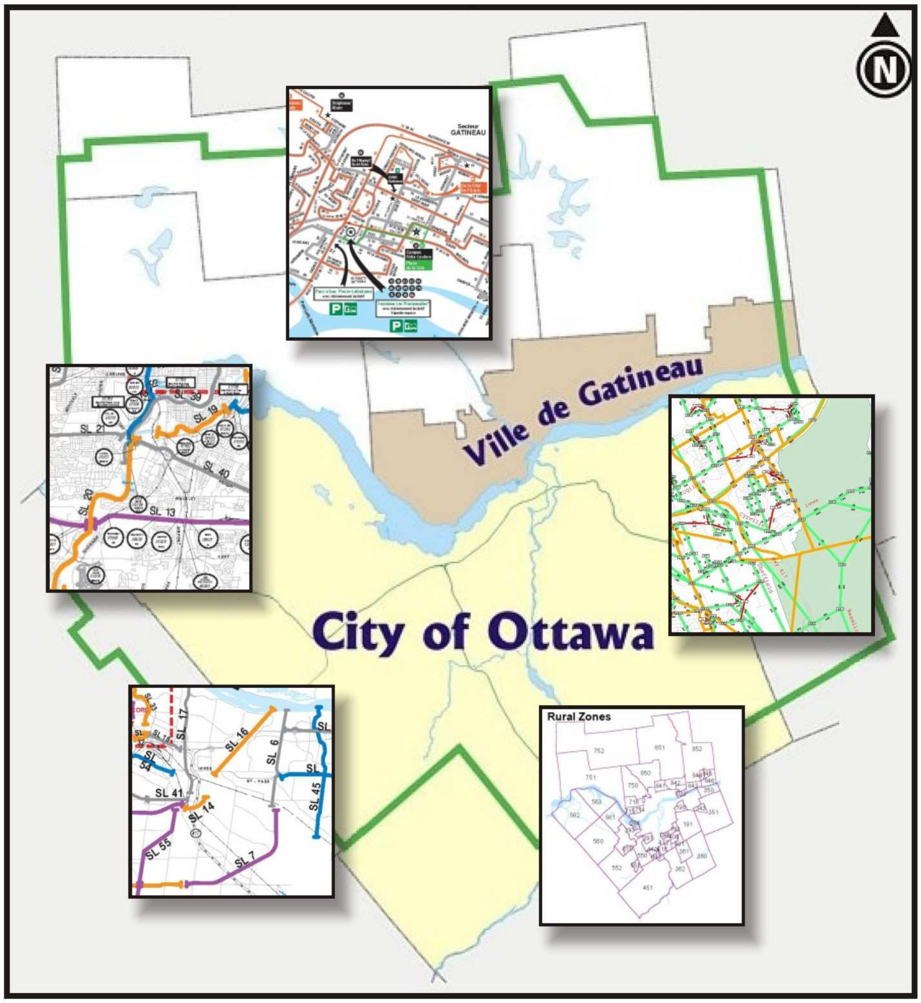
TRANS Model

Redevelopment



Technical Report

April 2008

McCORMICK RANKIN CORPORATION

Parsons Brinckerhoff

TECSULT

TRANS

UN COMITÉ CONJOINT POUR LA PLANIFICATION DES TRANSPORTS DANS LA RÉGION DE LA CAPITALE NATIONALE | A JOINT TRANSPORTATION PLANNING COMMITTEE SERVING THE NATIONAL CAPITAL REGION

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EXECUTIVE SUMMARY

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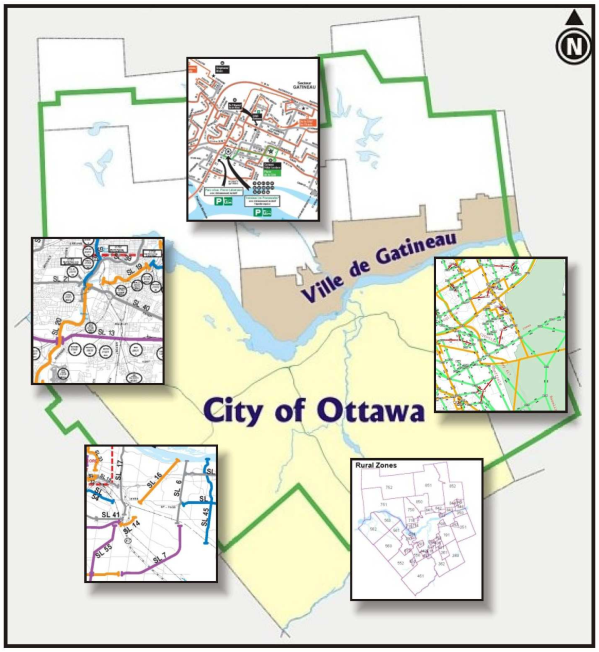
TRANS has a long standing commitment to travel forecasting and transportation model development, having been involved in joint model development programs since the late 1970's. With the completion of the Origin-Destination (O-D) Survey in the fall of 2005, as well as a number of related transportation data collection activities, the City of Ottawa, on behalf of TRANS member agencies, retained the services of a consultant team to conduct a comprehensive review of TRANS modelling techniques and practices, and an update to the TRANS model itself.



Ottawa-Gatineau
National Capital Region

The objectives of this review and updated model were:

- *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 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; and*
- *To recalibrate the transportation model based on recent data collection efforts, leading to an increased level of accuracy in carrying out both short-term and long-term forecasts.*

The updated TRANS model is almost entirely implemented in EMME, 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 that aim to explain regional travel behaviour. Ultimately, travel demand, in terms of person and vehicular travel, is organised within the EMME 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 and transit travel on the road and transit networks.

The redevelopment of the TRANS Model involved a full update of key demographic and land-use variables, as well as both the auto and transit networks that reflect 2005 conditions. In addition, a large part of the work included estimating statistical models based on the reported travel demand, trip patterns, and characteristics such that local observed travel behaviours are well captured and predicted within the model framework.

Summary of Model Features

The proposed model architecture was developed in the early stages of the study and focused on ensuring increased behavioural realism and the ability to permit further enhancements of the model system over time, as part of TRANS' ongoing maintenance and improvement efforts. It met the objectives set out by TRANS agencies and included several advanced features associated with the new generation of activity-based models, combined with more traditional 4-step model components. In addition, the adopted modelling framework was cognizant of data availability issues, particularly as they related to a modelled area spanning two provincial jurisdictions. Early emphasis on data availability issues ensured feasibility of the model estimation, implementation constraints, and calibration efforts, while at the same time recognizing and responding to both the project schedule and budgetary constraints and limitations.

An overview of the model framework and major features integrated into the new redeveloped model are summarized as follows:

Incorporation of Trip Chaining. *Considering an 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 often account for approximately 30% of the total daily trips). Secondly, it ensures a logical consistency for trips included in the same tour in terms of their destinations, time-of-day, and mode choice. The model architecture includes many entirely-tour-based and half-tour-based procedures. The introduction of these advanced modelling procedures is restricted to the trip generation and trip distribution stages, where they can be effectively implemented. Thus, the developed model is not a full tour-based model (compared for example, to the model used in the Montréal Region by MTQ) since the TRANS mode choice model is still essentially trip-based. A tour-based mode choice model would require a full micro-simulation approach. The opportunity for future enhancements to include these approaches within the new TRANS model, however, remains open.*

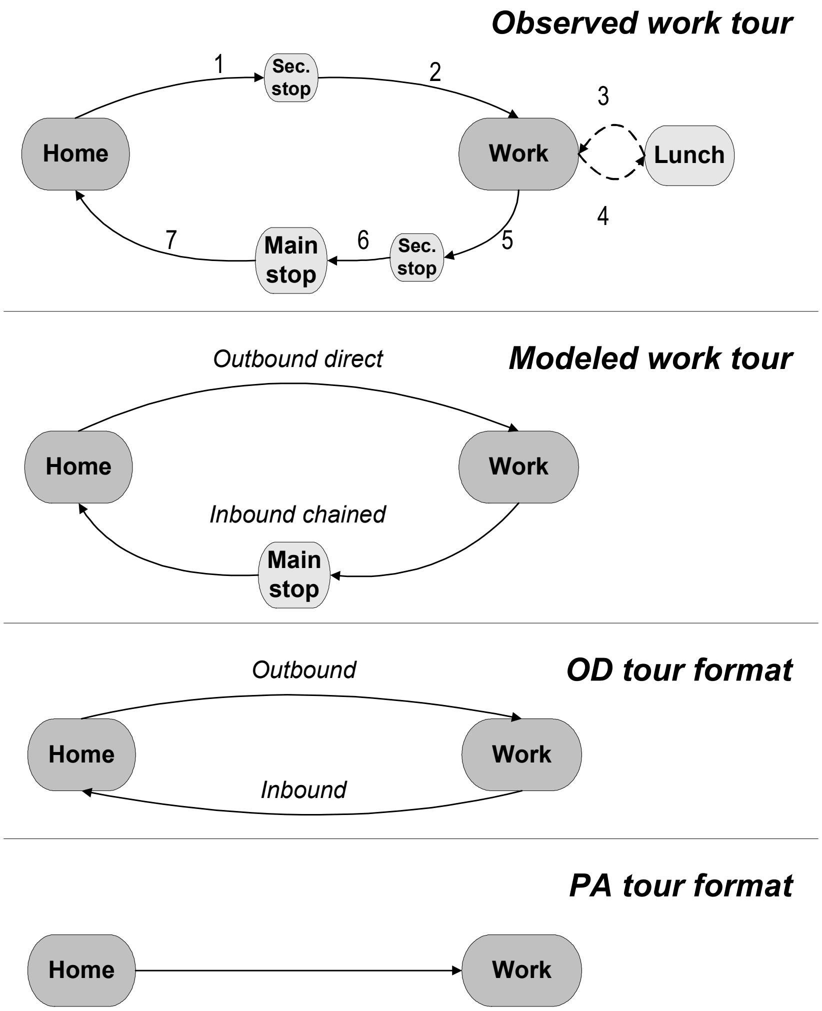
*The **tour construction** technique is illustrated in Exhibit 3-1, with an example of a typical work tour including 7 trip elements. This technique includes the following four major steps:*

- ***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 case illustrated, the primary destination is work. The primary destination naturally breaks the tour into two directional half-tours – outbound and inbound (with reference to the home). 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. These elements and trip components can be added if TRANS wishes to include and explicitly model the Midday period at some point in the future.*
- ***Identification of the simplified modelled tour**. After the 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 reality, it covers almost 90% of the observed trips and more than 97% of the observed VKT in the modelled time-of-day periods (AM and PM).*
- ***Origin-Destination (O-D) tour format.** This is a further aggregation that essentially reduces the tour to round trips by the elimination of intermediate stops. In the modelling*

process, the O-D tour format is applied at the second stage of the trip distribution (after which, at the third stage, intermediate stops are reinserted).

- ***Production-Attraction (PA) tour format****. This is the most aggregate tour representation that essentially considers the locations of the home and primary destination of the tour, with no distinction of 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 clarity sake, the levels of tour construction are presented in the order of simplification. This order also corresponds to the steps of data processing for the O-D Survey. However, it is noted that in the model application stream, the order is reversed. It starts with the most aggregate PA format, then converts it into O-D format with directional half-tours, and finally inserts stops into chained half-tours.*

Exhibit 1: Tour Construction Steps



This four-step approach provides daily trip values, from which specific time-of-day periods may be extracted as required.

Daily Tour Generation. *The new production and attraction sub-models operate with tours and provide daily trip numbers from which time-of-day-specific numbers are derived based on the implementation of 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, and car ownership. The tour (primary destination) attraction model is also daily (with subsequent time-of-day choice), however it is formulated as a zonal model using specific socio-economic and land-use variables.*

Daily Tour Distribution ensuring 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 (with commuting to work being the most important). Further in the distribution procedures, tours and half-tours are broken into time-of-day periods. At the final stage, half-tours are then converted into trips according to the various types of half-tours. Direct half-tours each represent a single trip. Chained half-tours are converted into two successive trips each, through the insertion of an intermediate stop. It should be noted that this technique is principally different from just having independent time-of-day-specific models. In the adopted structure, TOD-specific trip matrices are consistently derived from the full daily tour source and are therefore dependent on the same set of input variables.*

The updated TRANS distribution procedure for tours allows for the incorporation of a "seed matrix" (derived from the O-D Survey expansion) in a flexible combination with "gravity model" principles. 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 little or no change between the base and future years, the balancing component of the model will dominate and the distribution pattern will be most similar to the observed zone-to-zone matrix. The gravity component comes into play if employment and population change significantly, thus impacting the distribution. 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 45 segments, generated by 5 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 trip 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, one must consider a single segment (thus, the indices that relate to travel purpose, and TOD periods are temporarily dropped). One must first reproduce the standard model formulations for balancing and gravity procedures, and then combine them in a single "hybrid" formulation.

