only the mode choice and trip distribution models are subject to equilibration with LOS variables (that is the prevailing practice) but also travel generation, time-of-day choice, and even car ownership models are sensitive to the LOS variables. This way, all sub-models respond to changing LOS in future. The implemented sensitivity tests resulted in a very interesting analysis showing the magnitude of response of different sub-models to different policies. In general, I find the results very intuitive.

Overall, this model development effort resulted in a solid state-of-the-practice tool that can be used by the TRANS Agencies for important projects on policies including highway, transit, and bicycle components. I would also like to mention that this model represents an incremental step towards an advanced state-of-the-art micro-simulation ABM that would be a logical next step for the TRANS Model.

7.0 EMME USER GUIDE FOR TRANS MODEL

7.1 Database, Network Implementation

The model has been developed in EMME supported by auto, transit and bicycle network(s). In addition, separate distinct mode facilities, where appropriate been included to represent Bus and Train, as well as HOV2 and HOV3 facilities. The network has been maintained by TRANS Agencies, and as such receives ongoing attention in terms of updating network elements to best reflect new and proposed links (road, transit and cycling) based on the project planning related work being undertaken by the various stakeholders and associated planning agencies. The following network elements (EMME) are required for input into the model:

- 2.01 – modes: identify all the modes that will be used in the model
- 2.02 – transit vehicles: identify the different types of transit vehicles and/or facilities
- 2.11 – base network: develop the existing roadway network that serve as the baseline conditions. The roadway network includes attributes and/or links specific for each mode. Additional links are defined to connect traffic zones to the transportation network as the trip tables are related to TAZ. The base network includes the following:
    - Auto network links
    - Bicycle network
    - HOV network
    - Centroid connectors
- 2.21 – transit lines: OC Transpo and STO bus routes as well as any rail facility are defined including the routing and service frequency for all the various transit services in the NCR. Other transit link attributes are as follows:
    - dwt
    - noali / noboa
    - dwfac
    - ttf

7.2 Programming Implementation

The core model was implemented as an EMME/4 macro script structured in line with the model design flowchart in Exhibit 3-2. It has a three-level structure including the following components:

- Shell that is run by the user and calls sub-macros corresponding to particular model components,
- Sub-macros for main unique model components that call subroutines if necessary,
- Subroutines that correspond to procedures implemented multiple times.

The program structure, sub-macros, and subroutines are shown Table 6-1 below in the order of model flow execution. All macro files have the extension *“mac”.* The shell macro ***TRANSMod.mac*** represents a simple batch where all sub-macros are called is a sequence. Each sub-macro can be disabled if necessary. The following program logic and general rules should be taken into account:

- Sub-macros are sequenced in a logical order that correspond to their inputs and outputs. Each sub-macro requires outputs from the prior sub-macros. However, prior sub-macros are not dependent on the subsequent sub-macros. It should also be noted that each sub-macro has intermediate and final outputs that might override outputs of the subsequent sub-macros. Each sub-macro has a section where input and output matrices can be redefined in terms of their location in the EMME databank. This section, however, is intended for future model enhancements and for the user.
- The following run options can be derived from these rules:
    - The whole sequence can be run from sub-macro 1 through sub-macro 22,
    - Any sub-sequence with no gaps for example from sub-macro 1 through sub-macro 10 can be run and the results will be valid up to the output of sub-macro 10,

- Any subsequence with no gaps that not necessarily starts from sub-macro 1 can be run multiple times assuming that that the prior sub-macros have been run in the required sequence. For example, sub-macros 1-8 can be run to generate matrix marginals (tour productions and attractions) and then, the tour/trip distribution sub-macros 13-16 can be run multiple times (for example for testing or calibration purposes). In a similar way, sub-macros 1-16 can be run to construct trip matrices and then, the mode choice sub-macros 17 and 19 can be run multiple times (for testing different network scenarios).
- Submacro 18 is only required for feedback process to generate updated midday and early period transit and auto skims.
- Running sub-macro sequences with gaps (for example, 1-8 and then 13-14) or attempts to re-run some selected prior sub-macros before running later sub-macros will generate errors. If there is a need to change one of the inputs for say sub-macro 6, the whole sequence of sub-macros (6-14) should be re-run.

- Mode choice macros 17 (for the AM period) and 19 (for the PM period) represent the only exception from the sequencing rule. They can be run in any order and they are independent of each other. It should be noted that if both of them are run in a sequence, the network-relate results (road link and transit segment volumes, etc) will be stored in the corresponding networks. Some of the matrix-related results (LOS skims and mode trip matrices) will be saved for AM in the matrix range 2000-2999 and for PM in the range 3000-3999. However, some of the other matrix outputs (such as utility expressions, PNR adjustment factor and others) will be saved for the last run (say, AM) while the first run (say, PM) will be overridden because of the limited EMME databank space.

Table 7-1 | Transit Assignment Parameters

Shell	Sub-model	Subroutine
TRANSMod.mac **– call a sequence of sub-macros and specify network scenarios**	1. ***Input.mac*** – input all matrices from external files and calculate derived inputs	
	2. ***InputSkims.mac*** – input starting AM, MD and EA skims for accessibility calculations	
	3. ***SizeProd.mac*** – calculate total tour productions for use as size variable in accessibility calculation	
	4. ***SizeAttr.mac*** – calculate total tour attractions for use as size variable in accessibility calculation	
	5. ***Accessibility.mac*** – calculates various accessibility measures	
	6. ***CarOwner.mac*** – calculate car ownership choice	
	7. ***TourProd.mac*** – calculate total (motorized & non-motorized) tour productions	
	8. ***TourAttr.mac*** – calculate total (motorized & non-motorized) tour attractions	**8.1 AttrWorkInc.mac- splits the tour attraction for work by income groups**
	7-8. ***BalanTot.mac*** – balance total tour productions and attractions	
	9. ***NonMProd.mac*** – calculate share of	

Shell	Sub-model	Subroutine
	motorized tour productions	
	10. ***NonMAttr.mac*** – calculate share of motorized tour attractions	
	9-10. ***BalanMot.mac*** – balance motorized productions and attractions BalanWalk.mac?	
	11. ***TODProd.mac*** – call time-of-day & stop-frequency choice subroutine for tour productions for each purpose	**11.1.** *TODProd1.mac* **– for work low income**
		11.3. *TODProd2.mac* **– for work medium income**
		11.2. *TODProd3.mac* **– for work high income**
		11.4. *TODProd4.mac* **– for university**
		11.5. *TODProd5.mac* **– for school**
		11.6. *TODProd6.mac* **– for maintenance**
		11.7. TODProd7.mac **– for discretionary**
	12. ***TODAttr.mac*** – call time-of-day choice subroutine for tour attractions for each purpose	**12.1.** *TODAttr1.mac* **– for work low income**
		12.2. *TODAttr2.mac* **– for work medium income**
		12.3. *TODAttr3.mac* **– for work high income**
		12.4. *TODAttr4.mac* **– for university**
		12.5. *TODAttr5.mac* **– for school**
		12.6. *TODAttr6.mac* **– for maintenance**
		12.7. *TODAttr7.mac* **– for discretionary**
	11-12. ***BalanTOD.mac*** – balance productions and attractions for each time-of-day period	
	13. ***SeedMatr.mac*** – prepare seed matrices for tour ends (call ***MatSmoot.mac*** for each purpose)	**13.1.** *MatSmoot.mac* **– smooth up observed matrices from OD Survey**
	14. ***TourDist.mac*** – calculate tour-ends distribution (call ***MatConst.mac*** for each purpose, outbound time-of-day periods, and inbound time-of-day period)	**14.1.** *MatConst.mac* **– construct tour-end matrices by gravity-balancing method using seed matrices**
	15. ***StopAttr.mac*** – calculate stop-attraction size variables for stop-location choice	
	16. ***TripDist.mac*** – calculate trip distribution for direct and chained half-tours (call ChainDis.mac for each car-sufficiency group, purpose, direction, and time-of-day period)	**16.1.** *ChainDis.mac* **– calculate convoluted trip matrices for chained half-tour matrices based on stop-location choice**
	17. ***ModeAM.mac*** – calculate mode choice	

Shell	Sub-model	Subroutine
	for AM period	
	18. **CreateOffPeakSkims.mac** – updates EA and MD skims for accessibility calculation	
	19. *ModePM.mac* **– calculate mode choice for PM period**	

- Sub-macros 1-12 operate only with vectors (mo, md) except for macros 2,5 which read and use pre-calculated LOS variables (mf). These macros are independent of the network scenario because no procedures are performed on the network. Sub-macros 13-16 operate with vectors (mo, md), full matrices (mf), and use simple free-flow auto assignment or accessibility measures. Thus they are only slightly dependent on the network scenario. Sub-macros 17-19 operate with vectors (mo, md), full matrices (mf), and are heavily dependent on the network scenario in terms of both auto and transit networks. Thus, the corresponding network scenarios are passed as parameters to the macros in *TRANSMod.mac* batch.
- The following dimensions and components must be set for the EMME databank in order to run the entire model system:
    - The maximum number (9999) of matrices for all matrix types (ms, mo, md, mf); this requirement make it essential to use EMME/4 version of the pacakage.
    - Network scenarios for AM and PM periods including auto and transit networks with VDF and TTF functions ready for assignments.
    - Additional network scenario for EA and MD are required in order to update the skims between feedback iterations (**CreateOffPeakSkims.mac)**. If these scenarios are not available then user can comment out the **CreateOffPeakSkims.mac** macro and the input skims will be used for EA and MD scenarios for all feedback iterations.
    - Auto link extra-attributes for storage of multi-class auto assignment volumes. Initial content of these attributes is not important since it is overridden by the assignment. The following link extra attributes should be defined:
        - @sovd (peak hour SOV driver vehicle volume),
        - @hov2d (peak hour HOV 2 driver vehicle volume),
        - @hov2p (peak hour HOV 2 passenger volume),
        - @hov3d (peak hour HOV 3+ driver vehicle volume),
        - @hov3p (peak hour HOV 3+ passenger volume),
        - @comm (peak hour commercial vehicle volume),
        - @exte (peak hour external traffic volume).
    - Line-specific (@tboa) extra attributes for transit boarding time for both bus and rail lines. These attributes have been calibrated by TRANS staff and should not be changed. They are used as input parameters for transit assignments.
- The following additional link extra-attributes with traffic and transit counts should be prepared for calibration purposes for each period-specific network scenario (however, they are not used for forecasting runs, they are only used for analysis and validation with the macro *Valid.mac*):
    - @aucnt (peak hour traffic counts),

- @trcnt (peak hour transit counts),
- @cordn (cordon line index).

7.3 Model Run Options

The model system can be run in different ways as defined by the user and depending on the project need. The following standard model run options should be mentioned as probably the most frequently used:

- **Full daily run** including accessibility calculations, car ownership and tour generation stages; this is necessary for each base/target year and/or regional socioeconomic / land-use scenario. This run is preceded by the population synthesis procedure and invokes all sub-models 1-19.
- **Full Run with Feedback** includes first full daily run with AM assignment (17) and updating of Early and Midday skims (18). Then, the accessibilities are re-calculated with the revised set of skims and full daily run is conducted. After all the feedbacks are conducted, the PM assignments are done.
- **Daily run with fixed car ownership and tour/trip generation**; includes tour/trip distribution, mode choice, and assignments; this can be useful for comparing large-scale transportation network alternatives for a common horizon year. This run invokes sub-models 13-17, 19. It is assumed that a full daily run with a population synthesis procedure and sub-models 1-12 have already been implemented for the socioeconomic / land-use scenario.
- **Period-specific (AM or PM) run** with modelled (or fixed from prior run) car ownership, tour generation, and distribution that include only mode choice and assignments in the equilibrium framework with a fixed total trip matrix. The option could be used as the basic option in the evaluation of significant transit or highway projects. This run only invokes sub-model 17 or 19. It is assumed that a full run including tour/trip distribution stage (sub-models 1-16) have already been implemented for the socioeconomic / land-use scenario. If both AM and PM runs can be implemented in the same databank and the respective LOS matrices are saved in (2800-2999 and 4800-4999 range). However, if several runs for the same period with different network alternatives have to be implemented and the resulted demand and LOS matrices by modes have to be saved these runs have to be implemented in separate databanks.
- **Period-specific (AM or PM) and mode-specific (auto or transit) assignment** only, with fixed mode-specific trip matrix; this is an option frequently used for small-scale transportation improvements where a significant modal shift is not expected. It is assumed that a full run including mode choice stage (sub-models 1-17/19) have already been implemented for the socioeconomic / land-use / network scenario. This option is specified by the user using standard EMME/4 assignment procedures with the assignable matrices by modes (see **Subsections 3.9.1-3.9.2** above for details) and specific assignment settings.

7.4 Sub-Model Scripts

All macros are well commented and have self-explanatory headers for each section of scripts. The first section of each sub-model script contains user-defined parameters and specifications for input and output vectors *(mo, md)* and matrices *(mf).* The last section of each model script contains specifications for control, monitoring, and validation reports / summaries. Below is a detailed description of all sub-macros.