Detailed Mode Choice procedures to support TRANS planning needs. *As an additional improvement to the existing TRANS model that previously had a simplified binary mode choice (auto vs. transit), the newly developed mode choice sub-model explicitly incorporates a variety of transit modes (regular bus, Transitway, rail/LRT) and access options (walk, park & ride, kiss & ride), and distinguishes between auto driver and passenger modes. 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 and K&R were modelled in an explicit way, including a choice of the parking lot that ensures the shortest multimodal path* *between the trip origin and destination. This was carried out differently for AM and PM periods. The AM bi-modal combinations assume outbound order of legs (first auto, then transit). PM bi-modal combinations assume inbound order of legs (transit first, then auto). For Park and Ride locations, capacity constraints can be introduced (for the AM period). Modelling of constrained parking can be implemented through iterative adjustments 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 (and trip distribution in a full model run).*

In general, the probability of trips being made by auto is sensitive to the difference between free-flow travel time and congestion delays, reflecting the importance of reliability to road users. Likewise, the proportion of a transit trip being made on the Transitway (or on a semi-exclusive right-of-way) proved to be a strong positive factor favouring transit as the mode choice. The coefficients for some variables had to be set, rather than estimated, especially cost-related variables, which only vary over a very narrow range in the base year for which we want to calibrate the model. However, there turned out to be no need to introduce "rigid" or "flat" variables – such as geographic location (e.g. CBD) – which most regional mode choice models often require. The combination of estimated variables, such as auto delays, Transitway attractiveness (i.e. exclusive or semi-exclusive right-of-way transit operation not subject to auto congestion) and population/employment density managed to explain the observed variations in mode shares across the various geographic areas.

Overall Model Structure

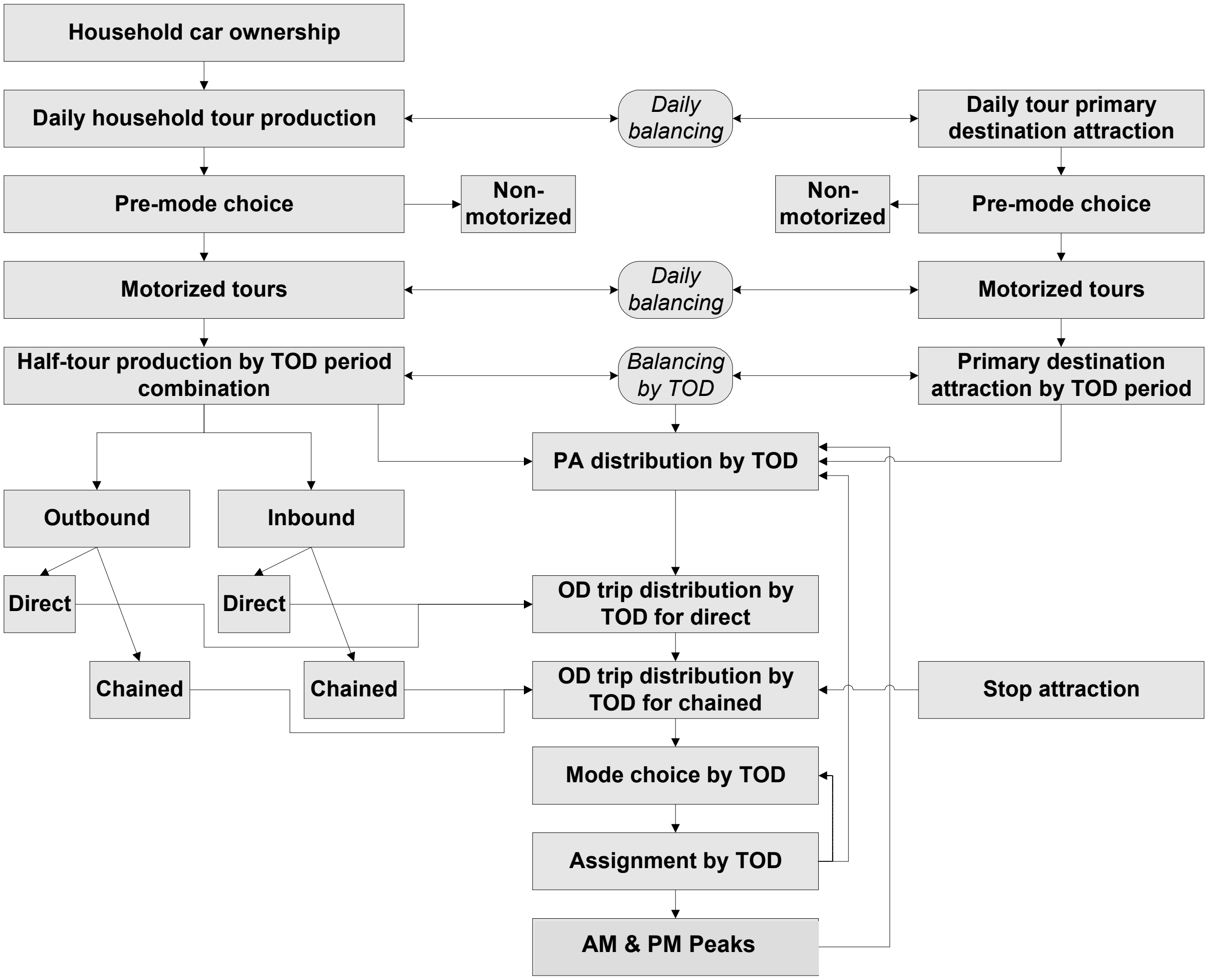
The levels of effort required for the development of the advanced approach described above translates in the implementation and calibration of the subsequent mode choice and trip assignment stages, to be restricted to the AM and PM periods for the current model version. It should be noted that the explicit modelling of both AM and PM periods represents a step forward from the previous TRANS model, which focused on the PM period only. In practical terms, TRANS Agencies' modelling of these key periods suffices for an effective supporting tool for most planning decisions. The model framework was also developed to allow for a comparatively straightforward extension of the model system to include some other (or possibly all) periods of a day, if needed or desired in the future. With a full set of time-of-day periods explicitly modelled, a congestion-sensitive peak spreading feedback procedure can then also be set in place.

Overall, the model development process was founded following a detailed review of all available land-use and socio-economic data in combination with the O-D Survey results. 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 O-D Survey, in order to build a synthetic distribution of households / persons needed to support the demand model. It is designed to re-weigh households in the O-D Survey for each target year, based on the socio-economic control data at the zonal level – household distribution by size, number of workers, dwelling types as well as population distribution by age range. The population synthesizer thus provides the necessary input variables to the travel forecasting model for any predetermined socio-economic scenario.

This approach, which separates the input data from the demand modelling framework, also allows for an easy modification of the model system in the future, including possible extensions to other time-of-day periods. The entire set of demand modelling system elements were implemented as a 3-level nested macro script compatible with the latest version of EMME software.

A flow chart highlighting each of the elements and sub-elements of the TRANS model system design is shown in Exhibit B.

Exhibit B – TRANS Model System Design



Model Calibration and Validation

The model calibration and validation work compared model results at various steps in the modelling process, as well as within the final stages of the demand estimation, which occurred following the mode split module, and provided the most comprehensive opportunity to compare base data (both reported and observed travel) with modelled results for the base year. The modelled results were initially compared to reported travel, as summarised from the TRANS O-D Survey, at a regional level. This comparison is summarised in Table 1: Regional Travel Demand Comparisons for the AM and PM Peak Periods for modelled and reported travel demands. It is noted that the modelled travel demand, when compared with the O-D Survey data, slightly underestimated both auto trips (-1% and -4%) and transit trips (-7% and -5%) during each of the AM and PM peaks. However, following further analysis of the observed count data (traffic and transit) across strategic screenlines, a comparison indicated that modelled demands were slightly higher than the observed traffic/transit count data. The model, of course, was estimated using the O-D Survey dataset and therefore compares well against said data at several different levels of aggregation. The differences noted between the O-D Survey results and the identified observed *traffic/transit flows therefore serve to provide both a high and low range of base year travel demand from which the model results can be compared with and fully evaluated against.*

Table 1: Regional Travel Demand Comparisons for the AM and PM Peak Periods

Regional System-wide Travel Demands*	AM Peak Period (6:30 to 9:29 AM)			PM Peak Period (15:30 to 18:29 AM)		
	EMME Model	OD Survey**	% Difference	EMME Model	OD Survey**	% Difference
Total Auto Drivers	298,400	300,700	-1%	431,800	448,800	-4%
Total Auto Passengers	68,700	62,200	11%	92,000	96,500	-5%
Average Car Occupancy	1.23	1.21		1.21	1.21	
Total Transit Trips	103,900	111,500	-7%	117,800	124,500	-5%
Transit Mode Split	22.1%	23.5%		18.4%	18.6%	

* Numbers rounded to nearest 100 trips.
** OD survey results for PM (15:30 to 18:00 PM) were factored to reflect the modelled period of 15:30 to 18:29 PM.

More detailed screenline comparisons of modelled demand with observed traffic count data were also carried out. In general, both the model demands and observed traffic counts (along key major travel corridors across the Ottawa-Gatineau region) indicated the following: i) inbound travel demand for the AM peak hour, across the vast majority of the regional screenlines, represents the highest hourly travel demand. This is typical of most urban centres that are similar in size to Ottawa-Gatineau, as the AM commuter peak tends to be more compressed; ii) the AM outbound (non-peak) direction is significantly lower than its counterpart during the afternoon peak hour (PM inbound). As a result, the sum of travel demands in both directions of travel across screenlines is higher for the PM than the AM, despite the higher peak direction of travel occurring during the AM peak hour for all of the major strategic travel corridors in the region.

Future Model Enhancements

The redevelopment of the TRANS modelling framework includes an advanced tour based modelling structure for daily tour generation and spatial distribution. The model also relies on a traditional trip-based structure for mode choice and traffic/transit assignments for both the AM and PM periods. The redevelopment of the TRANS model in this fashion has taken significant and deliberate steps forward toward a future, fully tour based model for the region. The redeveloped model framework nevertheless leaves considerable flexibility for TRANS as part of its ongoing annual programme to further develop and refine key elements of its modelling framework based on both data availability and funding constraints. TRANS Agencies recognise that the very nature of travel demand modelling requires an ongoing continuum of updating and revision to ensure the model remains current and relevant to both its users and city planners. Key model enhancements that TRANS should consider, and that would also contribute to wider use by area planners, have been identified. Equally important, specific data collection efforts to support further model development are also recognised. They will require TRANS' ongoing commitment to successfully implement the data collection efforts within reasonable timelines.

The core demand model, which has been implemented in a modular way, allows for a number of extensions, refinements, and modifications in the future, based on TRANS' priorities. In particular, the *following optional extensions are of particular interest, as TRANS continues to seek improvements and enhance modelling practises for area planning agencies:*

- *Model system extension to address all periods of the day in addition to AM and PM (i.e. midday, night) that would cover a complete daily forecast; this might be essential for environmental studies as well as toll road traffic and revenue studies;*
- *Addition of a time-of-day (peak spreading model); this is an integral element in ensuring that long term forecasts adequately consider congestion management policies;*
- *Implementation of a full system equilibrium including the dependence of trip distribution on mode choice logsums as part of the impedance function; this is essential for congestion pricing and other congestion management policies;*
- *Introduction of capacity constraints for Park and Ride lots; this is important for rapid transit studies (BRT, LRT, commuter rail) where Park and Ride might represent a significant share of the transit ridership;*
- *Introduction of capacity-constrained transit assignment through shadow pricing; this is important for more realistic ridership distribution by transit lines in dense urban areas;*
- *Introduction of frequency adjustment mechanisms for selected transit lines; this enhancements makes long-term forecasts more reasonable, since exact line frequencies are not known and cannot be coded with certainty;*
- *Separation of rail modes in the mode choice nested structure; this is needed for analysing various rail projects; since the current O-D Survey cannot support estimation of these nests, a 'stated preference survey' will be required. Alternatively, the nesting structure and parameters could be transferred from other regional models.*

Each of the optional improvements listed above have been successfully implemented and tested elsewhere and consequently offers additional analytical tools and techniques to improve and enhance the practical applications of long range planning models. The core structure of the redeveloped TRANS model was specifically designed to allow for future incorporation of a wide range of additional features without a requirement to significantly modify key elements of the main model framework.

Technical Report

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Appendix A.1 Matrix convolution procedure implemented in EMME for trip distribution for chained tours.

Appendix B.1 Progress Report1 includes estimation results for the car ownership, tour production, tour attraction, and pre-mode choice (motorized vs. non-motorized travel) models.

Appendix B.2 Progress Report 2 includes estimation results for the time-of-day choice, stop frequency, and stop-attraction models.

Appendix B.3 Progress Report 3 includes estimation results for the motorized trip mode choice models.

Appendix B.4 Progress Report 4 includes validation statistics for the car ownership, tour production, and tour attraction models.

Appendix B.5 Progress Report 5 includes validation statistics for the time-of-day choice and stop-frequency models.

Appendix B.6 Progress Report 6 includes validation statistics for the tour/trip distribution and trip mode choice models.

Appendix C.1 Regional Screenline validation of road and transit network volumes.

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1.0 Introduction

In June 2006, McCormick Rankin Corporation (MRC) in association with Parsons Brinckerhoff, Totten Sims Hubicki and Tecsult was retained to undertake the redevelopment of the 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 acted as the contracting agency on behalf of all TRANS Agencies – including the City of Ottawa, la Ville de Gatineau, la Société de transport de l'Outaouais (STO), the Ontario Ministry of Transportation (MTO), le Ministère des Transports du Quebec (MTQ), and the National Capital Commission (NCC).

1.1 Study Objectives

TRANS has a long standing commitment to transportation model development having been involved in joint model development programs since 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 had not been recalibrated for almost 10 years, after it had been updated and calibrated against the 1995 Origin-Destination (O-D) Survey results. Consequently with TRANS having completed a regional origin-destination survey in the Fall of 2005, as well as a number of related transportation data collection activities, the TRANS agencies determined it was appropriate to initiate a comprehensive review and update of modelling techniques and practices.

The objectives of the model redevelopment were:

- 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 modelled results as well as their sensitivity to various socio-economic scenarios, land-use development, and transportation improvements;
- To recalibrate the transportation model based on recent data collection efforts, leading to an increased level of accuracy in carrying out both short-term and long-term forecasts.

The TRANS model is almost entirely implemented in EMME, a software package 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 that aim to explain regional travel behaviour. Ultimately, travel demand, in terms of person and vehicular travel, is organised within the EMME 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 and transit travel on the road and transit networks.

The redevelopment of the TRANS Model involved a full update of key demographic and land-use variables, as well as both the auto and transit networks that reflect 2005 conditions. In addition, a large part of the work included estimating statistical models based on the reported travel demand, trip patterns, and characteristics such that local observed travel behaviours are well captured and predicted within the model framework.

1.2 Study Participants

The TRANS Committee is comprised of the following member agencies: the National Capital Commission (NCC), the Ontario Ministry of Transportation (MTO), the City of Ottawa (including OC Transpo), le Ministère des transports du Québec (MTQ), la Ville de Gatineau and la Société de transport de l'Outaouais (STO).

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

- **City of Ottawa**: Transportation – Strategic Planning, Transit Service Planning, Transit Scheduling and Analysis, Area Traffic Management and Environmental Sustainability;
- **Ministère des Transports du Québec** : Direction de l'Outaouais and Modélisation des systèmes de transport;
- **Ministry of Transportation of Ontario**: Data Management and Analysis;
- **National Capital Commission**: Capital Planning and Real Asset Management;
- **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. Vincent Patterson, Senior Project Manager in the Transportation – Strategic Planning Unit (City of Ottawa). The Sub-Committee also included Mr. Derek Washnuk, Transportation Planner in the Transportation - Strategic Planning Unit (City of Ottawa), as well as Mr. Pierre Tremblay, Planning Director and Mr. Luc Deneault, Transportation Analyst, both working in the Modélisation des systèmes de transport division (MTQ).

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

1.3 Report Overview

This report documents the model redevelopment process. It also provides a technical background, detailed information on the data and networks used, and 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 Background,
- Section 3 – Demand Model Architecture,
- Section 4 – Zones and Network Adjustments,
- Section 5 – Model Estimation,
- Section 6 – EMME User Guide for TRANS Model,
- Section 7 – 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, trip distribution, modal split and trip assignment algorithms. These models focussed 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 the PM peak period only and represented a 2 ½ hour time frame (3:30 PM to 5:59 PM) coincident with the afternoon peak commuter travel demands.

TRANS maintained comprehensive demographic datasets and also undertook roadside traffic counts as a means of keeping the model current. However, more comprehensive O-D surveys for the region tended to be carried out on a less frequent basis, on an approximate ten year cycle (1986, 1995, and 2005). Despite the rather long cycle for updating travel patterns and trip characteristics, a number of model updates occurred in 2004-2005, including redefined trip generation rates based on post-census demographic data as well as a recalibrated modal split model.

As part of the 1995 model update, the existing EMME/2 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 1995 and 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 conditions.

2.2 Redeveloped TRANS Model

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 the previous models 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-economic data, additional 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: approximately 600 traffic zones, 94 super zones, 26 districts, 2 provinces and/or as region-wide control targets. In general, the selection of specific variables was based on the results of rigorous statistical testing and analysis performed as part of model estimation procedure.

Ultimately, the retention of specific variables within the redeveloped 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 - 2005 OD Survey

The regional O-D Survey completed during the Fall of 2005 serves as a major source of trip patterns and trip characteristics for the redevelopment of the TRANS model. The TRANS O-D Survey represents a 5% sample of households in each of 22 urban and rural sampling districts and reports all trips made by persons 11 years of age or older, on an average weekday for each of the sampled households. The goal of an O-D Survey 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 three categories of data:

- **Household data**: location, size, number of vehicles 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, transit details (access mode, line used, transfer points, fare payment), Ottawa River bridge used (if any), etc.

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 data collected as part of these ongoing counts provide valuable information that can be used to validate the model estimates and results.

On-board transit ridership counts are also conducted by transit agencies through the use of an Automated Passenger Counting (APC) system, which are 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. In addition, the APC buses record the schedule adherence of the bus at specific time points along the routes, from which **transit travel time** data can also be established.

Region-wide travel time surveys are resource extensive data collection efforts and consequently are not normally undertaken very often. However, to complement the regional origin-destination data collection efforts, travel time data was captured on approximately 14 radial routes 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.

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 and dwelling type. 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 five groupings (1, 2, 3, 4 or 5, 6+). Two basic dwelling types were used: apartments and detached houses. These marginal zonal controls, in combination with the seed distribution of households from the O-D Survey, allowed for construction of a detailed synthetic population in each traffic zone including a joint distribution of households by size, dwelling type, and number of workers (42 joint categories).

The planning agencies located on the Outaouais side of the Ottawa River estimated most demographic variables based on the 2001 Census, using updated 2005 population estimates by dissemination areas (DA) as prepared by the Institute de la Statistique du Québec. The relationship between the DA boundaries and the traffic zones (TZ) was carried out by TRANS Agencies representatives based on examination of mapping for the area and the City of Gatineau's assessment data.

The City of Ottawa population estimates were based on 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.

City of Ottawa employment estimates were based primarily on results from the detailed 2000 Employment Survey, with adjustments made based on local economic considerations to reflect changing employment patterns up to 2005. It is noted that some aggregate results of the detailed 2005 Employment Survey were available in part to review and validate elements of the 2005 O-D Survey. The City of Gatineau, on the other hand, maintains an up-to-date employment dataset based on its ongoing active maintenance program undertaken by LIC-Outaouais (Liste Industries Commerces).

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 O-D Survey results. It was recognised that the region, in general, would be a net importer of labour force (i.e more persons commuting into the region from outside the region than those leaving the region for employment) and consequently the total employment located in the region would be significantly higher than the estimates of the resident employed labour force obtained from either StatsCan sources or inputted from the 2005 O-D Survey database. In addition, it should be noted that the 2005 O-D Survey tended to classify persons as fitting into a single category (i.e full time student, part time worker, part time student etc), while in some cases, a person could be classified in more than one category. During the process of assigning employment labour force by zone, issues arose regarding control totals: employed labour force from the StatsCan census data totalled 612,000, the weighted number of workers in the 2005 O-D Survey totalled approximately 537,000, and a regional employment figure was 587,000. Reconciling differences identified in terms of work trips and employment labour force estimates from various different sources resulted in adopting an employed labour force estimate for base year (2005) of 569,500. Of this control total, 425,000 jobs were in Ottawa and 144,500 were in Gatineau.

2.2.4.3 Number of workers per household

The 2005 O-D Survey 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 categorised as follows: no workers, 1 worker, 2 workers and 3 or more workers. A population synthesizer, developed outside the EMME/3 model framework using JAVA, was used for generating the joint household distribution by size, number of workers, and dwelling type.

2.2.4.4 Percentage of Low-income Households

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 percentage of low-income households per zone was used as a (aggregate) means to capture the impact of household income on trip making characteristics. Income specifically affects trip generation rates and mode choice preferences.

However, while the data available for each side of the Ottawa River differed slightly, efforts were made to retain income at least in its most basic form (low income households) within the proposed modelling structure. For the Outaouais side of the Ottawa River, income data was available in $10,000 increments and the defined threshold for a low-income household was set at $30,000. On the Ontario side of the Ottawa River, the City of Ottawa had set the low-income threshold as a function of household size, defined as follows:

- 1-person households = $18,371
- 2-person households = $22,964
- 3-person households = $28,560
- 4-person households = $34,572
- 5-person households = $38,646
- 6-person households = $42,719
- 7-person households = $46,793

Each of these definitions was retained in determining percentage of low-income households for traffic zones located on each side of the Ottawa River.

2.2.4.5 Employment by place of work

Employment levels for various classifications were to be retained in the modelling framework as they provided strong relationships 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	(22%)
Private Offices	(13%)
Retail	(11%)
Service	(25%)
Education	(8%)
Health	(8%)
Industrial	(13%)

The percentage in parenthesis indicates the regional share of the jobs in each of the categories noted.

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 non-motorised (walking/biking) trips, and mode choice. Land use variables were calculated and statistically tested at different levels of geography: traffic zone, super zone, and district, for each of the following variables:

- Share of 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.

2.2.6 School & University Related Variables

School trips were defined in the O-D Survey dataset as a trip purpose and could be further disaggregated into post secondary (including University) and secondary school trip categories based on the student's age. This was carried out as follows:

- **11 to 17 years**: Secondary schools as well as separate middle schools.
- **18 years and more**: while referred to as university trips do include all post secondary institutions.

As in past O-D surveys, school aged children less than 11 years old were not captured explicitly in the O-D Survey. The location and enrolment levels for both secondary and post-secondary school districts were compiled from information provided by the City of Ottawa and City of Gatineau.

In addition, post-secondary (university) catchment areas were established to provide a means of identifying specific sets of zones where, for example, large proportions of the student population typically tend to live within close proximately to the university.

2.2.7 Parking Related Data

The location of large parking suppliers and the cost of parking were 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 were 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 and future park and ride lots capacity, provided by TRANS Agencies (OC Transpo/STO),
- Locations and rates of privately owned parking lots in the region, based on a survey conducted on October 1, 2006,
- City-owned/leased parking lots (locations, rates, capacities), 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:
    - Park-and-Ride lots for rail (and bus),
    - Park-and-Ride lost for bus only.

3.0 Demand Model Architecture

3.1 Main Model Features and Sub-Models

3.1.1 Summary of Model Features

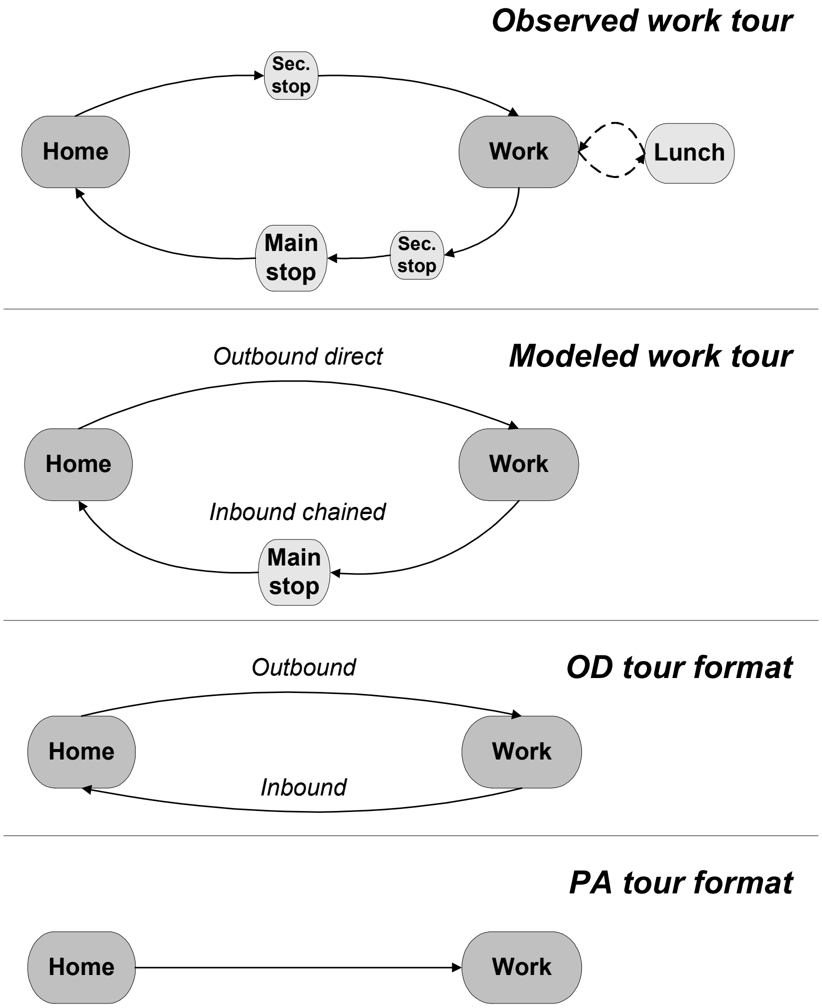
The proposed model architecture was developed to ensure increased behavioural realism and to permit future enhancement of the model over time. It includes several advanced features associated with the new generation of activity-based models, combined with more traditional 4-step model components. In addition, the proposed framework was cognisant 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 major features of the core new model are summarized here:

- **Incorporation of Trip Chaining.** Considering an individual's trips as part of a 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, it allows for better and more consistent modelling of non-home-based trips (which make up approximately 30% 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 full-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 implemented effectively. Thus, the developed model is not a full tour-based model (compared for example, to the MTQ 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, quite open.
- The **tour construction** technique is illustrated in Exhibit 3-1 using an 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 eliminating insignificant stops by linking the corresponding trips, a simplified tour structure is obtained 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 reality, it covers almost 90% of the observed trips and more than 97% of the observed vehicle kilometres travelled (VKT) in the modeled time-of-day periods (AM and PM).

3. **Origin-Destination (O-D) tour format**. This is a further aggregation that essentially reduces the tour to a round trip by eliminating intermediate stops. In the modelling process, the O-D tour format is applied at the second stage of 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 the primary destination of the tour with no distinction of travel direction. 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 the levels of aggregation 1-4 are presented in the order of simplicity. This order also corresponds to the steps of data processing of the O-D Survey. However, in the model application stream, the order is reversed. It starts with the most aggregate PA format, then converts it into O-D format with directional half-tours, and finally inserts stops into chained half-tours. They will provide daily trip numbers, from which specific time-of-day periods may be extracted.