7.4.1 Sub-Macro “1. Input”

Sub-Macro 1 (***Input.mac***) plays a special role. It prepares all necessary vector (*mo, md*) and matrix (*mf*) inputs for the subsequent core model chain. The inputs are divided into two groups:

- Primary inputs from the external files. All external files should be prepared in the EMME batch input format with the specified headers including vector/matrix type, short name, number, and default value. The following rules are important to keep in mind when preparing the external files:
    - It is essential to follow the specifications below exactly since the vectors/matrices are referred to by their short names and default values are used to fill up missing records in the subsequent demand modelling procedures; note that EMME macro script language is case sensitive with respect to matrix names. Short matrix names should be up to 6 characters long by the EMME convention rules.
    - Long vector/matrix names are not used in the modelling procedures but are useful as comments in the databank.
    - The vector/matrix location number is important since it can be overridden if not placed in the specified slot (only the specified input slots are protected from overriding).
    - Each vector/matrix is placed in a separate input file to avoid confusion. Each matrix file is prepared according to the EMME format and starts with the EMME command that deleted the existing matrix in the same slot / number.
    - All external files for primary inputs for the TRANS Model should be placed in one subfolder specified in the control section.
    - The external file names are used in the current sub-macro only. It is possible for the user to specify different names and change the references in the sub-macro accordingly. It is recommended, however to use the file names specified below for uniformity and not to change them without a compelling reason.
    - Auto and transit networks are not handled by the sub-macro. It is assumed that they network scenarios have been already created by the user in the EMME databank.
    - No permanent data items are stored in scalar matrices *ms*. They are only used for intermediate calculations, summaries, and screen/file outputs.
- Derived inputs that represent transformations of the primary inputs (aggregations, density calculations, etc). These inputs are calculated by the sub-macro automatically with no user intervention.

The sub-macro script has the following sections:

- Control section of input parameters specified by the user:

  - Full path for the folder that contains external input files. It is recommended to use simplified DOS conventions for the folder and subfolder names to avoid EMME failure to read the input; in particular all folder names in the path must not have blank gaps.

- Section 1.1 deletes all existing matrices from the databank. It is important to keep in mind that the TRANS Model uses almost all matrix slots available in EMME/4 databank, thus *Input.mac* cleans the space needed for the model operation. If the user needs to input some additional data items (for example for model calibration or validation) it should be done after the model run and using one of the matrix slots left available in the databank.
- Section 1.2 inputs number of households by TAZ jointly distributed by size, number of workers, income group and dwelling/housing type. The program loops over household size categories 1-6, number-of-worker categories 0-3, income groups 1-4, housing types 1-2, and reads the external files created by the population synthesizer listed in Table 7-2 below.
- Section 1.3 inputs number of households by TAZ distributed by size. The program loops household size categories 1-6 and reads the external files used as marginal controls by the population synthesizer as listed in Table 7-3 below.
- Section 1.4 that inputs number of households by TAZ distributed by workers. The program loops household worker categories 0-3 and reads the external files used as marginal controls by the population synthesizer as listed in Table 7-4 below.
- Section 1.5 that inputs number of households by TAZ distributed by income groups. The program loops household income categories 1-4 and reads the external files used as marginal controls by the population synthesizer as listed in Table 7-5 below.
- Section 1.6 that inputs number of households by TAZ distributed by dwelling type, zonal labour force, and zonal population distributed by 6 age brackets. The program reads the external files used as marginal controls by the population synthesizer as listed in Table 7-6 below.
- Section 1.7 that inputs additional zonal characteristics including geographic aggregations of TAZ into superzones, districts, CBD, provinces, corridors, and rings, as well as TAZ area and total population. The program reads the external files as listed in Table 7-7 below.
- Section 1.8 that converts geographic aggregations from vectors into group partitions (*gs*, *gd*, gp, *gc*, *gp*, *gr, go and gq* for superzones, districts, Quebec, corridors, provinces, rings, Ontario and Quebec consequently). This group partitions must not be changed or overridden by the user. Then the program inputs additional external files for total number of households, share of low-income population. Finally, the program calculates various derived zonal characteristics (share of population of age 45 and older, population density, share of low-income population, share of detached houses) at different levels of geographic aggregation (TAZ, superzone, district). The created vectors are listed in Table 7-8 below.
- Section 1.9 inputs zonal data items that relate to employment (total and by different categories – major shops, street stops, retail, service, public offices, private offices, education institutions, and health institutions etc.), shopping Gross Leasable Area, Museum Area, Theatre Area, Park Area, Warehousing Area, university and school enrolment, as well as parking cost estimates for long (daily) and short (2-hour) parking, Average income by place of work, park-and-ride lot capacity and parking cost. The program also

calculates derived zonal characteristics like employment density, retail density, university enrolment and school enrolment at different levels of geographic aggregation (TAZ, superzone, district). The created vectors are listed in Table 7-9 below.

- A special subsection inputs observed daily tour generation statistics from the OD survey. They are not directly used in the modelling process but are useful for model validation reports. Thus, the corresponding matrices are placed in the EMME databank in the slots starting from 931. The program loops over travel purposes 1-7 and reads the external files for total tour productions, motorized tour productions, total tour attractions, and motorized tour attractions. The created vectors are listed in Table 7-10 below.
- Section 1.10 inputs observed matrices from the OD Survey. The program loops over travel purposes (1-7) and inputs daily tour-end matrices, AM trip matrices, and PM trip matrices. Then the program inputs total motorized trip matrices and mode-specific trip matrices (by 15 modelled modes) for AM and PM period. The created matrices are listed in Table 7-11 below.
- Section 1.11 inputs additional matrices needed for mode choice model and assignment procedures. They include AM peak period factor by OD, matrices of trips made by trucks and commercial vehicles for AM and PM peak hour, and matrices of auto trips made to and from external zones for AM and PM peak period. The created matrices are listed in Table 7-12 below. This section also calculates the intra-zonal distance, intra-zonal auto and bicycle time to fill after the skimming procedures. It also input AM peak hour scaling matrix
- Section 1.12 summarizes and outputs main statistics on the screen, including total population, total number of households, total labour force, total employment, total university enrollment, and total school enrollment. This section is optional and intended for monitoring purpose only. It can be extended by the user if necessary. In case of extension, scalar matrices *ms* with numbers of 900-999 are recommended to be used for intermediate calculations in order to avoid conflicts with other temporary stored data items. AM and PM peak period external trips are scaled down to peak hour condition

All input data items except for trip matrices for external zones relate to internal TAZs 1-672. Cells that relate to external zones obtain a default zero value in all other vectors/matrices.

Table 7-2 | Input Components (Joint Household Distribution)

Type	No	Name		Source	
		Short	Long (description)	File name	Created by
mo	1	H1011	HHs Size=1 Workers=0 Dwelltype=1 Income Group=1	H1011.in	PopSyn/out
mo	2	H1012	HHs Size=1 Workers=0 Dwelltype=1 Income Group=2	H1012.in	PopSyn/out
mo	3	H1013	HHs Size=1 Workers=0 Dwelltype=1 Income Group=3	H1013.in	PopSyn/out
mo	4	H1014	HHs Size=1 Workers=0 Dwelltype=1 Income Group=4	H1014.in	PopSyn/out
mo	5	H1021	HHs Size=1 Workers=0 Dwelltype=2 Income Group=1	H1021.in	PopSyn/out
mo	6	H1022	HHs Size=1 Workers=0 Dwelltype=2 Income Group=2	H1022.in	PopSyn/out
mo	7	H1023	HHs Size=1 Workers=0 Dwelltype=2 Income Group=3	H1023.in	PopSyn/out
mo	8	H1024	HHs Size=1 Workers=0 Dwelltype=2 Income Group=4	H1024.in	PopSyn/out
mo	9	H1111	HHs Size=1 Workers=1 Dwelltype=1 Income Group=1	H1111.in	PopSyn/out
mo	10	H1112	HHs Size=1 Workers=1 Dwelltype=1 Income Group=2	H1112.in	PopSyn/out
mo	11	H1113	HHs Size=1 Workers=1 Dwelltype=1 Income Group=3	H1113.in	PopSyn/out
mo	12	H1114	HHs Size=1 Workers=1 Dwelltype=1 Income Group=4	H1114.in	PopSyn/out
mo	13	H1121	HHs Size=1 Workers=1 Dwelltype=2 Income Group=1	H1121.in	PopSyn/out
mo	14	H1122	HHs Size=1 Workers=1 Dwelltype=2 Income Group=2	H1122.in	PopSyn/out
mo	15	H1123	HHs Size=1 Workers=1 Dwelltype=2 Income Group=3	H1123.in	PopSyn/out
mo	16	H1124	HHs Size=1 Workers=1 Dwelltype=2 Income Group=4	H1124.in	PopSyn/out
mo	17	H2011	HHs Size=2 Workers=0 Dwelltype=1 Income Group=1	H2011.in	PopSyn/out
mo	18	H2012	HHs Size=2 Workers=0 Dwelltype=1 Income Group=2	H2012.in	PopSyn/out
mo	19	H2013	HHs Size=2 Workers=0 Dwelltype=1 Income Group=3	H2013.in	PopSyn/out
mo	20	H2014	HHs Size=2 Workers=0 Dwelltype=1 Income Group=4	H2014.in	PopSyn/out
mo	21	H2021	HHs Size=2 Workers=0 Dwelltype=2 Income Group=1	H2021.in	PopSyn/out
mo	22	H2022	HHs Size=2 Workers=0 Dwelltype=2 Income Group=2	H2022.in	PopSyn/out
mo	23	H2023	HHs Size=2 Workers=0 Dwelltype=2 Income Group=3	H2023.in	PopSyn/out
mo	24	H2024	HHs Size=2 Workers=0 Dwelltype=2 Income Group=4	H2024.in	PopSyn/out
mo	25	H2111	HHs Size=2 Workers=1 Dwelltype=1 Income Group=1	H2111.in	PopSyn/out
mo	26	H2112	HHs Size=2 Workers=1 Dwelltype=1 Income Group=2	H2112.in	PopSyn/out
mo	27	H2113	HHs Size=2 Workers=1 Dwelltype=1 Income Group=3	H2113.in	PopSyn/out
mo	28	H2114	HHs Size=2 Workers=1 Dwelltype=1 Income Group=4	H2114.in	PopSyn/out
mo	29	H2121	HHs Size=2 Workers=1 Dwelltype=2 Income Group=1	H2121.in	PopSyn/out
mo	30	H2122	HHs Size=2 Workers=1 Dwelltype=2 Income Group=2	H2122.in	PopSyn/out
mo	31	H2123	HHs Size=2 Workers=1 Dwelltype=2 Income Group=3	H2123.in	PopSyn/out
mo	32	H2124	HHs Size=2 Workers=1 Dwelltype=2 Income Group=4	H2124.in	PopSyn/out
mo	33	H2211	HHs Size=2 Workers=2 Dwelltype=1 Income Group=1	H2211.in	PopSyn/out
mo	34	H2212	HHs Size=2 Workers=2 Dwelltype=1 Income Group=2	H2212.in	PopSyn/out
mo	35	H2213	HHs Size=2 Workers=2 Dwelltype=1 Income Group=3	H2213.in	PopSyn/out

Type	No	Name		Source	
		Short	Long (description)	File name	Created by
mo	36	H2214	HHs Size=2 Workers=2 Dwelltype=1 Income Group=4	H2214.in	PopSyn/out
mo	37	H2221	HHs Size=2 Workers=2 Dwelltype=2 Income Group=1	H2221.in	PopSyn/out
mo	38	H2222	HHs Size=2 Workers=2 Dwelltype=2 Income Group=2	H2222.in	PopSyn/out
mo	39	H2223	HHs Size=2 Workers=2 Dwelltype=2 Income Group=3	H2223.in	PopSyn/out
mo	40	H2224	HHs Size=2 Workers=2 Dwelltype=2 Income Group=4	H2224.in	PopSyn/out
mo	41	H3011	HHs Size=3 Workers=0 Dwelltype=1 Income Group=1	H3011.in	PopSyn/out
mo	42	H3012	HHs Size=3 Workers=0 Dwelltype=1 Income Group=2	H3012.in	PopSyn/out
mo	43	H3013	HHs Size=3 Workers=0 Dwelltype=1 Income Group=3	H3013.in	PopSyn/out
mo	44	H3014	HHs Size=3 Workers=0 Dwelltype=1 Income Group=4	H3014.in	PopSyn/out
mo	45	H3021	HHs Size=3 Workers=0 Dwelltype=2 Income Group=1	H3021.in	PopSyn/out
mo	46	H3022	HHs Size=3 Workers=0 Dwelltype=2 Income Group=2	H3022.in	PopSyn/out
mo	47	H3023	HHs Size=3 Workers=0 Dwelltype=2 Income Group=3	H3023.in	PopSyn/out
mo	48	H3024	HHs Size=3 Workers=0 Dwelltype=2 Income Group=4	H3024.in	PopSyn/out
mo	49	H3111	HHs Size=3 Workers=1 Dwelltype=1 Income Group=1	H3111.in	PopSyn/out
mo	50	H3112	HHs Size=3 Workers=1 Dwelltype=1 Income Group=2	H3112.in	PopSyn/out
mo	51	H3113	HHs Size=3 Workers=1 Dwelltype=1 Income Group=3	H3113.in	PopSyn/out
mo	52	H3114	HHs Size=3 Workers=1 Dwelltype=1 Income Group=4	H3114.in	PopSyn/out
mo	53	H3121	HHs Size=3 Workers=1 Dwelltype=2 Income Group=1	H3121.in	PopSyn/out
mo	54	H3122	HHs Size=3 Workers=1 Dwelltype=2 Income Group=2	H3122.in	PopSyn/out
mo	55	H3123	HHs Size=3 Workers=1 Dwelltype=2 Income Group=3	H3123.in	PopSyn/out
mo	56	H3124	HHs Size=3 Workers=1 Dwelltype=2 Income Group=4	H3124.in	PopSyn/out
mo	57	H3211	HHs Size=3 Workers=2 Dwelltype=1 Income Group=1	H3211.in	PopSyn/out
mo	58	H3212	HHs Size=3 Workers=2 Dwelltype=1 Income Group=2	H3212.in	PopSyn/out
mo	59	H3213	HHs Size=3 Workers=2 Dwelltype=1 Income Group=3	H3213.in	PopSyn/out
mo	60	H3214	HHs Size=3 Workers=2 Dwelltype=1 Income Group=4	H3214.in	PopSyn/out
mo	61	H3221	HHs Size=3 Workers=2 Dwelltype=2 Income Group=1	H3221.in	PopSyn/out
mo	62	H3222	HHs Size=3 Workers=2 Dwelltype=2 Income Group=2	H3222.in	PopSyn/out
mo	63	H3223	HHs Size=3 Workers=2 Dwelltype=2 Income Group=3	H3223.in	PopSyn/out
mo	64	H3224	HHs Size=3 Workers=2 Dwelltype=2 Income Group=4	H3224.in	PopSyn/out
mo	65	H3311	HHs Size=3 Workers=3+ Dwelltype=1 Income Group=1	H3311.in	PopSyn/out
mo	66	H3312	HHs Size=3 Workers=3+ Dwelltype=1 Income Group=2	H3312.in	PopSyn/out
mo	67	H3313	HHs Size=3 Workers=3+ Dwelltype=1 Income Group=3	H3313.in	PopSyn/out
mo	68	H3314	HHs Size=3 Workers=3+ Dwelltype=1 Income Group=4	H3314.in	PopSyn/out
mo	69	H3321	HHs Size=3 Workers=3+ Dwelltype=2 Income Group=1	H3321.in	PopSyn/out
mo	70	H3322	HHs Size=3 Workers=3+ Dwelltype=2 Income Group=2	H3322.in	PopSyn/out
mo	71	H3323	HHs Size=3 Workers=3+ Dwelltype=2 Income Group=3	H3323.in	PopSyn/out