Exhibit 3.1 Tour Construction Steps



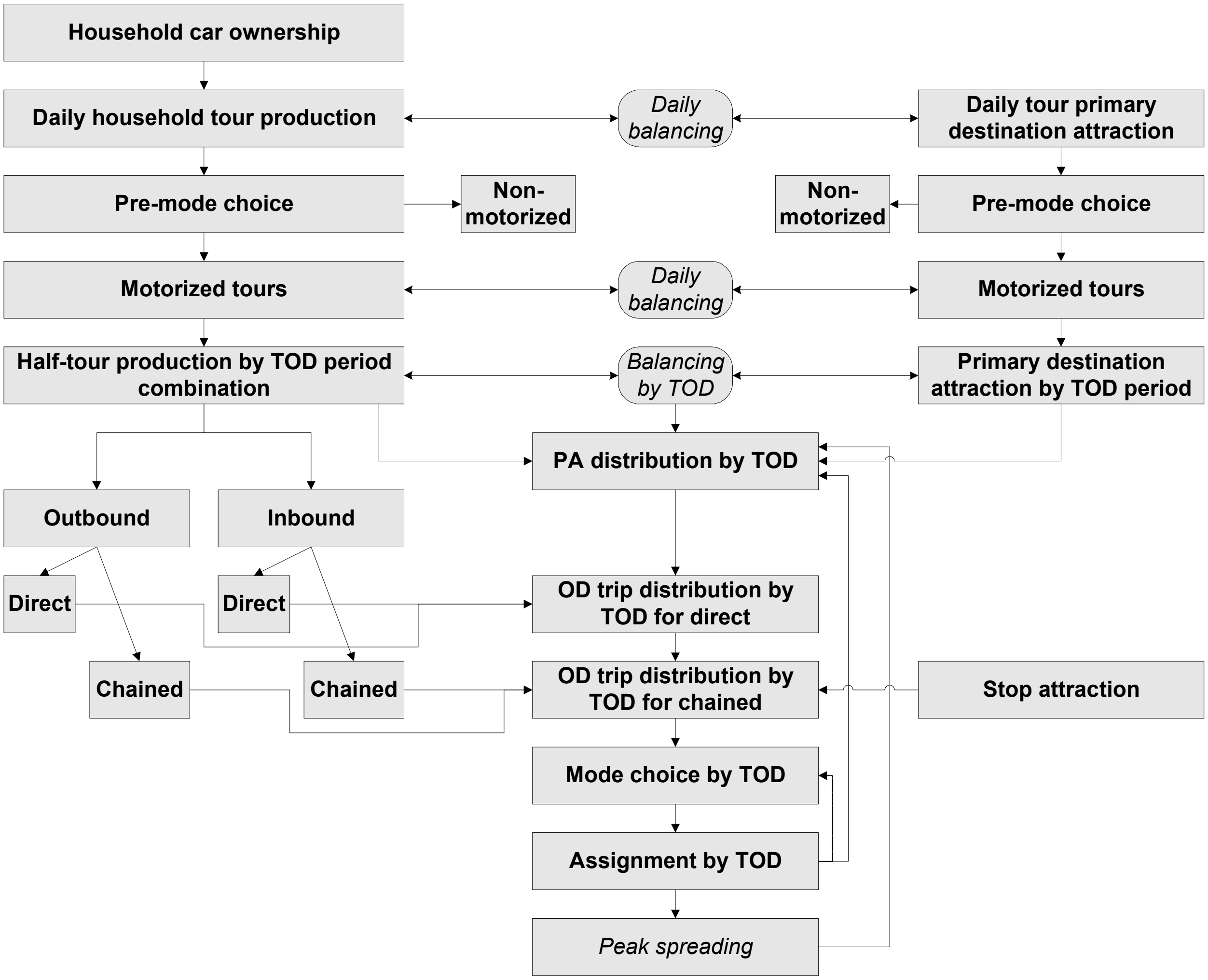
- **Daily Tour Generation.** The new production and attraction sub-models operate with tours and provide daily trip numbers, from which time-of-day-specific numbers are derived in a consistent way based on the time-of-day choice model. The tour production model does not focus on individual person rates, but rather on the household as a whole and on its composition (number of workers, number of non-workers, etc.), dwelling type, 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.
- **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. This provides an aggregated regional picture of major traffic flows, with commuting to work being the most dominant. Further on, tours and half-tours are broken down by time-of-day periods. At the final stage, half-tours are converted into trips by type of half-tour. Direct half-tours represent a single trip each. Chained half-tours are converted into two successive trips each by the insertion of an intermediate stop. It should be noted that this technique is principally different than simply having independent time-of-day-specific models. In the proposed structure, TOD-specific trip matrices are consistently derived from the same source and are dependent on the same input variables.
- **Detailed mode choice procedures to support TRANS planning needs.** As an additional improvement to the existing TRANS model, which had a simplified binary mode choice (auto vs. transit), the proposed mode choice sub-model explicitly incorporates a variety of transit modes (regular bus, Transitway, rail/LRT) and access options (walk, Park-and-Ride, Kiss-and-Ride) as well as distinguishes between auto driver and auto passenger modes.
- **Current focus on AM and PM peak periods.** The effort required for the development of a more advanced and thorough approach described above requires the implementation and calibration of the mode choice and trip assignment stages to be restricted to the AM and PM peak periods. It should be noted that the explicit modelling of both AM and PM periods represents a step forward from the previous TRANS model, which was developed for the PM period only. In practical terms, modelling these key periods suffices for an effective supporting of most planning decisions. The developed model framework allows for a comparatively straightforward extension of the model system to include other (or even all) periods of a day if required in future. With a full set of time-of-day periods explicitly modelled, a congestion-sensitive peak spreading feedback procedure can be set in place.
- **Taking maximum advantage of the available land-use and socio-economic data** in combination with the O-D Survey micro-sample. The model design, and in particular the population synthesizer, was subject to the availability, texture, and quality of the zonal population and employment data. However, it is flexible and can incorporate almost 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 O-D 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 latest version of EMME software. The TRANS Population Synthesizer (calculation of household distributions for each zone) is the only external procedure and is 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 the future, including extensions to the other time-of-day periods.

3.1.2 Demand Model System Design

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

1. **Tour and trip generation** sub-models and procedures are implemented in parallel with household production and zonal attraction, 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:
    - 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 (motorized vs. non-motorized) binary choice sub-model on the household production side,
    - Pre-mode (motorized vs. non-motorized) binary choice sub-model on the zonal attraction side,
    - Daily motorized tour balancing procedure designed to ensure equal regional motorized tour production and attraction totals (non-motorized travel is left out and is 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,
    - Motorized 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),
    - Multi-class traffic and transit assignment procedures by the same TOD periods,
    - Peak-spreading sub-model (optional extension currently not included).

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 others, such as 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 fashion:

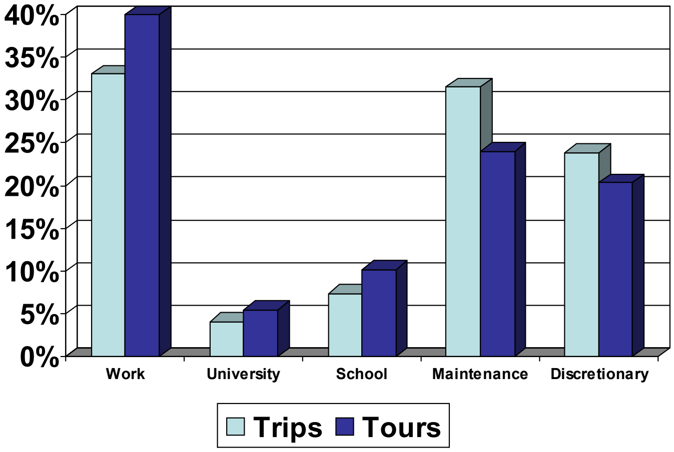
- **5 travel purposes** defined based on the original O-D Survey codes:
    1. **Work**, including original codes 1=usual place of work, 2=other work-related, and 3=work on the road / itinerant / no fixed workplace.
    2. **University**, including original code 4=school for students of age 19 or older as well as those who reported any type of university, college, CEGEP, business school, etc.

3. **School**, including original code 4=school for students of age under 19 who reported either elementary of high school.
4. **Maintenance**, including original codes 5=shopping, 8=restaurant (take-out), 11=medical / dentist visit, 12=drive someone somewhere, 13=pick someone up.
5. **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** before 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) with definitions based on the number of cars owned by the household relative to the number of workers:
    0. Zero cars (zero car sufficiency),
    1. At least one car, cars fewer than workers (low car sufficiency),
    2. At least one car, cars equal to workers (balanced car sufficiency),
    3. At least one car, cars greater than workers (high car sufficiency).

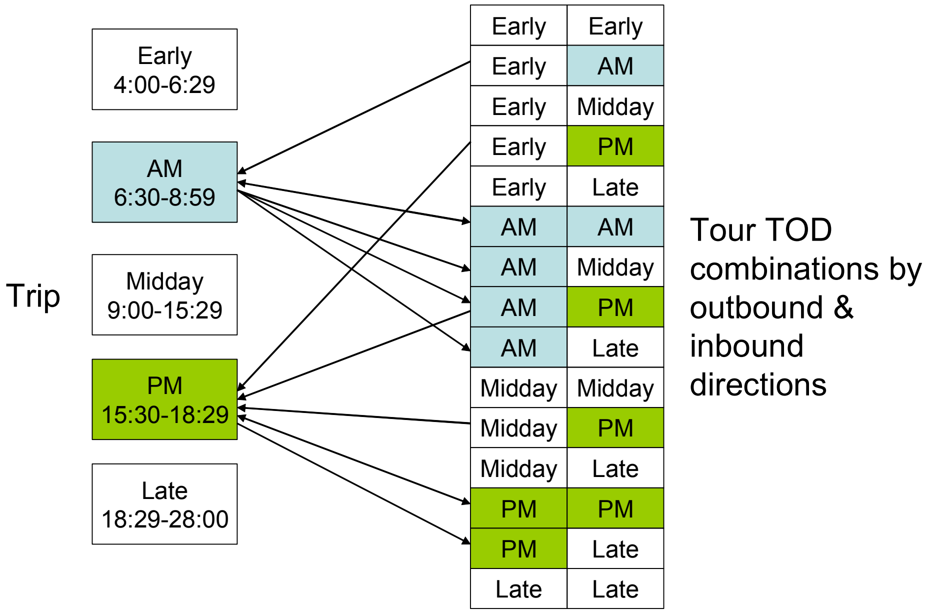
The observed frequency of trips and tours by travel purpose is compared in **Exhibit 3-3**. For tours, the purpose was defined based on the tour primary destination. For trips, the purpose for each was defined by the trip destination and return trips home were not counted. The comparison of tour and trip distribution illustrates an additional advantage of linking trips into tours – a higher and more realistic share of work and university / school related travel. In particular, commute-to-work tours include many non-work stops (for maintenance and discretionary purposes) on the way to and from work. When broken into elemental trips, these stops produce many non-work trips and reduce the number of work trips. However, in reality and in terms of travel behaviour, these trips are part 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, are 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**	**Non-motorized 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	
5 by travel purpose		X	X	X	X	X	
15 by tour TOD					9		
5 by trip TOD					2	2	2
Total	42	840	20	20	180/40	40	2

Car ownership is applied to the 42 different household types (by size, number of workers, and dwelling type) produced by the population synthesizer. After car ownership choice probabilities have been calculated, four additional segments (by car sufficiency) are generated for each household type and used in the tour generation model. The tour generation model uses the resulting 168 (42x4) household segments and is additionally segmented by 5 travel purposes. This creates 840 (168x5) 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 5 purposes, in order to avoid an infeasible number of calculations, especially for the matrix-based models (distribution and mode choice). The TOD choice model adds 5 trip and 15 tour segments, from which 2 trip and 9 relevant tour TOD segments are stored for subsequent calculations. The tour distribution model operates with 180 (20x9) segments, from which 40 trip matrices (by 5 purposes, 4 car sufficiency groups, and 2 TOD periods) are constructed and stored for mode choice. Mode choice is essentially fully segmented by these 40 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, with each period operating with 20 segments.

3.1.4 Observed Stop Frequency by Tour Purpose

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

Table 3-2 Observed stop-frequency, OD Survey, 2005

Tour purpose	Outbound number of stops					Total	Inbound number of stops					Total
	0	1	2	3	4+		0	1	2	3	4+	
Number of tours (unweighted)												
1=Work	22,469	1,803	254	49	25	24,600	20,189	3,282	779	233	117	24,600
2=University	2,575	116	12	3	1	2,707	2,346	288	52	11	10	2,707
3=School	5,284	76	17	1	0	5,378	4,914	346	90	23	5	5,378
4=Maintenance	13,296	1,455	294	96	43	15,184	12,482	1,991	487	155	69	15,184
5=Discretionary	11,688	604	103	12	7	12,414	11,458	781	127	35	13	12,414
Tour distribution												
1=Work	91.3%	7.3%	1.0%	0.2%	0.1%	100.0%	82.1%	13.3%	3.2%	0.9%	0.5%	100.0%
2=University	95.1%	4.3%	0.4%	0.1%	0.0%	100.0%	86.7%	10.6%	1.9%	0.4%	0.4%	100.0%
3=School	98.3%	1.4%	0.3%	0.0%	0.0%	100.0%	91.4%	6.4%	1.7%	0.4%	0.1%	100.0%
4=Maintenance	87.6%	9.6%	1.9%	0.6%	0.3%	100.0%	82.2%	13.1%	3.2%	1.0%	0.5%	100.0%
5=Discretionary	94.2%	4.9%	0.8%	0.1%	0.1%	100.0%	92.3%	6.3%	1.0%	0.3%	0.1%	100.0%

Tour and trip structure is defined after eliminating (linking) insignificant trips that are characterized by a short activity duration (less than 10 minutes in this preliminary analysis), and insignificant route deviation from the shortest path (less than 5%). Additionally, all non-motorized loop-trips (with destination zone equal to the origin) can be eliminated from motorized tours. However, passenger drop-off and pick-up trips were not eliminated because of their importance to mode choice. These infrequent cases are shaded 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 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 and university 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, modelling 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 Household Car-Ownership Model

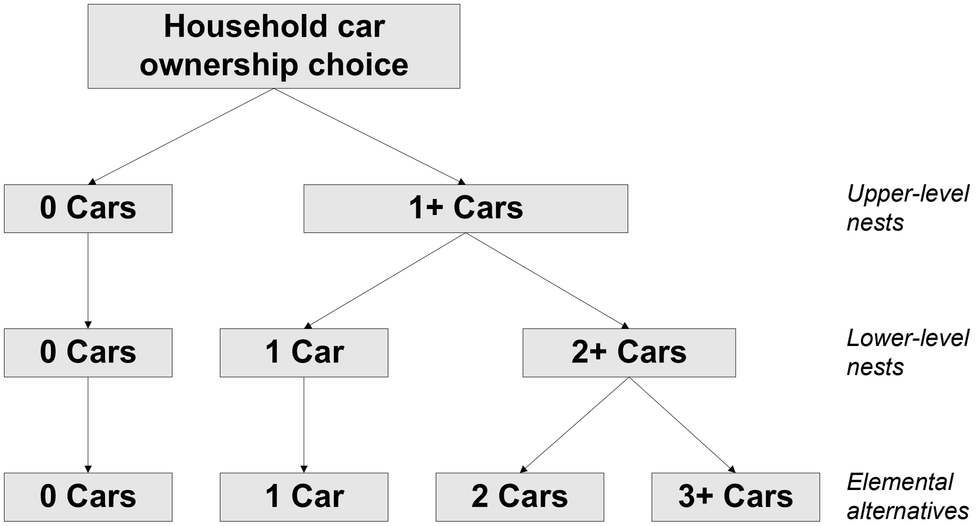
Car ownership model is placed in the model system after the population synthesizer and before the first set of travel models (tour generation). The number of cars available to the household is one of the strongest determinants of travel behaviour. Thus, the output of this model represents and important 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 (10.0%),
- 1 car (43.1%),
- 2 cars (38.3%),
- 3+ cars (8.6%) that includes:
    - 3 cars (6.7%),
    - 4 cars (1.5%),
    - 5 cars (0.3%),
    - 6+ cars (0.2%).

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 3-5**.

Exhibit 3.5 Nested Structure of Car-Ownership Choice



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

$$V_h^c = \alpha_{w(h)}^c + \sum_k \beta_k^c x_{hk} + \sum_m \gamma_m^c z_{i(h)m} ,$$ Equation 1

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),
- Zonal characteristics at three spatial level of aggregation (TAZ, superzone, district):
    - Population density,
    - Percentage of low-income households,
    - Percentage of detached houses.

As the result of model application each household segment (defined by a combination of household size, number of workers, 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 3-3** below.

Table 3-3 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, and 4 car-sufficiency categories) was constructed resulting in 42×4=168 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.

3.3 Tour Generation Sub-Models and Procedures

3.3.1 Household Daily Tour Production Model

Household-based daily tour production models were developed for the 5 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:

$$R^{uc}_{s(h),w(h),d(h),i(h)} = r^{uc}_{0} + \sum_{k} \beta^{u}_{k} x_{hk} + \sum_{m} \gamma^{u}_{m} z_{i(h)m} \,, \qquad \text{Equation 2}$$

where:

u = tour purpose from 1 through 5,
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),
R^{uc}_{swd} = daily household tour production rate,
r^{uc}_{0} = rate component (bias) specified by car-sufficiency for each purpose,
k = household variables,
x_{hk} = values of the household variables,
β^{u}_{k} = 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),
- Zonal characteristics at three spatial level of aggregation (TAZ, superzone, district):
    - Population density,
    - Percentage of detached houses,
    - Percentage of low income households (separate coefficients for Ontario and Quebec),
    - University enrolment (applied for university tours only).

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

$$P_i^{uc} = \sum_{swd} R_{swdi}^{uc} \times H_{swdi}^{c} , \quad \text{Equation 3}$$

where:
u = tour purpose from 1 through 5,
c = car-sufficiency categories from 0 through 3,
P_i^{uc} = zonal tour production,
R_{swd}^{uc} = daily household tour production rate,
H_{swdi}^{c} = number of households in the zone by segments.

3.3.2 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:

$$A_j^u = \sum_m a_m^u z_{jm} , \quad \text{Equation 4}$$

where:
u = tour purpose from 1 through 5,
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,
    - Retail employment (separate coefficients for Ontario and Quebec),
    - Service employment,
    - Office employment (public and private),
    - Education employment,
    - Health employment,
- Other characteristics of the traffic zone itself:
    - Shopping Gross Leasable Area (for Ontario only),
    - Total population,
    - Number of households living in detached houses,
    - Number of households living in apartments,
    - University enrollment (for university purpose),
    - School enrolment (for school and maintenance purposes),
- Super-zone or district densities:
    - Employment density,
    - Retail & service density.

3.3.3 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:

Step1: Calculate regional production and attraction totals for each purpose:

$$P^u = \sum_{ci} P_i^{uc} \,, \quad A^u = \sum_j A_j^u \,, \qquad \text{Equation 5}$$

Step2: Calculate control regional total for each purpose:

$$T^u = \sqrt{P^u \times A^u} \qquad \text{for work,} \qquad \text{Equation 6}$$

$$T^u = A^u \qquad \text{for university,} \qquad \text{Equation 7}$$

$$T^u = P^u \qquad \text{for school, maintenance and discretionary,} \qquad \text{Equation 8}$$

Step3: Scale original productions and attractions to match the regional total:

$$P_i^{uc} = \frac{T^u}{\sum_{ci} P_i^{uc}} \,, \quad A_j^u = \frac{T^u}{\sum_j A_j^u} \,, \qquad \text{Equation 9}$$

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 enrollment 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.

3.4 Pre-Mode Choice Model (Motorized vs. Non-Motorized)

3.4.1 Percentage of Non-Motorized Tours

This is a new model feature that estimates the percentage of non-motorized tours (walking and bicycling) produced and attracted in each traffic zone for the entire day, for each of the five travel purposes. The previous TRANS model (similar to many other regional models) operated with motorized trip productions and attractions ignoring non-motorized travel. In the current version of the new TRANS model, non-motorized travel is not modelled at the subsequent stages of time-of-day choice, tour/trip distribution, and mode choice. Thus this sub-model is essentially used to only generate motorized production and attraction vectors. However, having non-motorized travel generated allows for adding of non-motorized distribution and mode sub-models (walk, bicycling) in future that might be useful for testing certain policies. Also, having a full daily travel generation picture (including both motorized and non-motorized travel) is beneficial for analysis.

Table 3-4 below shows the observed percentage of non-motorized travel by tour purposes and trip chaining type.

Table 3-4 Observed % non-motorized trips by travel segments, OD Survey 2005

Tour purpose	Half-tour type	% Non-motorized	
		Records	Trips after expansion
1=Work	Direct	7.1%	8.2%
1=Work	Chained	4.3%	5.2%
2=University	Direct	14.1%	14.6%
2=University	Chained	10.6%	12.1%
3=School	Direct	23.7%	23.4%
3=School	Chained	12.9%	12.5%
4=Maintenance	Direct	8.8%	10.0%
4=Maintenance	Chained	4.8%	5.5%
5=Discretionary	Direct	16.4%	17.3%
5=Discretionary	Chained	9.3%	7.8%
6=Work-based sub-tours	Direct	28.5%	30.1%
6=Work-based sub-tours	Chained	13.9%	13.8%

Logically, chained trips are characterized by a lower non-motorized share. Also logically, and in line with the other regions, the highest non-motorized travel share is associated with school tours and at-work sub-tours. In the proposed model structure the non-motorized share of travel is estimated at the tour level and for entire day since non-motorized level of service does not significantly depend on congestion.

3.4.2 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 mode as the reference alternative with zero utility and non-motorized utility having the following form:

$$V_i^{uc} = \alpha^{uc} + \sum_m \gamma_i^u z_{im} \ , \qquad \text{Equation 10}$$

where:

u = tour purpose from 1 through 5,
c = household car sufficiency category from 0 through 3,
i = traffic zone of the household residence,
α^{uc} = non-motorized 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-households (separate coefficients for Ontario and Quebec),
    - Percentage of detached houses,
    - University enrolment (for university purpose),
    - School enrolment (for school purpose).

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

$$\tilde{P}_i^{uc} = P_i^{uc} \times \frac{1}{1+\exp\left(V_i^{uc}\right)} , \qquad \text{Equation 11}$$

where:

u = tour purpose from 1 through 5,
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.

3.4.3 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 mode as the reference alternative with zero utility and non-motorized utility having the following form:

$$V_j^u = \alpha^u + \sum_m \gamma_j^u z_{jm} \text{ ,} \qquad \text{Equation 12}$$

where:

u = tour purpose from 1 through 5,
j = traffic zone of the tour primary destination,
α^u = non-motorized 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):
    - CBD dummy,
    - Population density,
    - Retail & service employment density,
    - Logged product of population and employment density (proxy for mixed land use),
    - Percentage of detached houses,
    - University enrolment (for university purpose),
    - School enrolment (for school purpose).

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

$$\tilde{A}_j^u = A_j^u \times \frac{1}{1+\exp\left(V_j^u\right)} \text{,} \qquad \text{Equation 13}$$

where:

u = tour purpose from 1 through 5,
j = traffic zone of the tour primary destination,
A_j^u = zonal tour attraction,
V_j^u = non-motorized utility.

3.4.4 Balancing of Motorized Tour Productions and Attractions

After the zonal motorized 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 3.3.3** above.

3.5 Time-of-Day and Stop-Frequency Choice

3.5.1 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:

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

Equation 14

where:

u = tour purpose from 1 through 5,
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:

$$TO_i^{ucg} = \lambda^{ucg} + \sum_m \mu_m^{ug} z_{im} \,; \qquad TI_i^{uc\tau} = \delta^{uch} + \sum_m \nu_m^{uh} z_{im} \,, \qquad \text{Equation 15}$$

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:

$$SO_i^{ucr} = \lambda^{ucr} + \sum_m \mu_m^{ur} z_{im} \,; \qquad SI_i^{ucs} = \delta^{ucs} + \sum_m \nu_m^{us} z_{im} \,, \qquad \text{Equation 16}$$

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:

$$D_i^{ugh} = \Delta^{ugh} + \sum_m \rho_m^{ugh} z_{im} \,, \qquad \text{Equation 17}$$

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 households (separate coefficients for Ontario and Quebec),
    - Percentage of detached houses,
    - School enrollment,
    - Retail & service density,
- 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 households (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).

Travel impedance increment measure (difference in weighted auto and transit travel times between the target year and base year runs) will allow for a peak spreading feedback applied at the matrix level in future versions of the model. In the current model version, without a peak spreading feedback, the TOD distribution factors are not dependent on travel conditions.

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

$$P_i^{ucghrs} = \tilde{P}_i^{uc} \times \frac{\exp\left(V_i^{ucghrs}\right)}{\sum_{ghrs} \exp\left(V_i^{ucghrs}\right)}. \qquad \text{Equation 18}$$

After that, detailed joint probabilities by 4 car-sufficiency groups and 4 stop-frequency categories are calculated for each of 5 travel purposes and 9 relevant TOD slices. This results in 16×45=720 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:

$$p_i^{ugh}\left(crs\right)=\frac{P_i^{ucghrs}}{\sum\limits_{crs}P_i^{ucghrs}}. \qquad \text{Equation 19}$$

3.5.2 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:

$$V_j^{ugh}=TO_j^{ug}+TI_j^{uh}+D_j^{ugh}, \qquad \text{Equation 20}$$

where:

u = tour purpose from 1 through 5,
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:

$$TO_j^{ug} = \lambda^{ug} + \sum_m \mu_m^{ug} z_{jm} \; ; \qquad TI_j^{uc\tau} = \delta^{uh} + \sum_m \nu_m^{uh} z_{jm} \; , \qquad \text{Equation 21}$$

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:

$$D_j^{ugh} = \Delta^{ugh} + \sum_m \rho_m^{ugh} z_{jm} \; , \qquad \text{Equation 22}$$

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 households (separate coefficients for Ontario and Quebec),
        - University enrollment,
        - School enrollment,
- 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:

$$A_j^{ugh} = \widetilde{A}_j^u \times \frac{\exp\left(V_j^{ugh}\right)}{\sum_{gh} \exp\left(V_j^{ugh}\right)}.$$ Equation 23

3.5.3 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:

Step1: Calculate regional production and attraction totals for each purpose and TOD slice:

$$P^{ugh} = \sum_{crsi} P_i^{ucghrs}, \qquad A^{ugh} = \sum_j A_j^{ugh},$$ Equation 24

Step2: Calculate control regional total for each purpose:

$$T^{ugh} = \sqrt{P^{ugh} \times A^{ugh}}$$ for work, Equation 25

$$T^{ugh} = A^{ugh}$$ for university, Equation 26

$$T^{ugh} = P^{ugh}$$ for school, maintenance and discretionary, Equation 27

Step3: Scale original productions and attractions to match the regional total:

$$P_i^{ucghrs} = \frac{T^{ugh}}{\sum_{crsi} P_i^{ucghrs}}, \qquad A_j^{ugh} = \frac{T^{ugh}}{\sum_j A_j^{ugh}},$$ Equation 28

3.5.4 Zonal Stop-Frequency Size Variable for Stop Location

The tour primary destination attraction model described in Sections 3.3.2 (daily) and 3.5.2 (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 5 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:

$$S_k^{ud} = \sum_m s_m^{ud} \times z_{km} \,, \qquad \text{Equation 29}$$

where:

u = tour purpose from 1 through 5,

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:
    - Public office employment,
    - Retail employment (separate coefficients for Ontario and Quebec),
    - Service employment,
    - Health employment,
    - Education employment,
- Other characteristics of the traffic zone itself:
    - Shopping Gross Leasable Area (for Ontario only),
    - Number of households living in detached houses,
    - Number of households living in apartments,
    - University enrollment,
    - School enrollment,
    - Retail& service density,
- Super-zone or district densities and other characteristics:
    - Employment density,
    - Retail & service density,
    - Percentage of low-income households,
    - University enrollment,
    - Population density.