Type	No	Name		Source	
		Short	Long (description)	File name	Created by
mo	72	H3324	HHs Size=3 Workers=3+ Dwelltype=2 Income Group=4	H3324.in	PopSyn/out
mo	73	H4011	HHs Size=4 Workers=0 Dwelltype=1 Income Group=1	H4011.in	PopSyn/out
mo	74	H4012	HHs Size=4 Workers=0 Dwelltype=1 Income Group=2	H4012.in	PopSyn/out
mo	75	H4013	HHs Size=4 Workers=0 Dwelltype=1 Income Group=3	H4013.in	PopSyn/out
mo	76	H4014	HHs Size=4 Workers=0 Dwelltype=1 Income Group=4	H4014.in	PopSyn/out
mo	77	H4021	HHs Size=4 Workers=0 Dwelltype=2 Income Group=1	H4021.in	PopSyn/out
mo	78	H4022	HHs Size=4 Workers=0 Dwelltype=2 Income Group=2	H4022.in	PopSyn/out
mo	79	H4023	HHs Size=4 Workers=0 Dwelltype=2 Income Group=3	H4023.in	PopSyn/out
mo	80	H4024	HHs Size=4 Workers=0 Dwelltype=2 Income Group=4	H4024.in	PopSyn/out
mo	81	H4111	HHs Size=4 Workers=1 Dwelltype=1 Income Group=1	H4111.in	PopSyn/out
mo	82	H4112	HHs Size=4 Workers=1 Dwelltype=1 Income Group=2	H4112.in	PopSyn/out
mo	83	H4113	HHs Size=4 Workers=1 Dwelltype=1 Income Group=3	H4113.in	PopSyn/out
mo	84	H4114	HHs Size=4 Workers=1 Dwelltype=1 Income Group=4	H4114.in	PopSyn/out
mo	85	H4121	HHs Size=4 Workers=1 Dwelltype=2 Income Group=1	H4121.in	PopSyn/out
mo	86	H4122	HHs Size=4 Workers=1 Dwelltype=2 Income Group=2	H4122.in	PopSyn/out
mo	87	H4123	HHs Size=4 Workers=1 Dwelltype=2 Income Group=3	H4123.in	PopSyn/out
mo	88	H4124	HHs Size=4 Workers=1 Dwelltype=2 Income Group=4	H4124.in	PopSyn/out
mo	89	H4211	HHs Size=4 Workers=2 Dwelltype=1 Income Group=1	H4211.in	PopSyn/out
mo	90	H4212	HHs Size=4 Workers=2 Dwelltype=1 Income Group=2	H4212.in	PopSyn/out
mo	91	H4213	HHs Size=4 Workers=2 Dwelltype=1 Income Group=3	H4213.in	PopSyn/out
mo	92	H4214	HHs Size=4 Workers=2 Dwelltype=1 Income Group=4	H4214.in	PopSyn/out
mo	93	H4221	HHs Size=4 Workers=2 Dwelltype=2 Income Group=1	H4221.in	PopSyn/out
mo	94	H4222	HHs Size=4 Workers=2 Dwelltype=2 Income Group=2	H4222.in	PopSyn/out
mo	95	H4223	HHs Size=4 Workers=2 Dwelltype=2 Income Group=3	H4223.in	PopSyn/out
mo	96	H4224	HHs Size=4 Workers=2 Dwelltype=2 Income Group=4	H4224.in	PopSyn/out
mo	97	H4311	HHs Size=4 Workers=3+ Dwelltype=1 Income Group=1	H4311.in	PopSyn/out
mo	98	H4312	HHs Size=4 Workers=3+ Dwelltype=1 Income Group=2	H4312.in	PopSyn/out
mo	99	H4313	HHs Size=4 Workers=3+ Dwelltype=1 Income Group=3	H4313.in	PopSyn/out
mo	100	H4314	HHs Size=4 Workers=3+ Dwelltype=1 Income Group=4	H4314.in	PopSyn/out
mo	101	H4321	HHs Size=4 Workers=3+ Dwelltype=2 Income Group=1	H4321.in	PopSyn/out
mo	102	H4322	HHs Size=4 Workers=3+ Dwelltype=2 Income Group=2	H4322.in	PopSyn/out
mo	103	H4323	HHs Size=4 Workers=3+ Dwelltype=2 Income Group=3	H4323.in	PopSyn/out
mo	104	H4324	HHs Size=4 Workers=3+ Dwelltype=2 Income Group=4	H4324.in	PopSyn/out
mo	105	H5011	HHs Size=5 Workers=0 Dwelltype=1 Income Group=1	H5011.in	PopSyn/out
mo	106	H5012	HHs Size=5 Workers=0 Dwelltype=1 Income Group=2	H5012.in	PopSyn/out
mo	107	H5013	HHs Size=5 Workers=0 Dwelltype=1 Income Group=3	H5013.in	PopSyn/out

Type	No	Name		Source	
		Short	Long (description)	File name	Created by
mo	108	H5014	HHs Size=5 Workers=0 Dwelltype=1 Income Group=4	H5014.in	PopSyn/out
mo	109	H5021	HHs Size=5 Workers=0 Dwelltype=2 Income Group=1	H5021.in	PopSyn/out
mo	110	H5022	HHs Size=5 Workers=0 Dwelltype=2 Income Group=2	H5022.in	PopSyn/out
mo	111	H5023	HHs Size=5 Workers=0 Dwelltype=2 Income Group=3	H5023.in	PopSyn/out
mo	112	H5024	HHs Size=5 Workers=0 Dwelltype=2 Income Group=4	H5024.in	PopSyn/out
mo	113	H5111	HHs Size=5 Workers=1 Dwelltype=1 Income Group=1	H5111.in	PopSyn/out
mo	114	H5112	HHs Size=5 Workers=1 Dwelltype=1 Income Group=2	H5112.in	PopSyn/out
mo	115	H5113	HHs Size=5 Workers=1 Dwelltype=1 Income Group=3	H5113.in	PopSyn/out
mo	116	H5114	HHs Size=5 Workers=1 Dwelltype=1 Income Group=4	H5114.in	PopSyn/out
mo	117	H5121	HHs Size=5 Workers=1 Dwelltype=2 Income Group=1	H5121.in	PopSyn/out
mo	118	H5122	HHs Size=5 Workers=1 Dwelltype=2 Income Group=2	H5122.in	PopSyn/out
mo	119	H5123	HHs Size=5 Workers=1 Dwelltype=2 Income Group=3	H5123.in	PopSyn/out
mo	120	H5124	HHs Size=5 Workers=1 Dwelltype=2 Income Group=4	H5124.in	PopSyn/out
mo	121	H5211	HHs Size=5 Workers=2 Dwelltype=1 Income Group=1	H5211.in	PopSyn/out
mo	122	H5212	HHs Size=5 Workers=2 Dwelltype=1 Income Group=2	H5212.in	PopSyn/out
mo	123	H5213	HHs Size=5 Workers=2 Dwelltype=1 Income Group=3	H5213.in	PopSyn/out
mo	124	H5214	HHs Size=5 Workers=2 Dwelltype=1 Income Group=4	H5214.in	PopSyn/out
mo	125	H5221	HHs Size=5 Workers=2 Dwelltype=2 Income Group=1	H5221.in	PopSyn/out
mo	126	H5222	HHs Size=5 Workers=2 Dwelltype=2 Income Group=2	H5222.in	PopSyn/out
mo	127	H5223	HHs Size=5 Workers=2 Dwelltype=2 Income Group=3	H5223.in	PopSyn/out
mo	128	H5224	HHs Size=5 Workers=2 Dwelltype=2 Income Group=4	H5224.in	PopSyn/out
mo	129	H5311	HHs Size=5 Workers=3+ Dwelltype=1 Income Group=1	H5311.in	PopSyn/out
mo	130	H5312	HHs Size=5 Workers=3+ Dwelltype=1 Income Group=2	H5312.in	PopSyn/out
mo	131	H5313	HHs Size=5 Workers=3+ Dwelltype=1 Income Group=3	H5313.in	PopSyn/out
mo	132	H5314	HHs Size=5 Workers=3+ Dwelltype=1 Income Group=4	H5314.in	PopSyn/out
mo	133	H5321	HHs Size=5 Workers=3+ Dwelltype=2 Income Group=1	H5321.in	PopSyn/out
mo	134	H5322	HHs Size=5 Workers=3+ Dwelltype=2 Income Group=2	H5322.in	PopSyn/out
mo	135	H5323	HHs Size=5 Workers=3+ Dwelltype=2 Income Group=3	H5323.in	PopSyn/out
mo	136	H5324	HHs Size=5 Workers=3+ Dwelltype=2 Income Group=4	H5324.in	PopSyn/out
mo	137	H6011	HHs Size=6+ Workers=0 Dwelltype=1 Income Group=1	H6011.in	PopSyn/out
mo	138	H6012	HHs Size=6+ Workers=0 Dwelltype=1 Income Group=2	H6012.in	PopSyn/out
mo	139	H6013	HHs Size=6+ Workers=0 Dwelltype=1 Income Group=3	H6013.in	PopSyn/out
mo	140	H6014	HHs Size=6+ Workers=0 Dwelltype=1 Income Group=4	H6014.in	PopSyn/out
mo	141	H6021	HHs Size=6+ Workers=0 Dwelltype=2 Income Group=1	H6021.in	PopSyn/out
mo	142	H6022	HHs Size=6+ Workers=0 Dwelltype=2 Income Group=2	H6022.in	PopSyn/out
mo	143	H6023	HHs Size=6+ Workers=0 Dwelltype=2 Income Group=3	H6023.in	PopSyn/out

Type	No	Name		Source	
		Short	Long (description)	File name	Created by
mo	144	H6024	HHs Size=6+ Workers=0 Dwelltype=2 Income Group=4	H6024.in	PopSyn/out
mo	145	H6111	HHs Size=6+ Workers=1 Dwelltype=1 Income Group=1	H6111.in	PopSyn/out
mo	146	H6112	HHs Size=6+ Workers=1 Dwelltype=1 Income Group=2	H6112.in	PopSyn/out
mo	147	H6113	HHs Size=6+ Workers=1 Dwelltype=1 Income Group=3	H6113.in	PopSyn/out
mo	148	H6114	HHs Size=6+ Workers=1 Dwelltype=1 Income Group=4	H6114.in	PopSyn/out
mo	149	H6121	HHs Size=6+ Workers=1 Dwelltype=2 Income Group=1	H6121.in	PopSyn/out
mo	150	H6122	HHs Size=6+ Workers=1 Dwelltype=2 Income Group=2	H6122.in	PopSyn/out
mo	151	H6123	HHs Size=6+ Workers=1 Dwelltype=2 Income Group=3	H6123.in	PopSyn/out
mo	152	H6124	HHs Size=6+ Workers=1 Dwelltype=2 Income Group=4	H6124.in	PopSyn/out
mo	153	H6211	HHs Size=6+ Workers=2 Dwelltype=1 Income Group=1	H6211.in	PopSyn/out
mo	154	H6212	HHs Size=6+ Workers=2 Dwelltype=1 Income Group=2	H6212.in	PopSyn/out
mo	155	H6213	HHs Size=6+ Workers=2 Dwelltype=1 Income Group=3	H6213.in	PopSyn/out
mo	156	H6214	HHs Size=6+ Workers=2 Dwelltype=1 Income Group=4	H6214.in	PopSyn/out
mo	157	H6221	HHs Size=6+ Workers=2 Dwelltype=2 Income Group=1	H6221.in	PopSyn/out
mo	158	H6222	HHs Size=6+ Workers=2 Dwelltype=2 Income Group=2	H6222.in	PopSyn/out
mo	159	H6223	HHs Size=6+ Workers=2 Dwelltype=2 Income Group=3	H6223.in	PopSyn/out
mo	160	H6224	HHs Size=6+ Workers=2 Dwelltype=2 Income Group=4	H6224.in	PopSyn/out
mo	161	H6311	HHs Size=6+ Workers=3+ Dwelltype=1 Income Group=1	H6311.in	PopSyn/out
mo	162	H6312	HHs Size=6+ Workers=3+ Dwelltype=1 Income Group=2	H6312.in	PopSyn/out
mo	163	H6313	HHs Size=6+ Workers=3+ Dwelltype=1 Income Group=3	H6313.in	PopSyn/out
mo	164	H6314	HHs Size=6+ Workers=3+ Dwelltype=1 Income Group=4	H6314.in	PopSyn/out
mo	165	H6321	HHs Size=6+ Workers=3+ Dwelltype=2 Income Group=1	H6321.in	PopSyn/out
mo	166	H6322	HHs Size=6+ Workers=3+ Dwelltype=2 Income Group=2	H6322.in	PopSyn/out
mo	167	H6323	HHs Size=6+ Workers=3+ Dwelltype=2 Income Group=3	H6323.in	PopSyn/out
mo	168	H6324	HHs Size=6+ Workers=3+ Dwelltype=2 Income Group=4	H6324.in	PopSyn/out

Table 7-3 | Input Components (Household Distribution by Size)

Type	No	Name		Source	
		Short	Long (description)	File name	Created by
mo	169	H1	HHs Size =1	H1.in	PopSyn/inp
mo	170	H2	HHs Size =2	H2.in	PopSyn/inp
mo	171	H3	HHs Size =3	H3.in	PopSyn/inp
mo	172	H45	HHs Size =4 or 5	H45.in	PopSyn/inp
mo	173	H6	HHs Size =6+	H6.in	PopSyn/inp

Table 7-4 | Input Components (Household Distribution by Workers)

Type	No	Name		Source	
		Short	Long (description)	File name	Created by
mo	176	W0	HHs Workers=0	W0.in	176
mo	177	W1	HHs Workers=1	W1.in	177
mo	178	W2	HHs Workers=2	W2.in	178
mo	179	W3	HHs Workers=3+	W3.in	179

Table 7-5 | Input Components (Household Distribution by Income Groups)

Type	No	Name		Source	
		Short	Long (description)	File name	Created by
mo	180	I1	HHs Income =1	I1.in	180
mo	181	I2	HHs Income =2	I2.in	181
mo	182	I3	HHs Income =3	I3.in	182
mo	183	I4	HHs Income =4	I4.in	183

Table 7-6 | Input Components (Households by Dwelling, Labour Force, and Population by Age)

Type	No	Name		Source	
		Short	Long (description)	File name	Created by
mo	174	HHDet	HHs Dwelltype=1 (detached)	D1.in	PopSyn/inp
mo	175	HHApt	HHs Dwelltype=2 (apts)	D2.in	PopSyn/inp
mo	184	LF	Labor Force	LF.in	PopSyn/inp
mo	185	P0_4	Pop age group 0-4 years	P0_4.in	PopSyn/inp
mo	186	P5_14	Pop age group 5-14 years	P5_14.in	PopSyn/inp
mo	187	P15_24	Pop age group 15-24 years	P15_24.in	PopSyn/inp
mo	188	P25_44	Pop age group 25-44 years	P25_44.in	PopSyn/inp
mo	189	P45_64	Pop age group 45-64 years	P45_64.in	PopSyn/inp

Type	No	Name		Source	
		Short	Long (description)	File name	Created by
mo	190	P65	Pop age group >=65 years	P65.in	PopSyn/inp

Table 7-7 | Input Components (Geographic Aggregations, TAZ Area, and Total Population)

Type	No	Name		Source	
		Short	Long (description)	File name	Created by
mo	200	Quebec	Quebec province dummy	Quebec.in	User
mo	201	Superz	Superzone ID (1-94)	Superz.in	User
mo	202	Distri	District ID (1-26)	Distri.in	User
mo	203	Ring	Ring ID (1-4)	Ring.in	User
mo	204	Corrid	Corridor ID (1-6)	Corrid.in	User
mo	205	Area	TAZ Area in ha	Area.in	User
mo	206	PopTot	Total population	PopTot.in	PopSyn/inp
mo	210	Hotels	Hotel Rooms	Hotels.in	User
mo	211	RentAp	Rental Apartments	RentAp.in	User
mo	212	CBD	CBD dummy (district=1)	N/A	Derived
mo	229	DormSt	Dorm Resident Students	dormSt.in	User

Table 7-8 | Input Components (Population Density and Other Derived Characteristics)

Type	No	Name		Source	
		Short	Long (description)	File name	Created by
mo	207	HHTot	Total number of households	HHTot.in	PopSyn/inp
mo	208	PopLow	Low-income population Ontario	PopLow.in	User
mo	209	HHLow	Low-income households	HHLow.in	User
mo	213	PS45+	Population share of age 45+	N/A	Derived
mo	214	PopDe1	TAZ population density	N/A	Derived
mo	215	PopDe2	Superzone population density	N/A	Derived
mo	216	PopDe3	District population density	N/A	Derived
mo	217	LowIn1	TAZ share of low-income population	N/A	Derived
mo	218	LowIn2	Superzone share of low-income population	N/A	Derived
mo	219	LowIn3	District share of low-income population	N/A	Derived
mo	220	Detac1	TAZ share of detached houses	N/A	Derived
mo	221	Detac2	Superzone share of detached houses	N/A	Derived
mo	222	Detac3	District share of detached houses	N/A	Derived

Table 7-9 | Input Components (Employment and Other Derived Characteristics)

Type	No	Name		Source	
		Short	Long (description)	File name	Created by
md	1	EmpTot	Total employment	EmpTot.in	User
md	2	Retail	Retail employment	Retail.in	User
md	3	Servic	Service employment	Servic.in	User
md	4	OffPub	Public office employment	OffPub.in	User
md	5	OffPri	Private office employment	OffPri.in	User
md	6	Educat	Education institution employment	Educat.in	User
md	7	Health	Health institution employment	Health.in	User
md	8	ShopMa	Major Shops employment	ShopMa.in	User
md	9	ShopSt	Street Shops employment	ShopSt.in	User
md	10	Restau	restuarants employment	Restau.in	User
md	11	Theatr	Theatres employment	Theatr.in	User
md	12	Banks	Bank employment	Banks.in	User
md	13	PostOf	Post Office employment	PostOf.in	User
md	14	Hospit	Hospitals employment	Hospit.in	User
md	15	HiTech	High Tech employment	HiTech.in	User
md	16	Wareho	Warehousing employment	Wareho.in	User
md	17	Indus	Industry employment	Indus.in	User
md	20	EnUni1	TAZ university enrollment	EnUni1.in	User
md	21	EnUni2	Superzone university enrollment	EnUni2.in	Derived
md	22	EnUni3	District university enrollment	EnUni3.in	Derived
md	23	EnSch1	TAZ secondary school enrollment	EnSch1.in	User
md	24	EnSch2	Superzone secondary school enrollment	EnSch2.in	Derived
md	25	EnSch3	District secondary school enrollment	EnSch3.in	Derived
md	26	EnEle1	TAZ elementary school enrollment	EnEle1.in	User
md	27	EnEle2	Superzone elementary school enrollment	EnEle2.in	Derived
md	28	EnEle3	District elementary school enrollment	EnEle3.in	Derived
md	29	ParkLo	Cost for long parking, $	ParkLo.in	User
md	30	ParkSh	Cost for short parking, $	ParkSh.in	User
md	31	ShoGLA	Shopping Gross Leasable Area	ShoGLA.in	User
md	32	SpoGLA	Sporting Grounds Gross Area	SpoGLA.in	User
md	33	MusGLA	Museum Gross Leasable Area	MusGLA.in	User
md	34	TheGLA	Theater Gross Leasable Area	TheGLA.in	User
md	35	ParGLA	Parks and Recreation Gross Area	ParGLA.in	User
md	36	WarGLA	Warehousing Gross Leasable Area	WarGLA.in	User
md	37	AvgInc	Average Income at POW	AvgInc.in	User
mo	223	EmpDe1	TAZ Employment density	N/A	Derived
mo	224	EmpDe2	Superzone Employment density	N/A	Derived

Type	No	Name		Source	
		Short	Long (description)	File name	Created by
mo	225	EmpDe3	District Employment density	N/A	Derived
mo	226	RetDe1	TAZ retail+service density	N/A	Derived
mo	227	RetDe2	Superzone retail+service density	N/A	Derived
mo	228	RetDe3	District retail+service density	N/A	Derived

Table 7-10 | Input Components (Observed Tour Generation from OD Survey)

Type	No	Name		Source	
		Short	Long (description)	File name	Created by
mo	281	Prod1v	Total tour production Purp=1 observed	Prod1v.in	User
mo	282	Prod2v	Total tour production Purp=2 observed	Prod2v.in	User
mo	283	Prod3v	Total tour production Purp=3 observed	Prod3v.in	User
mo	284	Prod4v	Total tour production Purp=4 observed	Prod4v.in	User
mo	285	Prod5v	Total tour production Purp=5 observed	Prod5v.in	User
mo	286	Prod6v	Total tour production Purp=6 observed	Prod6v.in	User
mo	287	Prod7v	Total tour production Purp=7 observed	Prod7v.in	User
mo	291	PrMo1v	Motorized tour production Purp=1 observed	PrMo1v.in	User
mo	292	PrMo2v	Motorized tour production Purp=2 observed	PrMo2v.in	User
mo	293	PrMo3v	Motorized tour production Purp=3 observed	PrMo3v.in	User
mo	294	PrMo4v	Motorized tour production Purp=4 observed	PrMo4v.in	User
mo	295	PrMo5v	Motorized tour production Purp=5 observed	PrMo5v.in	User
mo	296	PrMo6v	Motorized tour production Purp=6 observed	PrMo6v.in	User
mo	297	PrMo7v	Motorized tour production Purp=7 observed	PrMo7v.in	User
md	281	Attr1v	Total tour attraction Purp=1 observed	Attr1v.in	User
md	282	Attr2v	Total tour attraction Purp=2 observed	Attr2v.in	User
md	283	Attr3v	Total tour attraction Purp=3 observed	Attr3v.in	User
md	284	Attr4v	Total tour attraction Purp=4 observed	Attr4v.in	User
md	285	Attr5v	Total tour attraction Purp=5 observed	Attr5v.in	User
md	286	Attr6v	Total tour attraction Purp=6 observed	Attr6v.in	User
md	287	Attr7v	Total tour attraction Purp=7 observed	Attr7v.in	User
md	291	AtMo1v	Motorized tour attraction Purp=1 observed	AtMo1v.in	User
md	292	AtMo2v	Motorized tour attraction Purp=2 observed	AtMo2v.in	User
md	293	AtMo3v	Motorized tour attraction Purp=3 observed	AtMo3v.in	User
md	294	AtMo4v	Motorized tour attraction Purp=4 observed	AtMo4v.in	User
md	295	AtMo5v	Motorized tour attraction Purp=5 observed	AtMo5v.in	User
md	296	AtMo6v	Motorized tour attraction Purp=6 observed	AtMo6v.in	User
md	297	AtMo7v	Motorized tour attraction Purp=7 observed	AtMo7v.in	User

Table 7-11 | Input Components (Seed Tour & Trip Matrices from OD Survey)

Type	No	Name		Source	
		Short	Long (description)	File name	Created by
mf	1	Purp1	Work Low tours PA from OD	Purp1.in	User
mf	2	Purp2	Work Med tours PA from OD	Purp2.in	User
mf	3	Purp3	Work High tours PA from OD	Purp3.in	User
mf	4	Purp4	Univ tours PA from OD	Purp4.in	User
mf	5	Purp5	Scho tours PA from OD	Purp5.in	User
mf	6	Purp6	Main tours PA from OD	Purp6.in	User
mf	7	Purp7	Disc tours PA from OD	Purp7.in	User
mf	8	Pur1AM	Work Low tour trips AM (OD)	Pur1AM.in	User
mf	9	Pur2AM	Work Med tour trips AM (OD)	Pur2AM.in	User
mf	10	Pur3AM	Work High tour trips AM (OD)	Pur3AM.in	User
mf	11	Pur4AM	Univ tour trips AM (OD)	Pur4AM.in	User
mf	12	Pur5AM	Scho tour trips AM (OD)	Pur5AM.in	User
mf	13	Pur6AM	Main tour trips AM (OD)	Pur6AM.in	User
mf	14	Pur7AM	Disc tour trips AM (OD)	Pur7AM.in	User
mf	15	Pur1PM	Work Low tour trips PM (OD)	Pur1PM.in	User
mf	16	Pur2PM	Work Med tour trips PM (OD)	Pur2PM.in	User
mf	17	Pur3PM	Work High tour trips PM (OD)	Pur3PM.in	User
mf	18	Pur4PM	Univ tour trips PM (OD)	Pur4PM.in	User
mf	19	Pur5PM	Scho tour trips PM (OD)	Pur5PM.in	User
mf	20	Pur6PM	Main tour trips PM (OD)	Pur6PM.in	User
mf	21	Pur7PM	Disc tour trips PM (OD)	Pur7PM.in	User
mf	22	MotAM	Motor trips AM from OD	MotAM.in	User
mf	23	SovdAM	SOV Driv trips AM from OD	SOVDAM.in	User
mf	24	Ho2dAM	HOV2 Driv trips AM from OD	HO2DAM.in	User
mf	25	Ho2pAM	HOV2 Pass trips AM from OD	HO2PAM.in	User
mf	26	Ho3dAM	HOV3+ Driv trips AM from OD	HO3DAM.in	User
mf	27	Ho3pAM	HOV3+ Pass trips AM from OD	HO3PAM.in	User
mf	28	WLocAM	Wk Loc trips AM from OD	WLocAM.in	User
mf	29	PLocAM	PR loc trips AM from OD	PLocAM.in	User
mf	30	KLocAM	KR Loc trips AM from OD	KlocAM.in	User
mf	31	BLocAM	BR Loc trips AM from OD	BlocAM.in	User
mf	32	WPreAM	Wk Pre trips AM from OD	WPreAM.in	User
mf	33	PPreAM	PR Pre trips AM from OD	PPreAM.in	User
mf	34	KPreAM	KR Pre trips AM from OD	KPreAM.in	User
mf	35	BPreAM	BR Pre trips AM from OD	BPreAM.in	User