3.6 Tour Ends' Distribution

3.6.1 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 5 travel purposes and 9 TOD period combinations relevant for either AM or PM periods the procedure builds 5*9=45 seed matrices. The procedure includes the following three steps:

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

Aggregation 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:

$$R_{ij}^{u} = \sum_{n \in N_{ij}^{u}} W_n , \qquad \text{Equation 30}$$

where:

u = tour purpose from 1 through 5,

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 60,900 tour records. This is not enough to cover 5 purpose-specific matrices with 556 TAZs (i.e 5×556×556=1,545,680 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 5,

$i, j \in I$ = 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,

Step1: 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 31

Step2: 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 32

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 33

<u>Scaling</u> 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 34

where:

u = tour purpose from 1 through 5,

$i, j \in I$ = 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.

3.6.2 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 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, etc). This method can handle newly built zones and is not dependent on the observed distribution pattern. However, it is generally is 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 45 segments generated by 5 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 35

subject to marginal constraints:

$$\sum_{j} X_{ij} = P_i$$, (i.e. match the tour productions) Equation 36

$$\sum_{i} X_{ij} = A_j$$, (i.e. match the tour attractions) Equation 37

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 38

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:

$$\min \sum_{ij} Y_{ij} \ln \frac{Y_{ij}}{\exp(-\lambda c_{ij})},$$ (i.e. find the closest possible matrix to the impedance) Equation 39

subject to the same marginal constraints as (36-37),

$$\sum_j Y_{ij} = P_i,$$ (i.e. match the tour productions) Equation 40

$$\sum_i Y_{ij} = A_j,$$ (i.e. match the tour attractions) Equation 41

where:

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

The gravity model has the following solution:

$$Y_{ij} = P_i \alpha_i A_j \beta_j \exp(-\lambda c_{ij}).$$ Equation 42

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

$$\mu_i = \min\left(\frac{\sum_j S_{ij}}{P_i}, 1\right), \quad \nu_j = \min\left(\frac{\sum_i S_{ij}}{A_j}, 1\right),$$ Equation 43

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 44

where:

$$B^1 = \sum_{ij} X_{ij}^1 \ln \frac{X_{ij}^1}{S_{ij}} ,$$

(distribution of observed productions modelled by balancing) Equation 45

$$B^2 = \sum_{ij} X_{ij}^2 \ln \frac{X_{ij}^2}{S_{ij}} ,$$

(distribution of observed attractions modelled by balancing) Equation 46

$$G^1 = \sum_{ij} Y_{ij}^1 \ln \frac{Y_{ij}^1}{\exp\left(-\lambda c_{ij}\right)} ,$$

(distribution of new productions modelled by gravity) Equation 47

$$G^2 = \sum_{ij} Y_{ij}^2 \ln \frac{Y_{ij}^2}{\exp\left(-\lambda c_{ij}\right)} ,$$

(distribution of new attractions modelled by gravity) Equation 48

subject to the same marginal constraints as (35-36) and (39-40):

$\sum_j Z_{ij} = P_i$, (i.e. match the tour productions) Equation 49

$\sum_i Z_{ij} = A_j$, (i.e. match the tour attractions) Equation 50

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,

$Y_{ij}^1 = \left(1 - \mu_i\right) Z_{ij}$ = share of new productions modelled by gravity,

$Y_{ij}^2 = \left(1 - \nu_j\right) Z_{ij}$ = share of new attractions modelled by gravity.

The hybrid model has the following solution:

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

Equation 51

where:

$$W_{ij} = w_i + w_j ,$$

Equation 52

$$w_i = \begin{cases} \mu_i \ln \mu_i + (1-\mu_i)\ln(1-\mu_i) & if \quad 0 < \mu_i < 1 \\ 0 & if \quad \mu_i = 0,1 \end{cases},$$ Equation 53

$$w_j = \begin{cases} \nu_j \ln \nu_j + (1-\nu_j)\ln(1-\nu_j) & if \quad 0 < \nu_j < 1 \\ 0 & if \quad \nu_j = 0,1 \end{cases}.$$ Equation 54

The balancing and gravity models can be derived as particular cases of the hybrid model. The general solution (51) is reduced to the balancing formula (38) if all growth indices are equal to 1 (i.e. there is no growth). The general solution (51) is reduced to the gravity formula (42) 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.

Currently, free-flow auto time has been used as the impedance measure with the dispersion coefficient calibrated 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):

- Bi-directional mode choice logsums for the corresponding network time and cost "skims" for each TOD periods combining both outbound and inbound LOS variables,
- Linear and non-linear distance terms allowing for shaping the trip-length distribution,
- Borders of province / municipalities / school districts,
- Income incompatibility between the origin and destination population,
- 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 mode choice logsums also would 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 45 segments:

$$\left\{Z_{ij}^{ugh}\right\},$$ Equation 55

where:

$i, j \in I$ = origin and destination TAZs,
u = tour purpose from 1 through 5,
g, h = 9 relevant outbound and inbound TOD period combinations.

3.7 Trip Distribution

3.7.1 Construction of Half-Tour Matrices in OD Format

This model splits 45 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 3.5.1 above (formula (19)). 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:

$$D_{ij}^{ucg,d=1} = \sum_{h=g}^{5} Z_{ij}^{ugh} \sum_{s=0}^{1} p_i^{ugh}\left(c, r=0, s\right), \text{(outbound direct half-tours),} \qquad \text{Equation 56}$$

where:

$i, j \in I$ = origin and destination TAZs,
u = tour purpose from 1 through 5,
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),

$$C_{ij}^{ucg,d=1} = \sum_{h=g}^{5} Z_{ij}^{ugh} \sum_{s=0}^{1} p_i^{ugh}\left(c, r=1, s\right), \text{(outbound chained half-tours),} \qquad \text{Equation 57}$$

where:

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

$$D_{ij}^{uch,d=2} = \sum_{g=1}^{h} Z_{ji}^{ugh} \sum_{r=0}^{1} p_i^{ugh}\left(c, r, s=0\right), \text{(inbound direct half-tours),} \qquad \text{Equation 58}$$

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),

$$C_{ij}^{uch,d=2} = \sum_{g=1}^{h} Z_{ji}^{ugh} \sum_{r=0}^{1} p_i^{ugh}\left(c, r, s=1\right), \text{(inbound chained half-tours),} \qquad \text{Equation 59}$$

where:

$s = 1$ = inbound stop frequency (1=stop), The procedure results in 160 directional (OD format) half tour matrices built for 20 segments (5 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.

3.7.2 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 3.7.1) consequently:

$$TD_{ij}^{uch} = \sum_{d=1}^{2} D_{ij}^{uchd} , \qquad \text{Equation 60}$$

where:

$i, j \in I$ = half-tour origin and destination TAZs,
u = tour purpose from 1 through 5,
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.

3.7.3 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 3.7.1 above):

$$C_{ij}^{uchd} \qquad \text{Equation 61}$$

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:

$$\sum_{j} C_{ij}^{uchd} = \sum_{k} TC_{ik}^{uchd}(1), \text{ (flows from the origin are preserved),} \qquad \text{Equation 62}$$

$$\sum_{i} C_{ij}^{uchd} = \sum_{k} TC_{kj}^{uchd}(2), \text{ (flows to the destination are preserved),} \qquad \text{Equation 63}$$

$$\sum_{i} TC_{ik}^{uchd}(1) = \sum_{j} TC_{kj}^{uchd}(2), \text{ (flows through the intermediate stops are convoluted),} \qquad \text{Equation 64}$$

where:

$i, j, k \in I$ = half-tour origin, destination, and stop TAZs,

u = tour purpose from 1 through 5,
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:

$$p_{ikj}^{uchd} = \frac{\exp\left(V_{ikj}^{uchd}\right)}{\sum_{k} \exp\left(V_{ikj}^{uchd}\right)} = \frac{\exp\left(V_{ikj}^{uchd}\right)}{DEN_{ij}^{uchd}}, \qquad \text{Equation 65}$$

where the stop-location utility function is defined as

$$V_{ikj}^{uchd} = \begin{cases} \ln S_{k}^{ud} - \left(\lambda_{1}^{ud} d_{ik} + \lambda_{2}^{ud} d_{kj}\right), & if \quad \max\left(d_{ik}, d_{kj}\right) \leq \bar{d}^{u} \\ -999, & if \quad \max\left(d_{ik}, d_{kj}\right) > \bar{d}^{u} \end{cases}, \qquad \text{Equation 66}$$

where:

S_{k}^{ud} = zone attraction for intermediate stops explained in subsection 3.5.4 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 5 travel purposes and 2 directions that yields 10 segments). In future versions of the TRANS model, free-flow time can be substituted with a more elaborate measure like mode choice logsum which would make it TOD period-specific. 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:

$$\exp\left(V_{ikj}^{uchd}\right) = U_{ik}^{uchd} \times U_{kj}^{uchd}, \qquad \text{Equation 67}$$

where:

$$U_{ik}^{uchd} = \begin{cases} S_k^{ud} \times \exp\left(-\lambda_1^{ud} d_{ik}\right), & if \quad d_{ik} \le \bar{d}^u \\ 0, & if \quad d_{ik} > \bar{d}^u \end{cases},$$ Equation 68

$$U_{kj}^{uchd} = \begin{cases} \exp\left(-\lambda_2^{ud} d_{kj}\right), & if \quad d_{kj} \le \bar{d}^u \\ 0, & if \quad d_{kj} > \bar{d}^u \end{cases}.$$ Equation 69

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 70

$$TC_{kj}^{uchd}(2) = \sum_i C_{ij}^{uchd} \times p_{ikj}^{uchd} = U_{kj}^{uchd} \times \sum_i \frac{C_{ij}^{uchd}}{DEN_{ij}^{uchd}} \times U_{ik}^{uchd}.$$ Equation 71

Since this model component is not a trivial matrix or vector calculation a more detailed technical description is provided is 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 72

where:

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

3.7.4 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 3.7.2 above) and chain half-tours (explained in subsection 3.7.3 above) in the following straightforward way:

$$T_{ij}^{uch} = TD_{ij}^{uch} + TC_{ij}^{uch},$$ Equation 73

where:

$i, j \in I$ = trip origin and destination TAZs,
u = tour purpose from 1 through 5,
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 5 travel purposes, 4 car-sufficiency groups, and 2 TOD periods (AM and PM) resulting in 40 full trip matrices that constitute demand input to the mode choice model.

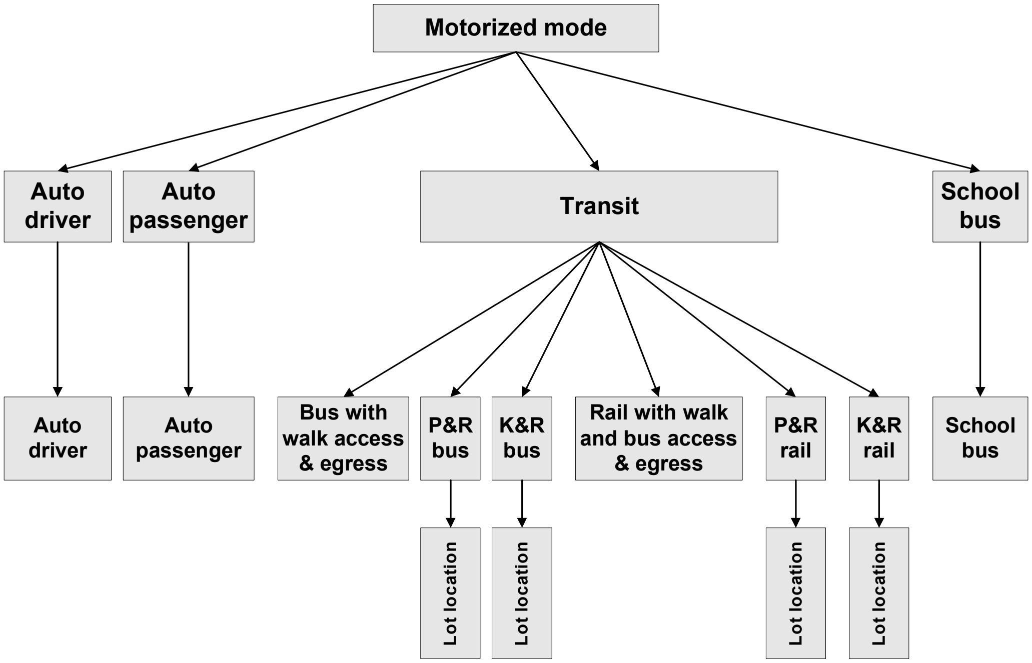
3.8 Mode Choice Model

3.8.1 Mode Choice Structure

The mode choice model is estimated and applied at the trip level. It included motorized modes only. The model operates with 9 modes grouped into 4 nests. The choice model has the following nested logit form shown in **Exhibit 3.6** below. The model is fully segmented by 5 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 driver nest including:
    - (*m*=1) Auto driver (Driv),
- (*n*=2) Auto passenger nest including:
    - (m=2) Auto passenger (Pass),
- (*n*=3) Transit nest including:
    - (*m*=3) Bus with walk access (WB),
    - (*m*=4) Park and Ride bus (PRB),
    - (*m*=5) Kiss and Ride bus (KRB),
    - (*m*=6) Rail with walk and/or bus access/egress (WR),
    - (*m*=7) Park and Ride rail (PRR) that can also include bus access/egress,
    - (*m*=8) Kiss and Ride rail (KRR) that can also include bus access/egress,
- (*n*=4) School bus nest including:
    - (*m*=9) School bus (SB) available for school trips only.