Type	No	Name		Source	
		Short	Long (description)	File name	Created by
mf	36	SchbAM	Sch bus trips AM from OD	SchbAM.in	User
mf	37	BikeAM	Bicycle trips AM from OD	BikeAM.in	User
mf	38	MotPM	Motor trips PM from OD	MotPM.in	User
mf	39	SovdPM	SOV Driv trips PM from OD	SOVDPM.in	User
mf	40	Ho2dPM	HOV2 Driv trips PM from OD	HO2DPM.in	User
mf	41	Ho2pPM	HOV2 Pass trips PM from OD	HO2PPM.in	User
mf	42	Ho3dPM	HOV3+ Driv trips PM from OD	HO3DPM.in	User
mf	43	Ho3pPM	HOV3+ Pass trips PM from OD	HO3PPM.in	User
mf	44	WLocPM	Wk Loc trips PM from OD	WLocPM.in	User
mf	45	PLocPM	PR loc trips PM from OD	PLocPM.in	User
mf	46	KLocPM	KR Loc trips PM from OD	KlocPM.in	User
mf	47	BLocPM	BR Loc trips PM from OD	BlocPM.in	User
mf	48	WPrePM	Wk Pre trips PM from OD	WPrePM.in	User
mf	49	PPrePM	PR Pre trips PM from OD	PPrePM.in	User
mf	51	KPrePM	KR Pre trips PM from OD	KPrePM.in	User
mf	52	BPrePM	BR Pre trips PM from OD	BPrePM.in	User
mf	53	SchbPM	Sch bus trips PM from OD	SchbPM.in	User
mf	54	BikePM	Bicycle trips PM from OD	BikePM.in	User

Table 7-12 | Input Components (Additional Matrices)

Type	No	Name		Source	
		Short	Long (description)	File name	Created by
mf	55	ComAM	Commercials and trucks AM	CVS_AM_FinalMatrix.in	User
mf	56	ComPM	Commercials and trucks PM	CVS_PM_FinalMatrix.in	User
mf	57	ExtAM	External trips AM	External_Matrix_AM	User
mf	58	ExtPM	External trips PM	External_Matrix_PM	User
mf	59	AMFac	AM Peak Hour Factor	Amfac	User

7.4.2 Sub-Macro “2. InputSkims”

Sub-Macro 2 (***InputSkims.mac***) inputs the starting skims for calculation of the accessibility measures. These skims are provided by the user.

The sub-macro script has the following sections:

- Control section of input parameters specified by the user:
    - Full path for the folder that contains external input files. It is recommended to use simplified DOS conventions for the folder and subfolder names to avoid EMME failure to read the input; in particular all folder names in the path must not have blank gaps.
    - The skims are located in the C:\Projects\TRANS\Skims\ folder which is defined in the macro. The user could define a new location for skims in the macro, if desired.
- Section 2.1 reads AM skims for auto modes (SOV time, HOV time, Distance), walk to transit (in-vehicle time, walk time, wait time, number of boardings and fare) and drive to transit skims (in-vehicle time, walk time, wait time, number of boardings, auto drive time and fare).
- Section 2.2 reads midday (MD) skims for auto modes (SOV time, HOV time, Distance), walk to transit (in-vehicle time, walk time, wait time, number of boardings and fare) and drive to transit skims (in-vehicle time, walk time, wait time, number of boardings, auto drive time and fare).
- Section 2.3 reads early (EA) skims for auto modes (SOV time, HOV time, Distance), walk to transit (in-vehicle time, walk time, wait time, number of boardings and fare) and drive to transit skims (in-vehicle time, walk time, wait time, number of boardings, auto drive time and fare).

7.4.3 Sub-Macro “3. SizeProd”

Sub-Macro 3 (***SizeProd***) calculates total tour productions (production size term) for each purpose. The model estimation result is described in Subsection 3.4 above. The sub-macro script has the following sections:

- Control section of input parameters specified by the user:
    - Location of output vectors/matrices (*mo*) in the databank (not recommended to change by the user unless the model structure is modified),
- Section 3.1 contains household tour production rates by purpose 1-7 as function of household composition, dwelling type, and zonal characteristics (not supposed to be changed by the user unless the model has been re-estimated).
- Section 3.2 calculates zonal tour productions accumulated for each purpose (1-7) from the household variables. The program loops over purpose (1-7), household size (1-6), number of workers (0-3), income category (1-4) and dwelling type (1-2).
- Section 3.3 adds zonal tour productions accumulated for each purpose (1-7) from the zonal variables. The program loops over purpose (1-7), household size (1-6), number of workers (0-3), income category (1-4) and dwelling type (1-2).

- Section 3.4 replaces any negative size values with zeros.
- Section 3.5 computes non-mandatory size term as a sum of maintenance and discretionary size term
- Section 3.6 summarizes and outputs main statistics on total tour production by purpose. This section is optional and intended for monitoring purpose only. It can be extended by the user if necessary. In case of extension, scalar matrices *ms* with numbers of 900-999 are recommended to be used for intermediate calculations in order to avoid conflicts with other temporary stored data items.

7.4.4 Sub-Macro “4. SizeAttr”

Sub-Macro 4 (***TourAttr***) calculates total tour attractions or attraction size term for accessibility measures. The model specification is described in Subsection 3.4.2 above including estimated model coefficients. The sub-macro script has the following sections:

- Control section of input parameters specified by the user:
  - Location of output vectors/matrices (*md*) in the databank (not recommended to change by the user unless the model structure is modified),
- Section 4.1 contains zone tour attraction rates by purpose 1-7 as function of zonal characteristics (not supposed to be changed by the user unless the model has been re-estimated).
- Section 4.2 calculates zonal tour attractions for each purpose (1-7) in a loop.
- Section 4.3 computes non-mandatory size term as a sum of maintenance and discretionary size term
- Section 4.4 summarizes and outputs main statistics on total tour attraction by purpose. This section is optional and intended for monitoring purpose only. It can be extended by the user if necessary. In case of extension, scalar matrices *ms* with numbers of 900-999 are recommended to be used for intermediate calculations in order to avoid conflicts with other temporary stored data items.

7.4.5 Sub-Macro “5. Accessibility”

Sub-Macro 5 (***Accessibility***) calculates various accessibility measures that are used as explanatory variables in the various models such as pre-mode choice, time-of-day choice, tour distribution etc. The accessibility specifications are described in Subsection 3.2 above. The sub-macro script has the following sections:

- Control section of input parameters specified by the user:
  - Location of output vectors/matrices (*mf, mo, md, ms*) in the databank (not recommended to change by the user unless the model structure is modified),
  - Parameters used in the script such as nesting coefficients and period codes for the time-period LOS used (not recommended to change by the user unless the model structure is modified).
- Section 5.1 defines the fixed components of the mode choice utility by car sufficiency type (0,1,2) and purposes (1-4) (not supposed to be changed by the user unless a new mode choice specification is defined).

- Section 5.2 calculates OD mode choice utilities by 5 modes (SOV, HOV, Walk to Transit, Drive to Transit and Walk) and 3 time periods (Early, AM Peak and Midday).
- Section 5.3 calculates 25 OD impedance or mode choice logsums
- Section 5.4 calculates production and attraction end accessibilities.

7.4.6 Sub-Macro “6. CarOwner”

Sub-Macro 6 (***CarOwner***) calculates car-ownership choice probabilities for each household segment. The model specification is described in Section 3.3 above and the estimated model coefficients are reported in Section 5.2 above. The sub-macro script has the following sections:

- Control section of input parameters specified by the user:
    - Location of output vectors/matrices (*mo*) in the databank (not recommended to change by the user unless the model structure is modified),
- Section 6.1 contains coefficients of the car-ownership utilities (not supposed to be changed by the user unless the model has been re-estimated) and additional adjustment parameters for calibration if needed (currently not used). Then car-ownership utilities for four alternatives (0 cars, 1 car, 2 cars, and 3 or more cars) are calculated for all household segments. The program loops over household size (1-6), number of workers (0-3), income groups (1-4), and dwelling type (1-2).
- Section 6.2 calculates car-ownership probabilities by the nested logit formula for all household segments. The program loops over household size (1-6), number of workers (0-3), income groups (1-4), and dwelling type (1-2).
- Section 6.3 calculates household distribution by four car-sufficiency categories (0 cars, cars fewer than workers, cars equal to workers, and cars greater than workers) for each household segment. The program loops over household size (1-6), number of workers (0-3), income groups (1-4), and dwelling type (1-2). For each segment (i.e. combination of these three categories) it calculates a number of households for each car sufficiency category by grouping car-ownership probabilities relative to the number of workers. Resulted detailed household distribution vectors by household size (1-6), number of workers (0-3), income groups (1-4), dwelling type (1-2), and car sufficiency (0-3) constitute the primary output of this sub-model used by the subsequent sub-models (*mo”H10110”-mo”H6343”*).
- Section 6.4 summarizes and outputs main statistics on household distribution by car ownership on the screen. This section is optional and intended for monitoring purpose only. It can be extended by the user if necessary. In case of extension, scalar matrices *ms* with numbers of 900-999 are recommended to be used for intermediate calculations in order to avoid conflicts with other temporary stored data items.
- Section 6.5 summarizes and outputs main statistics on household distribution by car sufficiency on the screen. This section is optional and intended for monitoring purpose only. It can be extended by the user if necessary. In case of extension, scalar matrices *ms* with numbers of 900-999 are recommended to be used for intermediate calculations in order to avoid conflicts with other temporary stored data items.
- Section 6.6 summarizes and outputs main statistics on joint household distribution by number of workers and cars on the screen. This section is optional and intended for monitoring purpose only. It can be

extended by the user if necessary. In case of extension, scalar matrices *ms* with numbers of 900-999 are recommended to be used for intermediate calculations in order to avoid conflicts with other temporary stored data items.

7.4.7 Sub-Macro “7. TourProd”

Sub-Macro 7 (***TourProd***) calculates total (including motorized and non-motorized) tour productions for each household segment. The model specification is described in Subsection 3.4.1 above and the estimated model coefficients are reported in Section 5.3.1 above. The sub-macro script has the following sections:

- Control section of input parameters specified by the user:
  - Location of output vectors/matrices (*mo*) in the databank (not recommended to change by the user unless the model structure is modified),
- Section 7.1 contains household tour production rates by purpose 1-7 as function of car sufficiency, household composition, income group, dwelling type, and zonal characteristics (not supposed to be changed by the user unless the model has been re-estimated) and additional adjustment parameters for calibration if needed (currently some of them were used).
- Section 7.2 calculates zonal tour productions accumulated for each car-sufficiency group (0-3) and purposes (1-7) from the household variables. The program loops over car-sufficiency group (0-3), purpose (1-7), household size (1-6), number of workers (0-3), income group (1-4) and dwelling type (1-2).
- Section 7.3 adds zonal tour productions and income variables accumulated for each car-sufficiency group (0-3) and purposes (1-7) from the zonal variables. The program loops over car-sufficiency group (0-3), purpose (1-7), household size (1-6), number of workers (0-3), income group (1-4) and dwelling type (1-2).
- Section 7.4 contains ring and province level adjustments based on the comparison of the model to the observed data. This section can be extended by the user and incorporate any other special travel generators not covered by the core model. This section is designed to be used and modified in the model validation/calibration process.
- Section 7.5 contains additional adjustments to specific districts based on the comparison of the model to the observed data. This section is designed to be used and modified in the model validation/calibration process.
- Section 7.6 aggregate tour production for each purpose (1-7) over car-sufficiency groups (0-3). The final output of this sub-model is comprised of detailed tour production vectors by car-sufficiency group (0-3) and purpose (1-7) (*mo”Prod01”-mo”Prod37”*) as well as aggregate tour production vectors by purpose (1-7) (*mo”Prod1”-mo”Prod7”*).
- Section 7.7 summarizes and outputs main statistics on total tour production by purpose compared to the observed tour production in OD survey. This section is optional and intended for monitoring purpose only. It can be extended by the user if necessary. In case of extension, scalar matrices *ms* with numbers of 900-999 are recommended to be used for intermediate calculations in order to avoid conflicts with other temporary stored data items.

7.4.8 Sub-Macro “8. TourAttr”

Sub-Macro 8 (***TourAttr***) calculates total (including motorized and non-motorized) tour attractions. The model specification is described in Subsection 3.4.2 above and the estimated model coefficients are reported in Section 5.3.2 above. The sub-macro script has the following sections:

- Control section of input parameters specified by the user:
    - Location of output vectors/matrices (*md*) in the databank (not recommended to change by the user unless the model structure is modified),
- Section 8.1 contains zone tour attraction rates by purpose 1-7 as function of zonal characteristics (not supposed to be changed by the user unless the model has been re-estimated) and additional adjustment parameters for calibration if needed (currently some of them were used).
- Section 8.2 calculates zonal tour attractions for each purpose (1-7) in a loop.
- Section 8.3 runs another submacro (*AttrWorkInc.mac*) which calculates the split of attractions between low, medium and high income groups at the zonal level.
- Section 8.4 contains adjustments by ring and province based on the comparison of the model to the observed data. This section can be extended by the user and incorporate any other special travel generators not covered by the core model. This section is designed to be used and modified in the model validation/calibration process. The final output of this sub-model is comprised of tour attraction vectors by purpose (1-5) (*md”Attr1”-md”Attr7”*).
- Section 8.5 summarizes and outputs main statistics on total tour attraction by purpose compared to the observed tour production in OD survey. This section is optional and intended for monitoring purpose only. It can be extended by the user if necessary. In case of extension, scalar matrices *ms* with numbers of 900-999 are recommended to be used for intermediate calculations in order to avoid conflicts with other temporary stored data items.

7.4.9 Sub-Macro “7-8. BalanTot”

Sub-Macro 3-4 (***BalanTot***) balances total regional tour productions and attractions. The algorithm is described in Subsection 3.4.3 above. The sub-macro script has the following sections:

- Control section where the user specifies one of the three possible balancing principles (1=by the production total, 2=by the attraction total, or 3=by the geometric average of the production and attraction totals) for each travel purpose (1-7). The switches are currently set in the following way:
    - 3 (by average) for Work (purpose=1-3),
    - 2 (by attractions) for University (purpose=4),
    - 1 (by productions) for School, Maintenance, and Discretionary (purposes=5, 6, 7).
- Main section that implements the formal balancing procedure (no additional parameters are specified and no user intervention is assumed). Note that the balancing overrides the original values stored in the production and attraction vectors *mo”Prod1” – mo“Prod7”* and *md”Attr1” – md“Attr7”*.

- Section that summarizes and outputs balancing (correction factors) applied for the total productions and attractions for each purpose.

7.4.10 Sub-Macro “9. NonMProd”

Sub-Macro 9 (***NonMProd***) calculates share of motorized and bicycle tour productions for each household car-sufficiency segment. It is based on binary (pre-mode) choice between walk and non-walk travel at the tour production end (household residence). The model specification is described in Subsection 3.5.2 above and the estimated model coefficients are reported in Section 5.4.1 above. The sub-macro script has the following sections:

- Control section of input parameters specified by the user:
    - Location of intermediate and output vectors/matrices (*mo*) in the databank (not recommended to change by the user unless the model structure is modified),
    - Coefficients of the non-motorized utility (not supposed to be changed by the user unless the model has been re-estimated),
    - Adjustments (additional non-motorized biases) introduced during the model calibration (region-wide and for rings 1-2 characterized by the highest densities); these adjustments are purpose-specifics and can be changed by the user in a new calibration effort.
- Section 9.1 calculates utilities for walk travel (non-walk utilities are all set to zero as the reference case) for each segment. The program loops over car-sufficiency groups (0-3) and travel purposes (1-7).
- Section 9.2 calculates walk probabilities based on the binary logit choice model. The program loops over car-sufficiency groups (0-3) and travel purposes (1-7).
- Section 9.3 calculates non-walk production vectors based on the total productions and walk share for each segment. The program loops over car-sufficiency groups (0-3) and travel purposes (1-7). The resulted vectors (*mo”PrMo01”-mo”PrMo37”*) constitute the primary output of this sub-model.
- Section 9.4 aggregates the non-walk tour production vectors across car-sufficiency groups (0-3) and creates non-walk (i.e. motorized & bicycle) tour production vectors by purpose (1-7) (*mo”PrMo1”-mo”PrMo7”*).
- Section 9.5 summarizes and outputs main statistics on non-walk tour production by purpose compared to the observed motorized tour production in OD survey for the entire region. Section 9.6 does the same for urban rings 1 and 2. Section 9.7 and 9.8 do the same for suburban/ rural rings 3, 4, and 5. These sections are optional and intended for monitoring purpose only. They can be modified or extended by the user if necessary. In case of extension, scalar matrices *ms* with numbers of 900-999 are recommended to be used for intermediate calculations in order to avoid conflicts with other temporary stored data items.

7.4.11 Sub-Macro “10. NonMAttr”

Sub-Macro 10 (***NonMAttr***) calculates share of motorized tour attractions based on binary (pre-mode) choice between non-walk and walk travel at the tour attraction end (primary destination). The model specification is described in Subsection 3.5.3 above and the estimated model coefficients are reported in Section 5.4.2 above. The sub-macro script has the following sections:

- Control section of input parameters specified by the user:
  - Location of intermediate and output vectors/matrices (*md*) in the databank (not recommended to change by the user unless the model structure is modified),
  - Coefficients of the walk utility (not supposed to be changed by the user unless the model has been re-estimated),
  - Adjustments (additional walk biases) introduced during the model calibration; these adjustments are purpose-specifics and can be changed by the user in a new calibration effort.
- Section 10.1 calculates utilities for walk travel (non-walk utilities are all set to zero as the reference case) for each segment. The program loops over travel purposes (1-7). Additional subsection allows for utility adjustments for selected traffic zones (several of them currently used for large schools).
- Section 10.2 calculates walk probabilities based on the binary logit choice model. The program loops over travel purposes (1-7).
- Section 10.3 calculates motorized attraction vectors based on the total attractions and walk share for each segment (purpose). The program loops over travel purposes (1-7). The resulted vectors (*md"AtMo1"-mo"AtMo7"*) constitute the <u>primary output</u> of this sub-model.
- Section 10.4 summarizes and outputs main statistics on motorized and bicycle tour attraction by purpose compared to the observed motorized tour attraction in OD survey for the entire region. Section 10.5 does the same for urban rings 1 and 2. Section 10.6 and 10.7 do the same for suburban/ rural rings 3, 4, and 5. These sections are optional and intended for monitoring purpose only. They can be modified or extended by the user if necessary. In case of extension, scalar matrices *ms* with numbers of 900-999 are recommended to be used for intermediate calculations in order to avoid conflicts with other temporary stored data items.

7.4.12 Sub-Macro "9-10. BalanMot"

Sub-Macro 9-10 (***BalanMot***) balances regional motorized tour production and attraction totals. The algorithm is described in Subsection 3.5.4 above. The sub-macro script has the following sections:

- Control section where the user specifies one of the three possible balancing principles (1=by the production total, 2=by the attraction total, or 3=by the geometric average of the production and attraction totals) for each travel purpose (1-7). The switches are currently set in the following way and in line with the balancing principles applied for total tour generation:
  - 3 (by average) for Work (purpose=1-3),
  - 2 (by attractions) for University (purpose=4),
  - 1 (by productions) for School, Maintenance, and Discretionary (purposes=5-7).

- Main section that implements the formal balancing procedure (no additional parameters are specified and no user intervention is assumed). Note that the balancing overrides the original values stored in the production and attraction vectors *mo"PrMo1" – mo"PrMo7"* and *md"AtMo1" – md"AtMo7"*.
- Section that summarizes and outputs balancing (correction factors) applied for the motorized and bicycle productions and attractions for each purpose.

7.4.13 Sub-Macro "11. TODProd"

Sub-Macro 11 (***TODProd***) calls subroutines (***TODProd1-7***) for each travel purpose in sequence. The subroutines have an identical structure and calculate joint choice of TOD and stop frequency for motorized tour productions for each household car-sufficiency segment. The model specification is described in Subsection 3.6.1 above and the estimated model coefficients are reported in Section 5.5.1 above. The subroutine script has the following sections:

- Control section of input parameters specified by the user:
    - Location of output vectors/matrices (*mo*) and intermediate vectors/matrices (*md*) in the databank (not recommended to change by the user unless the model structure is modified),
- Section 11.1-11.7 (depending on the purpose) with coefficients of the time-of-day and stop-frequency utility components (not supposed to be changed by the user unless the model has been re-estimated),
- Section with adjustments (for outbound and inbound tour time and stop frequency) introduced during the model calibration; these adjustments can be changed by the user in a new calibration effort,
- Section that calculates combined TOD and stop-frequency utilities for each segment. The program loops over car-sufficiency groups (0-3), outbound TOD periods (1-5), inbound TOD periods (1-5), outbound stop frequency (0-1) and inbound stop frequency (0-1),
- Section that calculates joint TOD and stop-frequency choice probabilities for each segment according to the multinomial logit model. The program (for each of the travel purposes 1-7) loops over car-sufficiency groups (0-3), outbound TOD periods (1-5), inbound TOD periods (1-5), outbound stop frequency (0-1) and inbound stop frequency (0-1) twice. First time, it calculates the denominator of the multinomial logit model. Second time, it calculates probabilities.
- Section that calculates detailed segmented TOD & stop-frequency production vectors for each purpose and car-sufficiency group based on the daily motorized productions and joint TOD & stop-frequency probabilities. This represents the most detailed intermediate output of the sub-model.
- Section that calculates purpose-specific aggregate segments by relevant TOD combinations (including either AM=2 or PM=4 periods). The program loops over outbound TOD periods (1-5) and inbound TOD periods (1-5), and accumulates purpose-specific and TOD-specific productions across outbound stop-frequency categories (0-1), inbound stop-frequency categories (0-1), and car-sufficiency groups (0-3). The resulted vectors (*mo"Pr112"-mo"Pr745"*) represent the primary aggregate output of the sub-model (TOD demand slices).
- Section that calculates purpose-specific detailed probabilities for car-sufficiency and stop-frequency categories within each TOD slice. The program loops over outbound TOD periods (1-5), inbound TOD

periods (1-5), outbound stop-frequency categories (0-1), inbound stop-frequency categories (0-1), and car-sufficiency groups (0-3). The resulted vectors (*mo"011200"-mo"354411"*) represent the primary disaggregate output of the sub-model (internal car-sufficiency and stop-frequency proportions within each TOD slice).

- Sections that summarize and output TOD distribution for outbound and inbound half-tours and distribution of tours by stop frequency categories. These sections are optional and intended for monitoring purpose only. They can be modified or extended by the user if necessary. In case of extension, scalar matrices *ms* with numbers of 900-999 are recommended to be used for intermediate calculations in order to avoid conflicts with other temporary stored data items.

7.4.14 Sub-Macro "12. TODAttr"

Sub-Macro 12 (***TODAttr***) calls subroutines (***TODAttr1-7***) for each travel purpose in sequence. The subroutines have an identical structure and calculate TOD choice for motorized tour attractions. The model specification is described in Subsection 3.6.2 above and the estimated model coefficients are reported in Section 5.5.2 above. The subroutine script has the following sections:

- Control section of input parameters specified by the user:
    - Location of intermediate and output vectors/matrices (*md*) in the databank (not recommended to change by the user unless the model structure is modified),
- Section 12.1-12.7 (depending on the purpose) with coefficients of the time-of-day utility components (not supposed to be changed by the user unless the model has been re-estimated),
- Section with adjustments (for outbound and inbound tour time and stop frequency) introduced during the model calibration; these adjustments can be changed by the user in a new calibration effort,
- Section that calculates TOD utilities for each segment (purpose). The program loops over outbound TOD periods (1-5) and inbound TOD periods (1-5),
- Section that calculates TOD choice probabilities for each segment according to the multinomial logit model. The program (for each of the travel purposes 1-5) loops over outbound TOD periods (1-5) and inbound TOD periods (1-5) twice. First time, it calculates the denominator of the multinomial logit model. Second time, it calculates probabilities.
- Section that calculates purpose-specific segments by relevant TOD combinations (including either AM=2 or PM=4 periods) based on the daily motorized tractions and TOD choice probabilities. The program loops over outbound TOD periods (1-5) and inbound TOD periods (1-5). The resulted vectors (*md"At112"-mo"At745"*) represent the primary output of the sub-model (TOD demand slices).
- Section that summarizes and outputs TOD distribution for outbound and inbound half-tours on the screen. This section is optional and intended for monitoring purpose only. It can be modified or extended by the user if necessary. In case of extension, scalar matrices *ms* with numbers of 900-999 are recommended to be used for intermediate calculations in order to avoid conflicts with other temporary stored data items.

7.4.15 Sub-Macro "11-12. BalanTOD"

Sub-Macro 11-12 (***BalanMot***) balances regional motorized tour production and attraction totals. The algorithm is described in Subsection 3.6.3 above. The sub-macro script has the following sections:

- Control section where the user specifies one of the three possible balancing principles (1=by the production total, 2=by the attraction total, or 3=by the geometric average of the production and attraction totals) for each travel purpose (1-7). The switches are currently set in the following way and in line with the balancing principles applied for total and motorize tour generation:
    - 3 (by average) for Work (purpose=1-3),
    - 2 (by attractions) for University (purpose=4),
    - 1 (by productions) for School, Maintenance, and Discretionary (purposes=5-7).
- Main section that implements the formal balancing procedure (no additional parameters are specified and no user intervention is assumed). Note that the balancing overrides the original values stored in the production and attraction vectors *mo"Pr111" – mo"Pr745"* and *md"At111" – md"At745"*.
- Section that summarizes and outputs balancing (correction factors) applied for productions and attractions for each purpose and TOD slice.

7.4.16 Sub-Macro "13. SeedMatr"

Sub-Macro 13 (***SeedMatr***) prepares seed matrices for tour ends (residential and primary destination). This sub-macro serves as a shell for multiple calls for subroutine 13.1(***MatSmoot***). The sub-macro script has the following sections:

- Control section of input parameters specified by the user:
    - Location of intermediate and output matrices (*mf*) in the databank (not recommended to change by the user unless the model structure is modified),
    - Scaling factor that puts an additional weight on either gravity component or seed matrix itself. Currently, is set to 1.0 that is most theoretically consistent. A value greater than 1.0 would favour seed matrix more while a value between 0 and 1 would favour the gravity component.
- Section that implements a free-flow assignment and skimming procedure to build a free-flow time skim used as the impedance measure in the subsequent calculations.
- Section that implements a smoothing procedure for each travel purpose. The program loops over travel purposes (1-7) and calls subroutine *MatSmoot* (described in the next subsection) for each purpose. As the result, smoothed daily tour-end matrices (*mf"Purp1s"-mf"Purp7s"*) are prepared.
- Section that scales the daily purpose-specific matrices for each TOD demand slice. The program loops over travel purposes (1-7), outbound TOD periods (1-5), and inbound TOD periods (1-5) selecting the relevant slices where either outbound or inbound period is AM=2 or PM=4. The resulted smoothed and scaled matrices (*mf"See112"-mf"See745"*) constitute the <u>primary output</u> of the sub-model. These matrices are used as seeds in the subsequent matrix construction procedure.