Exhibit 3.6 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-model combinations like P&R and K&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. It was done differently for AM period versus PM period. 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 can be introduced (for AM period). Modelling of constrained parking can be 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 (and trip distribution in a full model run). The iterative algorithm that integrates the mode choice and assignment models a well as specific technical issues associated with bi-modal trips are discussed in (the subsequent) **Subsection 3.8.2** below.

The observed frequency of trip modes by tour purpose is shown in **Table 3-5** below. The shadowed entries correspond to infrequent (non-modelled) modes. In general, there is a problem with estimation of the rail modes since there are only a few rail trips in the OD Survey across all purposes. For this reason bus and rail sub-nests were not distinguished within the transit nest. Also, in the current structure of the OD Survey trip file, there is no differentiation between mixed-traffic bus and transit way. This distinction was added to the survey mode codes via EMME skims in order to support the estimation and calibration of the proposed mode choice structure that distinguishes bus in mixed traffic from the guide-way transit.

Table 3-5 Observed frequency of trip modes by tour purpose

Trip mode	**1=Work**		**2=University**		**3=School**		**4=Maintenance**		**5=Discretionary**		**6=Work-Based**		**Total**	
	Records	**Trips**	**Records**	**Trips**	**Records**	**Trips**	**Records**	**Trips**	**Records**	**Trips**	**Records**	**Trips**	**Records**	**Trips**
Car driver	40,159	745,047	2,063	40,837	441	9,820	27,640	501,989	15,393	284,548	1,858	35,003	87,554	1,617,244
Car passenger	4,813	91,171	558	11,508	2,262	53,685	5,009	93,207	5,857	118,342	220	4,358	18,719	372,270
Walk to bus	8,108	166,550	2,255	51,268	2,566	61,601	1,388	30,677	960	21,482	107	2,294	15,384	333,872
P&R bus	619	11,071	72	1,410	14	328	14	235	11	168	1	16	731	13,228
K&R bus	216	4,002	62	1,296	66	1,656	7	125	20	452	2	29	373	7,560
Walk to rail/bus	76	1,559	159	3,814	34	905			14	311	2	40	285	6,629
P&R rail	12	220	6	145	2	42			2	26	0	0	22	433
K&R rail	10	157	4	90	5	135					0	0	19	382
Non-motorized	3,828	84,599	843	20,359	2,650	61,648	3,022	63,727	4,216	86,692	882	18,116	15,441	335,141
School bus	157	3,326	35	788	3,380	78,434	1	16	7	160	9	163	3,589	82,886
Other/unknown	443	8,932	66	1,385	90	2,285	211	4,211	316	6,942	129	2,603	1,255	26,358
Total	58,441	1,116,632	6,123	132,902	11,510	270,538	37,292	694,187	26,796	519,122	3,210	62,622	143,372	2,796,003
Car driver	68.7%	66.7%	33.7%	30.7%	3.8%	3.6%	74.1%	72.3%	57.4%	54.8%	57.9%	55.9%	61.1%	57.8%
Car passenger	8.2%	8.2%	9.1%	8.7%	19.7%	19.8%	13.4%	13.4%	21.9%	22.8%	6.9%	7.0%	13.1%	13.3%
Walk to bus	13.9%	14.9%	36.8%	38.6%	22.3%	22.8%	3.7%	4.4%	3.6%	4.1%	3.3%	3.7%	10.7%	11.9%
P&R bus	1.1%	1.0%	1.2%	1.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.5%
K&R bus	0.4%	0.4%	1.0%	1.0%	0.6%	0.6%	0.0%	0.0%	0.1%	0.1%	0.1%	0.0%	0.3%	0.3%
Walk to rail/bus	0.1%	0.1%	2.6%	2.9%	0.3%	0.3%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.2%	0.2%
P&R rail	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
K&R rail	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Non-motorized	6.6%	7.6%	13.8%	15.3%	23.0%	22.8%	8.1%	9.2%	15.7%	16.7%	27.5%	28.9%	10.8%	12.0%
School bus	0.3%	0.3%	0.6%	0.6%	29.4%	29.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.3%	2.5%	3.0%
Other/unknown	0.8%	0.8%	1.1%	1.0%	0.8%	0.8%	0.6%	0.6%	1.2%	1.3%	4.0%	4.2%	0.9%	0.9%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

In the current version of OD Survey, auto modes were defined as “car driver” and “car passenger” rather than SOV and HOV. While “car passenger” always relates to HOV, car driver is split between SOV and HOV. It will be possible to link the “car driver” and “car passenger” trips within the household to partially restore the underlying SOV or HOV categorization for each trip record (also using pick up and drop off trip purpose as an additional indicator). This however, will not account for HOV associated with non-household passengers.

However, using SOV and HOV mode definitions is only essential if multi-class auto assignment and skimming procedures are going to be applied because of specific HOV/HOT facilities or road pricing schemes. Currently and taking into account that the Updated TRANS model will only be applied to a homogeneous auto network with no specifications relating to SOV / HOV categories, it is more convenient to have a “car driver” mode that would suffice to directly produce a single auto matrix for assignment.

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

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

Equation 74

where:

$i, j \in I$ = trip origin and destination TAZs,
u = tour purpose from 1 through 5,
c = household car sufficiency category from 0 through 3,
h = relevant trip TOD period (AM or PM),
m = modes from 1 through 9,
n = nests from 1 through 4,
$n(m)$ = 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:

$$p_{ij}^{uch}(m) = \frac{\exp\left(V_{ijm}^{uch}\right)}{\sum\limits_{m \in M_{n(m)}} \exp\left(V_{ijm}^{uch}\right)},$$

Equation 75

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:

$$p_{ij}^{uch}(n) = \frac{\exp\left(\mu \widetilde{V}_{ijn}^{uch}\right)}{\sum\limits_{n} \exp\left(\mu \widetilde{V}_{ijn}^{uch}\right)},$$

Equation 76

where:

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

The mode utilities are specified in the following parsimonious way:

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

Equation 77

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:

$$UO_{im}^{uh} = \alpha_{m}^{uh} + \sum_{q} \beta_{mq}^{uh} z_{iq} \,, \qquad \text{Equation 78}$$

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:

$$UD_{jm}^{uh} = \sum_{q} \gamma_{mq}^{uh} z_{jq} \,, \qquad \text{Equation 79}$$

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:

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

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 (20 for each TOD period), modes (9), and variables (more than 20 zonal variables, and more than 30 different skims). A full segmentation would have resulted in 20×9=180 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,
- Auto mode LOS skims for Driver, Passenger, and School Bus:
    - Free-flow time,
    - Congestion delay,
    - Operating cost proportional to distance (10 cents per km); halved for Auto Passenger,
- Transit mode skims for Walk to Bus and Walk to Rail:
    - In-vehicle time,
    - Wait time,
    - Walk time,
    - Number of boardings (to capture perceived transfer penalty),
    - Proportion of Transitway in the in-vehicle distance for bus,
    - Proportion of rail in the in-vehicle time for rail,
    - Fare
- Combined LOS skims for P&R / K&R bus and rail:
    - Auto access (in-vehicle) time,
    - Auto operating cost proportional to distance (10 cents per km); halved for K&R,
    - In-vehicle transit time,
    - Wait time,
    - Walk time,
    - Number of boardings (to capture perceived transfer penalty),
    - Proportion of Transitway in the in-vehicle distance for bus,
    - Proportion of rail in the in-vehicle time for rail,
    - Transit fare,
    - Route logic (ratio of the total in-vehicle time to the transit in-vehicle time),
- 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,
    - 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 halved for Auto Passenger; 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 Transitway and rail in-vehicle distance from bus in mixed traffic (on the transit side) 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 3-6** below.

Table 3-6 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=Auto driver	X					
2=Auto passenger						
3=Walk to bus			X (60 min)	X (2)		Bus
4=P&R bus	X		X (30 min)	X (1)	X (1/4)	Bus/Auto
5=K&R bus			X (30 min)	X (1)	X (1/4)	Bus/Auto
6=Walk to rail			X (60 min)	X (3)		Rail
7=P&R rail	X		X (60 min)	X (2)		Rail/Auto
8=K&R rail			X (60 min)	X (2)		Rail/Auto
9=School bus		X				

3.8.2 Integration of Mode Choice and Assignment Procedures

In the model application, mode choice is fully integrated with the auto 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 and K&R) cannon be immediately assigned as such. These trips have to be broken into mode legs including an auto leg and transit leg that are assigned onto the auto and transit networks respectively. This requires a choice model for identification of the mode interchange (parking lot for P&R and dropping-off / picking-up point for K&R) at the TAZ level. The mode interchange TAZ is subsequently used to construct auto 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 bee developed and implemented – see **Exhibit 3.7** 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 5 travel purposes and 4 car-sufficiency groups (that yields 20 full matrix segments split into 9 modes each). At the assignment stage, all purposes and car-sufficiency groups are combined together.

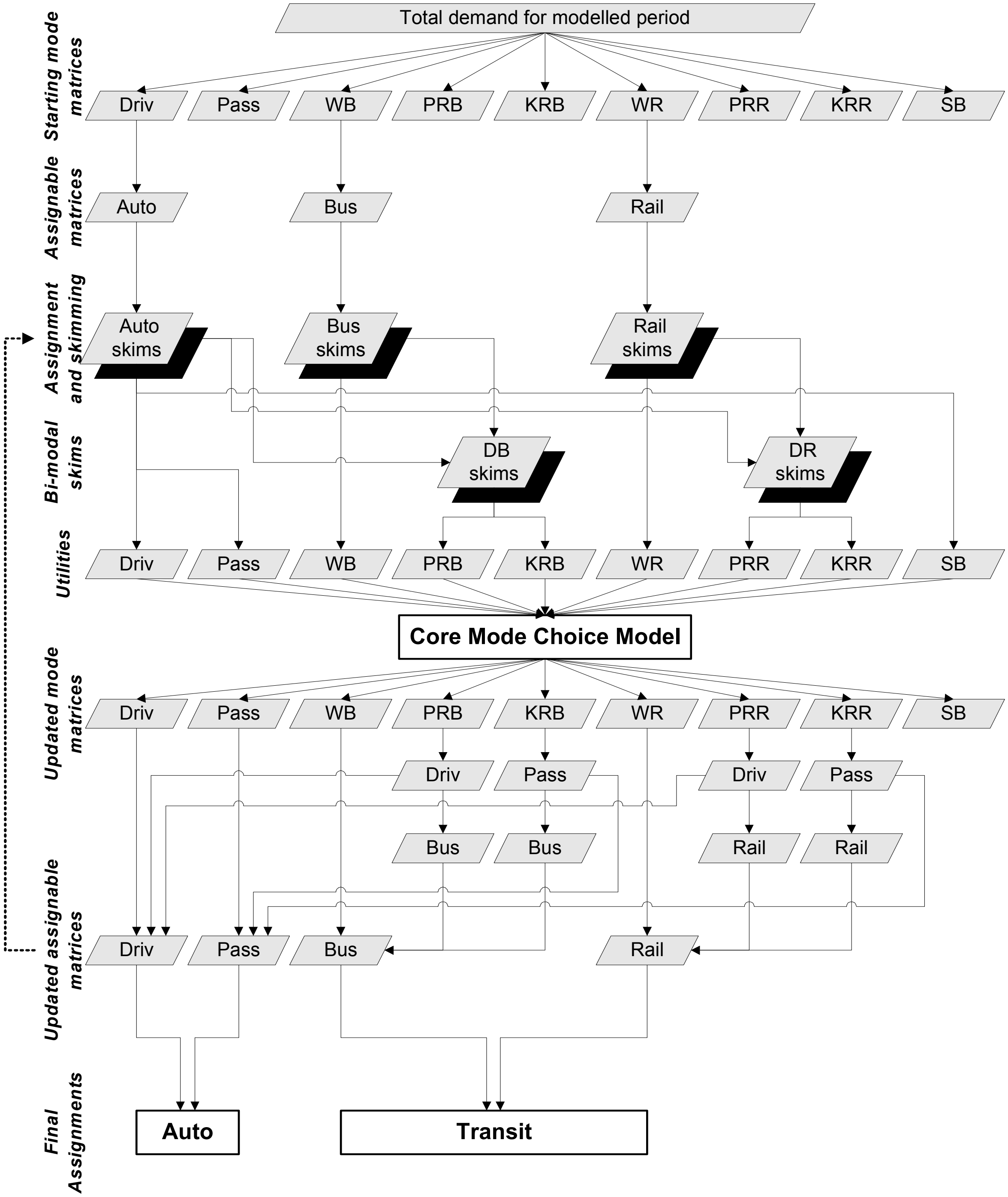
The integrated procedure is organized by the following major steps:

1. Preliminary mode choice (starting demand matrices by mode and assignable matrices),
2. Basic assignment and skimming for auto and transit modes,
3. Combination of skims for P&R and K&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 3.7 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:

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

Equation 80

where:

$i, j \in I$ = trip origin and destination TAZs,
h = relevant trip TOD period (AM or PM),
m = modes from 1 through 9,
$n = 0$ = 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 3.7.4** 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:

$D_{ij}^{h,n=0} = T_{ij}^{h,n=0}(m=1)$, (auto assignment with the auto driver matrix m=1), Equation 81

$B_{ij}^{h,n=0} = T_{ij}^{h,n=0}(m=3)$, (bus assignment with the walk-to-bus matrix m=3), Equation 82

$R_{ij}^{h,n=0} = T_{ij}^{h,n=0}(m=6)$, (rail assignment with the walk-to-rail matrix m=6), Equation 83

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

At the result of basic auto assignment the following auto skims are created (these LOS skims are shared between auto driver and passenger modes since there are no specific HOV facilities in the region):

$C_{ijk}^{h}(m=1,2)$, Equation 84

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).