7.4.17 Subroutine “13.1. MatSmoot”

Subroutine 13.1 (***MatSmoot***) calculate smoothed seed matrices for tour ends (residential and primary destination) based on the observed distribution patterns from the (expanded) OD Survey. The algorithm is described in Subsection 3.7.1 above. The sub-macro script has the following sections:

- Control section of input parameters specified by the user:
- Dispersion coefficient for the gravity component Control section of input parameters specified by the user:
    - Dispersion coefficient for the gravity component (currently set to the calibrated value; not recommended to change by the user unless the model has been recalibrated),
    - Zone partition used for aggregation (currently set to superzones *gs*; not recommended to change by the user until after an intensive testing has been implemented with a different partition).
- Section 13.1.1 calculates original (raw/observed) matrix marginals (production and attraction totals),
- Section 13.1.2 implements an auxiliary gravity model with the calculated marginals and specified impedance function.
- Section 13.1.3 aggregates the original matrix and auxiliary gravity-based matrix according to the specified partition.
- Section 13.1.4 calculates final smooth matrix that replicates the original matrix at the aggregate level but follows the gravity model for internal / disaggregate proportions.

7.4.18 Sub-Macro “14. TourDist”

Sub-Macro 10 (***TourDist***) calculates final matrices for tour ends (residential and primary destination). This sub-macro serves as a shell for multiple calls for subroutine 14.1 (***MatConst***). The sub-macro script has the following sections:

- Control section of input parameters specified by the user:
    - Location of output tour-end matrices (*mf*) in the databank (not recommended to change by the user unless the model structure is modified),
    - Stopping criteria for the matrix balancing procedure (currently set to 100 iterations and 0.000001 gap; not recommended to change by the user).
- Main section that serves as a shell calling the matrix construction subroutine *MatConst* for each segment. The program loops over travel purposes (1-7) outbound TOD periods (1-5), and inbound TOD periods (1-5) selecting the relevant slices where either outbound or inbound period is AM=2 or PM=4. The resulted matrices (*mf”Tou112”-mf”Tou745”*) constitute the <u>primary output</u> of the sub-model. These matrices are used as tour-end controls in the PA format in the subsequent trip matrix construction procedure.

7.4.19 Subroutine “14.1. MatConst”

Subroutine 14.1 (***MatConst***) calculate final matrices for tour ends (residential and primary destination) based on the hybrid gravity-balancing model. The model specification is described in Subsection 3.7.2

above. The calibrated dispersion coefficients for the gravity distribution component are reported in Subsection 5.6.2 above. The sub-macro script has the following sections:

- Control section of input parameters specified by the user:
  - Dispersion coefficients for the gravity component (currently set to the calibrated values; not recommended to change by the user unless the model has been recalibrated),
  - Coefficients for river crossing penalty (currently set to the calibrated values; not recommended to change by the user unless the model has been recalibrated),
- Section that calculates gravity-balancing indices based on comparison of the modelled and observed (from the seed matrix) productions and attractions,
- Section that calculates optimal proportions between gravity and balancing components based on the indices,
- Section that creates hybrid matrix structure where the seed matrix is blended with gravity-based matrix based on the optimal proportions,
- Section that balances the hybrid matrix with the modelled productions and attractions. This section produces the final output of the sub-model stored in *mf"Tou112" – mf"Tou745"*.
- Section that summarizes average tour length (in terms of free-flow time) for the built matrix and compare it to the seed matrix. This section is optional and intended for monitoring purpose only. It can be modified or extended by the user if necessary. In case of extension, scalar matrices *ms* with numbers of 900-999 are recommended to be used for intermediate calculations in order to avoid conflicts with other temporary stored data items.

7.4.20 Sub-Macro "15. StopAttr"

Sub-Macro 15 (***StopAttr***) calculates stop attraction size variables for stop-location choice that are used in the trip distribution procedure for chained half-tours. The model specification is described in Subsection 3.6.4 above and the estimated model coefficients are reported in Section 5.5.3 above. The sub-macro script has the following sections:

- Control section of input parameters specified by the user:
  - Location of output vectors/matrices (*md*) in the databank (not recommended to change by the user unless the model structure is modified),
  - Coefficients for the stop-attraction regression model (currently set to the estimated values; not recommended to change by the user unless the model has been re-estimated),
  - Adjustment factors for selected districts (currently set to the calibrated values, can be changed by the user in a new calibration effort),
- Section 15.1 calculates outbound stop attractions for each segment (purpose) by application of the regression model with the employment and other zonal variables. The program loops over travel purposes (1-7). The resulted vectors (*md"StAt1o"-md"StAt7o"*) constitute the sub-model output. It is used in the subsequent trip matrix construction procedure for outbound chained half-tours.

- Special subsection defines the coefficients for the inbound direction stop-attraction regression model (currently set to the estimated values; not recommended to change by the user unless the model has been re-estimated)
- Section 15.2 calculates inbound stop attractions for each segment (purpose) by application of the regression model with the employment and other zonal variables. The program loops over travel purposes (1-5). The resulted vectors (*md"StAt1i"-md"StAt5i"*) constitute the sub-model output. It is used in the subsequent trip matrix construction procedure for inbound chained half-tours.
- Section 15.3 summarizes the stop-attraction statistics in terms of the number of stops for each tour purpose and direction (outbound and inbound). This section is optional and intended for monitoring purpose only. It can be modified or extended by the user if necessary. In case of extension, scalar matrices *ms* with numbers of 900-999 are recommended to be used for intermediate calculations in order to avoid conflicts with other temporary stored data items.

7.4.21 Sub-Macro "16. TripDist"

Sub-Macro 16 (***TripDist***) calculates final trip distribution matrices. It breaks tour into directional half-tours (outbound and inbound), calculates shares of direct and chained half-tours, breaks chained half-tours into trips, and summarizes trip matrices including both direct and chained half-tours. This sub-macro calls multiple times for subroutine 16.1 (***ChainDis***). The algorithm is described in Section 3.8 above. The sub-macro script has the following sections:

- Control section of input parameters specified by the user:
    - Location of intermediate and final output matrices (*mf*) in the databank (not recommended to change by the user unless the model structure is modified),
    - Zone partitions used for the validation reports at two levels of spatial aggregation (currently is set to superzones *gs* and districts *gd*; can be changed by the user if necessary for additional validation/calibration),
- Section 16.1 calculates directional half-tour matrices in OD format from the tour-end matrices in PA format. The program loops over car-sufficiency categories (0-3) and travel purposes (1-7). For each segment (i.e. combination of car sufficiency and purpose), it calculates the following 8 matrices based on the tour-end tables for the purpose & TOD periods and internal proportions by car-sufficiency & stop-frequency within each segment:
    - Outbound direct half-tours in the AM period
    - Outbound chained half-tours in the AM period,
    - Inbound direct half-tours in the AM period,
    - Inbound chained half-tours in the AM period,
    - Outbound direct half-tours in the PM period,
    - Outbound chained half-tours in the PM period,
    - Inbound direct half-tours in the PM period,

  - Inbound chained half-tours in the PM period.
- Section 16.2 calculates trip matrices for chained half-tours (direct half-tours already represent final trip matrix components). The program loops over car-sufficiency categories (0-3) and travel purposes (1-7). For each segment it calls subroutine *ChainDis* to implement a procedure of convoluted trip distribution based on the half-tour ends and stop-attraction size variables. For each combination of car-sufficiency and travel purpose, the subroutine is called four times:
  - For outbound chained half-tours in the AM period,
  - For inbound chained half-tours in the AM period,
  - For outbound chained half-tours in the PM period,
  - For inbound chained half-tours in the PM period.
- Section 16.3 summarizes final (assignable) trip matrices for each segment that are used as an input to the mode choice model. The program loops over car-sufficiency categories (0-3) and travel purposes (1-7). For each segment and relevant TOD period (AM and PM), it totals all pertinent trip components from direct and chained half-tours. The following resulted sets of trip matrices constitute the sub-model output:
  - mf"TrAM01"-mf"TrAM37" for the AM period,
  - mf"TrPM01"-mf"TrPM37" for the PM period.
- Validation section that summarizes main distribution statistics by purpose and TOD period. It included half-tour statistics by direction (outbound and inbound) and stop frequency (direct and chained), as well as trip matrix totals compared to the expanded matrices from the OD Survey. This section is optional and intended for monitoring purpose only. It can be modified or extended by the user if necessary. In case of extension, scalar matrices *ms* with numbers of 900-999 are recommended to be used for intermediate calculations in order to avoid conflicts with other temporary stored data items.

7.4.22 Subroutine "16.1. ChainDis"

Subroutine 12 (***ChainDis***) calculates convoluted trip distribution matrices for chained half-tours based on the intermediate stop-location choice. The model specification is described in Subsection 3.8.3 above and the calibrated dispersion coefficients for route deviation are reported in Subsection 5.6.3 above. The sub-macro script has the following sections (following the EMME implementation steps described in detail in Appendix A.1):

- Control section of input parameters specified by the user:
  - Dispersion coefficient for the stop-location / route-deviation choice by half-tour purpose (1-5), direction (outbound and inbound), and stop proximity to the tour end (home and primary destination); not recommended to change by the user unless the model has been recalibrated,
  - Maximum allowable route deviations for intermediate stop location (currently set to 70 km from both home and primary-destination ends based on the maximum observed deviations in the OD Survey; can be changed by the user if new data are available).

- Section that calculates exponentiated stop-location utility components for the 1st (from the half-tour origin to stop) and 2nd (from the stop to half-tour destination),
- Section that calculates the denominator of stop-location choice,
- Section that calculates scaled half-tour matrix,
- Section that calculates 1st trip leg,
- Section that calculates 2nd trip leg,
- Validation section that implements logical consistency checks as well as calculates control number of trips and other statistics. The logical consistency checks include matrix convolution statistics at half-tour origins (productions of half-tours should be equal to productions of 1st trip legs), at half-tour destinations (attractions of half-tours should be equal to attractions of 2nd trip legs), and at intermediate stops (attractions of 1st trip legs should be equal to productions of 2nd trip legs). The program reports discrepancies between these vectors on the screen and for a normal run they all have to be equal to zero. Non-zero discrepancies indicate on a problem and the run cannot be considered valid. The control number of trips include total of the original half-tour matrix compared to totals of the 1st and 2nd trip leg matrices (again for a normal run all three total must be identical). Additionally the program outputs route deviation statistics used in the model calibration.

7.4.23 Sub-Macros "17. ModeAM" and "19. ModePM"

Sub-Macros 17 (***ModeAM***) and 19 (***ModePM***) implement integrated mode choice and assignment procedures for AM and PM periods consequently. Both macros have an identical structure that integrates the mode choice model specified in Subsection 3.9.1 with the assignment procedures as described in Subsection 3.9.2. The estimated coefficients for mode utilities are reported in Section 5.5. The differences between periods are in the input demand matrices, model parameters, and the order of trip mode legs for P&R, K&R and B&R (as explained in Subsection 3.9.2). The sub-macro script has the following sections:

- Control section of input parameters specified by the user:
    - Setting of scenario based on input macro parameter and setting of time period number (not recommended to change by the user unless the model structure is modified),
    - Location of intermediate matrices (*ms, mo, md, mf*) and final output matrices (*mf*) in the databank (not recommended to change by the user unless the model structure is modified),
    - Value of Time by mode used for Auto Assignment; it can be updated by the user, if required.
    - Zone partitions used for the validation reports (currently is set to corridors *gc*; can be changed by the user if necessary for additional validation/calibration, but would require adjustments in the program if the number of partitions is different from 9),
    - Mode-specific constants by corridors introduced in the calibration process (can be changed by the user in the additional calibration effort for the base year),

- ▶ Number of global iterations (including mode choice and assignments); normally is set to 5 that produces a good level of convergence in a reasonable time frame. A smaller number of iterations (3) will suffice for a crude analysis with a large number of alternatives.
- ▶ Minimum number of auto assignment iterations that serves also as an increment from one global iteration to the next one (currently set to a recommended value of 10 that means 50 iterations at the last global iteration),
- ▶ Number of iterations between auto and bicycle assignment (currently set to 3)
- ▶ Number of iterations for transit assignment (currently set to 3)
- ▶ Number of iterations for finding PNR location in order to match the parking capacity at the PNR lot (currently set to 10)
- ▶ Switch for enabling or disabling fare discounts for university students
- ▶ Scaling coefficient for the peak hour auto and bicycle demand within the peak period auto and bicycle demand; it is currently set to the following values (based on the observed peak patterns):
  - For 2.5-hour AM period: 2.1 (bicycle), varies by OD for auto (1.9-2.1) and is read from Amfac.in
  - For 3.0-hour PM period: 2.5 (both auto and bicycle)
- ▶ List of P&R lots and station locations for K&R and B&R (should be defined by the user for each run according to the network scenario).

► Section 17.0 / 19.0 includes all calculations implemented once and outside the global equilibrium loop:

- ▶ Starting demand matrices by modes (definitions can be changed for a "warm" start),
- ▶ Fixed components of mode utilities not dependent on LOS variables; not supposed to change by the user until the model has been re-estimated,
- ▶ Initialization of all arrays / matrices needed for further calculations within equilibrium loops,
- ▶ Defining the parameters for transit assignment and skimming procedures

► Section 17.1 / 19.1 (located within the global equilibrium loop) includes assignments and skimming procedures (described in **Subsections 3.9.1** and **3.9.2** above):

- ▶ Creating assignable trip tables
- ▶ Auto and Bicycle Assignment Equilibrium Loop
  - Free-flow assignment,
  - Congested multi-class auto assignment,
  - Calculation of bike VDF parameters
  - Bike Assignment
  - Updating bicycle preloads for auto assignment and repeat the steps above
  - Skim bicycle network for bicycle time skims by facility type

    - Auto Skimming by modes (SOV, HOV2 and HOV3+) for congested time and tolls; adding intra-zonal times,
    - Averaging of congested time skims and calculation of delays,
  - Transit assignment (iterative loop)
    - Walk to Local Transit assignment
    - Walk to Premium Transit assignment
    - Averaging of transit line volumes and segment boardings
    - Calculation of crowding function and effective headway; Repeat above steps to include crowding impacts and revised headways
    - Create Walk to local transit and premium transit skims, in-vehicle time (by stop density and Transitway), walk time, wait time, number of boardings, fare
  - Identify boarding station locations for K&R and B&R trips and build K&R and B&R skims for both local and premium transit by station choice and skim convolution.
  - Identifying parking lot and apply capacity constraint for P&R trips (iterative loop with the steps below)
    - Identify parking location for P&R trips (include shadow price).
    - Break P&R transit trips based on the boarding station identified in the previous step
    - Compare P&R parking capacity with P&R trips for each station and compute shadow pricing
  - Building P&R skims for both local and premium transit by parking lot choice and skim convolution,
- Section 17.2 / 19.2 (located within the global equilibrium loop) calculates exponentiated mode-specific utilities for each segment (car-sufficiency category and purpose). For each mode (1-15), the program loops over car sufficiency categories (0-3) and calculates utilities based on the purpose-specific coefficients. This section should be modified only if the mode choice model has been re-estimated. Additional sub-sections calculate composite nest utilities (log-sums),
- Section 17.3 / 19.3 (located within the global equilibrium loop) calculates mode probabilities for each segment (car-sufficiency category and purpose). The program loops over car-sufficiency categories (0-3) and travel purposes (1-7 or 5) and applies a nested logit model to calculate probabilities for modes (1-15). A special sub-section implements a logical check (sum of all mode probabilities for each segment and OD pair must be equal to 1.000000) and outputs the results on the screen. In a normal run all values should be equal to 1.0000000. If there is a value different from 1.000000 the run cannot be considered valid.
- Section 17.4 / 17.4 (located within the global equilibrium loop) calculates trip demand matrices for each mode based on the total demand and mode choice probabilities. It implements an averaging procedure based on the modified MSA to ensure an effective convergence. Additional sections report the mode choice and convergence statistics on the screen (and in the report file) as well as handle combined P&R, K&R and B&R modes. For these modes, demand matrices are split into auto/bicycle and transit legs that are subsequently added to the corresponding assignable matrices.

- Validation section (after the global equilibrium loop) provides detailed statistics on number of modelled trips by 15 modes and 9 corridors compared to the observed trips in the OD Survey.
- Section with final assignments (after the global equilibrium loop) ensures that the calculated mode matrices after equilibration are properly assigned to ensure all necessary network-related outputs:
  - Additional options auxiliary auto assignment with P&R and K&R auto components to save auto passenger volumes,
  - Final auto assignment with P&R and K&R auto components to save link volumes by class (SOV, HOV2 driver, HOV3+ driver, commercials, externals),
  - Final local transit assignment with P&R, K&R and B&R transit components (iterative assignment to account for crowding and capacity constraint),
  - Final premium transit assignment with P&R, K&R and B&R transit components (iterative assignment to account for crowding and capacity constraint),

7.4.24 Sub-Macros "18. CreateOffPeakSkims.mac"

Sub-Macros 18 (***CreateOffPeakSkims***) implements assignment and skimming procedures for off-peak periods. The sub-macro calls another submacro "***18.1 TransSkim.mac***" for early (EA) and midday (MD) time periods separately.

7.4.25 Subroutine "18.1 TransSkim.mac"

Sub-Macros 18.1 (***TransSkim***) calculates auto skims for off-peak period using AM auto skims and assignment and implements transit skimming procedures for off-peak periods. The script has the following sections:

- Control section of input parameters specified by the user:
  - Setting of scenario and time period number based on input macro parameter (not recommended to change by the user unless the model structure is modified),
  - Location of final output matrices (*mf*) in the databank (not recommended to change by the user unless the model structure is modified),
  - Number of iterations for transit assignment (currently set to 3)
- Section 18.1.1 includes calculation of auto free flow time, distance and congested times for SOV and HOV:
  - Free flow time is set to AM free flow time
  - Distance is set to AM distance
  - Congested time is set to AM free flow time for Early period
  - Congested time is set to AM free flow time + 1/3 (AM congested time + transpose of AM congested time) for MD period
- Section 18.1.2 includes transit assignment and skimming procedures.

- Setting of parameters for transit assignment and skimming procedures
- Transit assignment for walk to premium transit (including all modes)
- Create Walk to local transit and premium transit skims, in-vehicle time, walk time, wait time, number of boardings, fare
- Identify boarding station locations for P&R, K&R and B&R trips and build respective premium transit skims by station choice and skim convolution.

7.5 User Guide for Population Synthesizer

The synthesizer should be run for each base year or future year scenario associated with different zonal controls (e.g. change in population, workforce etc.). It is not limited to the actual number of zones so it allows for the TAZ system expansion in future. The Population synthesizer is the only non-EMME component implanted in JAVA that requires installation.

7.5.1 Software and Installation Procedures

- Minimum OS
    - Windows 7: Basic Installation with Service Pack updates
- Microsoft Office
    - Microsoft Office 2007 or Microsoft Office 2010 (at least MS Access is required)
- JAVA
    - jdk-6u37-windows-i586.exe – This JAVA installation file is included in the installation package at C:\Projects\TRANS\PopSyn\Software\.
    - Install the Java at default location - C:\ProgramFiles\Java\ jdk1.6.0_37\
    - It is suggested that the java 1.6.0 update 37 version is installed. If there is another java 32 bit version already installed on the desktop, you may try running it with by changing 'runpopsyn.bat' file java path location accordingly.
- Setting environmental variables: in Windows 7, the environmental variables PATH needs to be edited as below:
    - In Windows 7, Start → Right Click on Computer → Select Properties →Advanced System Settings → Advanced→Environmental Variables.
    - If the JAVA_HOME variable does not exist already, create a new JAVA_HOME variable under 'user variables' section. Variable name should be JAVA_HOME and variable value would be 'C:\Program Files (x86)\Java\jdk1.6.0_27' or any other java path that is required to run java program for other models or applications. All it is needed here is that the JAVA_HOME variable should be in place. Rest of the settings are in the 'runpopsyn.bat' file.

7.5.2 Population Synthesis Directory Structure

This should be created under C:\Projects\TRANS\PopSyn\

- PopSyn
    - Data: Input Access database (SynPop.mdb)
    - EmmeT: Final Emme T matrices
    - Jar: Java Jar file and a batch file to run the program
    - MetaLog: Meta-balancing log files (output)
    - Software: Java software exe file for installation
    - UserDocs: User documentation

All the required files in 'Data' and 'Jar' folders should be in place to run the model.

7.5.3 Input Files Preparation

The user needs to create a new empty Microsoft Access Database file named "SynPop.mdb" at C:\Projects\TRANS\PopSyn\data\ . Once the Access database is created then the following three files need to be imported into SynPop database:

- ZSED : This file should contain the Zonal Socio Economic data for all 672 traffic analysis zones from Ottawa and Quebec regions. This file can be prepared in Excel first and then be imported into Access. The structure should be as shown below in **Table 6-13**.

Table 7-13 | Zonal Socio-Economic Controls for Population Synthesis

Field Number	Field Name	Description
1	taz	Traffic analysis zone number
2	superzone	Superzone ID
3	district	District ID
4	totpop	Total population
5	age04	Number of persons in age group 0-4 years
6	age514	Number of persons in age group 5-14 years
7	age1524	Number of persons in age group 15-24 years
8	age2544	Number of persons in age group 25-44 years
9	age4564	Number of persons in age group 45-64 years
10	age65	Number of persons in age group > 64 years
11	tothh	Total number of households
12	hh1per	Number of one-person households
13	hh2per	Number of two-person households
14	hh3per	Number of three-person households
15	hh45per	Number of four or five person households
16	Hh6per	Number of six or more persons households
17	grndhh	Number of detached households
18	apts	Number of apartments
19	emplabf	Employee labor force

20	Hh0work	Number of household with 0 workers
21	Hh1work	Number of household with 1 workers
22	Hh2work	Number of household with 2 workers
23	Hh3work	Number of household with 3+ workers
24	Hh1inc	Number of households with income < $30,000
25	Hh2inc	Number of households with income $30,000 - $59,999
26	Hh3inc	Number of households with income $60,000 - $89,999
27	Hh4inc	Number of households with income $90,000 or more

Note: ZSED table should have at least the above 27 fields with the exact same field names. It can have more fields and that wouldn't affect results. These 27 fields can be in any sequence.

- LOGIS: This file can be simply imported from the current version of Origin-Destination Survey database. The user may have to verify the following fields in Logis table for the presence and names see **Table 6-14** below. All other fields could be left in the file.

Table 7-14 | Seed Household File For Population Synthesis

Field Number	Field Name	Description
1	CLELOGIS	Household ID
2	NBPERS	Number of persons in the household
3	TYPELOGIS	Household type
4	FacLog	Household factor
5	ztlogis07	TAZ ID for the respective household ID
6	hhincome	Household Income Categories (values 1-4)
7	Hworker	Number of workers in the household (0-3+)

- PERSONNES: This file can be simply imported from the current version of Origin-Destination survey database. The user may have to verify the following fields in Personnes database for the presence and names – see **Table 6-15** below. All other fields could be left in the file.

Table 7-15 | Seed Person File for Population Synthesis

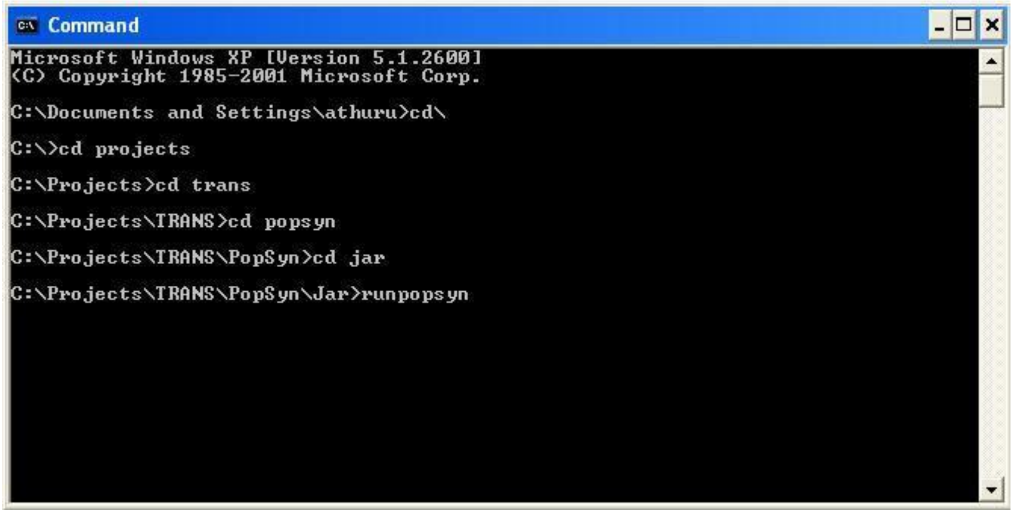
Field Number	Field Name	Description
1	CLELOGIS	Household ID
2	CLEPERSONNE	Person ID
3	AGE	Person age
4	GRPAGE	Person age group
5	OCCUP	Occupation

Note: Alternatively, the user can rename the SynPop_backup.accdb file to SynPop.accdb and run the program.

7.5.4 Running the Population Synthesis process

The user needs to open the DOS command prompt to run the population synthesis procedures. The DOS window needs to be set to the path C:\Projects\TRANS\PopSyn\Jar\. Once the path is set, type "runpopsyn" and then press enter as shown in Exhibit 7-1 below.

Exhibit 7-1 | Run Window for Population Synthesizer



7.5.5 Output Files

The Population Synthesis process takes about 60 minutes to complete the run and create all the required output files. The following three sets of output files are created.

Meta-balancing log files:

These are the first set of output files from the population synthesis process. The user needs to check these meta-balancing log files and confirm that meta-balancing process is the desired procedure to resolve the inconsistencies in the input zonal data. If necessary, the user can also opt for manual process to fix the data. Six log files correspond to the six conditions mentioned in Tech Memo are written out as below.

Location: C:\Projects\TRANS\PopSyn\MetaLog\

List of files:

i. MetaBalanceLog1.txt: Reports the list of TAZs that are with the difference between total households and sum over household size distribution is greater than 5
ii. MetaBalanceLog2.txt: Reports the list of TAZs that are with the difference between total households and sum over household type distribution is greater than 5
iii. MetaBalanceLog3.txt: Reports the list of TAZs when total households exceeds total population by 5
iv. MetaBalanceLog4.txt: Reports the list of TAZs that are with the difference between total population and sum over age groups is greater than 5
v. MetaBalanceLog5.txt: Reports the list of TAZs when employee labor force exceeds total population by 5

vi. MetaBalanceLog6.txt: Reports the list of TAZs when this condition "Total population and number of households should either both be positive or both equal to zero" is NOT met

vii. MetaBalanceLog7.txt: Reports the list of TAZs with the difference between total number of households and sum over household by income distribution > 5. All cases with >0 and <=4 were normalized and not reported here

viii. MetaBalanceLog8.txt: Reports the list of TAZs with the difference between total number of households and sum over household by worker distribution > 5. All cases with >0 and <=4 were normalized and not reported here

Once the meta-balancing process is done then the corresponding output table "ZSEDN" is created in the SynPop.mdb access database. From this point onwards, the zonal data table is ZSEDN and the table ZSED will no longer be used.

Synthetic Household Distribution File

This is the primary output file from the population synthesis process and contains the TAZ synthetic household distribution data as per Table 2 in the Tech Memo – list of all TAZs with the data for 42 household categories. This table is named as "SyntheticHH" in the "SynPop.mdb" access database.

Location: C:\Projects\TRANS\PopSyn\data\

Access database: SynPop.mdb

Table Name: SyntheticHH

Note: The SynPop.mdb access database has three preliminary input tables (ZSED, LOGIS, and PERSONNES) and one primary output table 'SyntheticHH'. In addition to these four tables three more intermediary tables are created during the population synthesis procedure: ODSurvey, SeedSample and ZSEDN.

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