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

$C_{ijk}^{h}(m=3)$, Equation 85

where:

$k = 1$ = total transit time (in-vehicle, walk, and wait),
$k = 2$ = in-vehicle time,

$k=3$ = walk time,
$k=4$ = total waiting time,
$k=5$ = number of boardings,
$k=6$ = total in-vehicle distance,
$k=7$ = in-vehicle distance on the Transit Way,
$k=8$ = proportion of the Transit Way in the total in-vehicle distance (measure of reliability),
$k=9$ = average bus fare (pre-calculated matrix),

At the result of basic rail assignment (onto the network including rail and bus lines) the following walk-to-rail skims are created:

$$C_{ijk}^{h}(m=6), \qquad \text{Equation 86}$$

where:

$k=1$ = total transit time (in-vehicle, walk, and wait),
$k=2$ = total in-vehicle time (rail and bus),
$k=3$ = walk time,
$k=4$ = total waiting time,
$k=5$ = total number of boardings,
$k=6$ = rail in-vehicle time,
$k=7$ = rail number of boardings,
$k=8$ = proportion of rail in the total in-vehicle time (measure of reliability),
$k=9$ = average rail fare (pre-calculated matrix),

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

LOS skims for the bi-modal combinations like P&R / K&R for either bus or rail are constructed by convoluting the corresponding auto 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. The possible lots are predefined as subsets of TAZs for bus and rail 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. P&R and K&R interchange as well as the resulting LOS skims are currently assumed identical within each transit mode (bus or rail) for the same reason why the skims for auto driver and passenger are not separated (no specific HOV facilities in the region). They are different across transit modes. 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 is followed by the transit leg. In the PM period, the order is reversed. In the current version of the TRANS model, there is now explicit control for parking lot capacity constraint. This can be introduced by means of shadow pricing in future versions. 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 bus in the AM period (*h*=2), choice of interchange can be formalized in the following way:

$$l_{ij}^{h=2}(m=4,5)=\left\{\, l\in L(m=4,5) \,\middle|\, \min\left[C_{il,k=3}^{h=2}(m=1,2)+C_{lj,k=1}^{h=2}(m=3)\right] \right\}, \qquad \text{Equation 87}$$

where:

$l \in L(m = 4{,}5)$ = possible P&R/K&R lots for bus in the region,

$C^{h=2}_{il,k=3}(m = 1{,}2)$ = congested auto time from trip origin to parking lot in AM period,

$C^{h=2}_{il,k=1}(m = 3)$ = total transit time by bus from parking lot to trip destination in AM period,

$l^{h=2}_{ij}(m = 4{,}5)$ = the best interchange for P&R/K&R bus for the given OD-pair in AM period.

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

$$l^{h=2}_{ij}(m = 7{,}8) = \left\{ l \in L(m = 7{,}8) \middle| \min\left[C^{h=2}_{il,k=3}(m = 1{,}2) + C^{h=2}_{lj,k=1}(m = 6)\right] \right\}, \quad \text{Equation 88}$$

where:

$l \in L(m = 7{,}8)$ = possible P&R/K&R lots for rail in the region,

$C^{h=2}_{il,k=1}(m = 6)$ = total transit time by rail from parking lot to trip destination in AM period,

$l^{h=2}_{ij}(m = 7{,}8)$ = the best interchange for P&R/K&R rail 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):

$$l^{h=4}_{ij}(m = 4{,}5) = \left\{ l \in L(m = 4{,}5) \middle| \min\left[C^{h=4}_{il,k=1}(m = 3) + C^{h=4}_{lj,k=3}(m = 1{,}2)\right] \right\}, \quad \text{Equation 89}$$

where:

$C^{h=2}_{il,k=1}(m = 3)$ = total transit time by bus from trip origin to parking lot in PM period,

$C^{h=4}_{lj,k=3}(m = 1{,}2)$ = congested auto time from parking lot to trip destination in PM period,

$l^{h=4}_{ij}(m = 4{,}5)$ = the best interchange for P&R/K&R bus for the given OD pair in PM period.

$$l^{h=4}_{ij}(m = 7{,}8) = \left\{ l \in L(m = 7{,}8) \middle| \min\left[C^{h=4}_{il,k=1}(m = 6) + C^{h=4}_{lj,k=3}(m = 1{,}2)\right] \right\}, \quad \text{Equation 90}$$

where:

$C^{h=2}_{il,k=1}(m = 6)$ = total transit time by rail from trip origin to parking lot in PM period,

$l^{h=4}_{ij}(m = 7{,}8)$ = the best interchange for P&R/K&R rail for the given OD pair in PM period.

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

$$C^{h=2}_{ij,k=0}(m = 4{,}5) = C^{h=2}_{i,l^{h=2}_{ij}(m=4.5),k=3}(m = 1{,}2), \text{ (P\&R / K\&R bus auto leg for AM period),} \quad \text{Equation 91}$$

$$C^{h=2}_{ijk}(m = 4{,}5) = C^{h=2}_{l^{h=2}_{ij}(m=4.5),jk}(m = 3), \text{ (P\&R / K\&R bus transit leg for AM period) ,} \quad \text{Equation 92}$$

$$C^{h=2}_{ij,k=0}(m = 7{,}8) = C^{h=2}_{i,l^{h=2}_{ij}(m=7.8),k=3}(m = 1{,}2), \text{ (P\&R / K\&R rail auto leg for AM period),} \quad \text{Equation 93}$$

$$C^{h=2}_{ijk}(m = 7{,}8) = C^{h=2}_{l^{h=2}_{ij}(m=7.8),jk}(m = 6), \text{ (P\&R / K\&R rail transit leg for AM period) ,} \quad \text{Equation 94}$$

$$C_{ij,k=0}^{h=4}\left(m=4{,}5\right)=C_{l_{ij}^{h=2}(m=4.5),j,k=3}^{h=2}\left(m=1{,}2\right)$$, (P&R / K&R bus auto leg for PM period), Equation 95

$$C_{ijk}^{h=4}\left(m=4{,}5\right)=C_{i,l_{ij}^{h=2}(m=4.5),k}^{h=4}\left(m=3\right)$$, (P&R / K&R bus transit leg for PM period) , Equation 96

$$C_{ij,k=0}^{h=4}\left(m=7{,}8\right)=C_{l_{ij}^{h=2}(m=7.8),j,k=3}^{h=4}\left(m=1{,}2\right)$$, (P&R / K&R rail auto leg for PM period), Equation 97

$$C_{ijk}^{h=4}\left(m=7{,}8\right)=C_{i,l_{ij}^{h=2}(m=7.8),k}^{h=4}\left(m=6\right)$$, (P&R / K&R rail transit leg for PM period) , Equation 98

Step 4: Calculation of mode utilities

This step was described in detail in (the previous) **Subsection 3.8.1**.

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

This step was described in detail in (the previous) **Subsection 3.8.1**.

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:

$$T_{ij}^{h,n}\left(m\right)=\left(1-\lambda^{n}\right)T_{ij}^{h,n-1}\left(m\right)+\lambda^{n}\sum_{u=1}^{5}\sum_{c=0}^{3}T_{ij}^{uch,n}\left(m\right),$$ Equation 99

where:

m = modes from 1 through 9,

u = tour purpose from 1 through 5,

c = household car-sufficiency category from 0 through 3,

n = global iteration number,

$T_{ij}^{uch,n}\left(m\right)$ = 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: $\lambda^{n}=\max\left[\left(1.2-0.2\times n\right),\left(1/n\right)\right]$.

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 and K&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 auto driver, bus, and rail modes. Additionally, at the last iteration, an assignable matrix for auto passenger trips is produced in order to get link-level auto-passenger volumes. The calculations are implemented in the following straightforward way:

- Auto-driver assignable trip matrix includes auto driver trips (*m*=1), auto leg from P&R bus trips (*m*=4), and auto leg from the P&R rail trips (*m*=7),

- Auto-passenger assignable trip matrix includes auto passenger trips (*m*=2), auto leg from K&R bus trips (*m*=5), and auto leg from K&R rail trips (*m*=8),
- Bus assignable trip matrix includes walk-to-bus trips (*m*=3), transit leg from P&R bus trips (*m*=4), and transit leg from K&R bus trips (*m*=5),
- Rail assignable trip matrix includes walk-to-rail trips (*m*=6), transit leg from P&R rail trips (*m*=7), and transit leg from rail K&R trips (*m*=8).

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

$$D_{ij}^{h=2,n} = T_{ij}^{h=2,n}(m=1) + T_{i,l_{ij}^{h=2}(m=4,5)}^{h=2,n}(m=4) + T_{i,l_{ij}^{h=2}(m=7,8)}^{h=2,n}(m=7) \text{, (auto driv. / AM period),} \quad \text{Equation 100}$$

$$P_{ij}^{h=2,n} = T_{ij}^{h=2,n}(m=2) + T_{i,l_{ij}^{h=2}(m=4,5)}^{h=2,n}(m=5) + T_{i,l_{ij}^{h=2}(m=7,8)}^{h=2,n}(m=8) \text{, (auto pass. / AM period),} \quad \text{Equation 101}$$

$$B_{ij}^{h=2,n} = T_{ij}^{h=2,n}(m=3) + T_{l_{ij}^{h=2}(m=4,5),j}^{h=2,n}(m=4) + T_{l_{ij}^{h=2}(m=4,5),j}^{h=2,n}(m=5) \text{, (bus / AM period),} \quad \text{Equation 102}$$

$$R_{ij}^{h=2,n} = T_{ij}^{h=2,n}(m=6) + T_{l_{ij}^{h=2}(m=7,8),j}^{h=2,n}(m=7) + T_{l_{ij}^{h=2}(m=7,8),j}^{h=2,n}(m=8) \text{, (rail / AM period),} \quad \text{Equation 103}$$

$$D_{ij}^{h=4,n} = T_{ij}^{h=4,n}(m=1) + T_{l_{ij}^{h=4}(m=4,5),j}^{h=4,n}(m=4) + T_{l_{ij}^{h=4}(m=7,8),j}^{h=4,n}(m=7) \text{, (auto driv. / PM period),} \quad \text{Equation 104}$$

$$P_{ij}^{h=4,n} = T_{ij}^{h=4,n}(m=2) + T_{l_{ij}^{h=4}(m=4,5),j}^{h=4,n}(m=5) + T_{l_{ij}^{h=4}(m=7,8),j}^{h=4,n}(m=8) \text{,(auto pass. / PM period),} \quad \text{Equation 105}$$

$$B_{ij}^{h=4,n} = T_{ij}^{h=4,n}(m=3) + T_{i,l_{ij}^{h=4}(m=4,5)}^{h=4,n}(m=4) + T_{i,l_{ij}^{h=4}(m=4,5)}^{h=4,n}(m=5) \text{, (bus / PM period),} \quad \text{Equation 106}$$

$$R_{ij}^{h=4,n} = T_{ij}^{h=4,n}(m=6) + T_{i,l_{ij}^{h=4}(m=7,8)}^{h=4,n}(m=7) + T_{i,l_{ij}^{h=4}(m=7,8)}^{h=4,n}(m=8) \text{, (rail / PM period).} \quad \text{Equation 107}$$

Step 8: Final assignments

This step is described in detail in (the next) **Section 3.9** below.

3.9 Assignment & Skimming Procedures

3.9.1 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. These procedures serve the following purposes:

- Properly incorporate all traffic components 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; a single auto driver matrix w/o vehicle distinction by occupancy is currently modelled by the mode choice model 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,
  - A single auto passenger matrix (including K&R auto legs) assigned as additional demand (not contributing to the congested travel time through Volume-Delay functions) to get the auto passenger link volume estimates; auto passenger volumes being combined with auto driver volumes provides estimates for auto occupancy,
- Provide necessary LOS skims for the mode choice model - see (the previous) **Section 3.8**:
  - Free-flow auto travel time,
  - Congested auto travel time,
  - Auto distance.
- Provide class-specific link volumes for which the following link extra attributes are created:
  - @driv (peak hour auto driver vehicle volume),
  - @pass (peak hour auto 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:

$$Volau = @driv + @comm + @exte, \qquad \text{Equation 108}$$

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 3-7** 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 use 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 set to 2.0, which means that the peak hour volume is by 25% higher than the average AM period volume,
- 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.

Table 3-7 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**	**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	Free-flow time (basic), Distance (additional options with length as link attribute)		Min×IterMod
	2. Skim congested auto time	Multiclass:			Volad	Congested auto time (basic)		Min×IterMod
		1(a) – auto	Driver+ P&R auto legs+ Ext×PeakF	PeakF				
		2(c) – comm.	Commercial	≡1				
Final assignments (after the last iteration)	3. Save auto passenger link volumes	Multiclass additional options:			Cannot be used		@pass (additional options with Auto Pass matrix divided by PeakF for additional volumes)	Min×IterMax
		1(a) – auto	Driver+ P&R auto legs	PeakF				
		2(c) – comm.	Commercial	≡1				
		3(a) – ext	External	≡1				
	4. Save auto driver, commercial, and external link volumes	Multiclass with saved class-specific volumes:			Volad			Min×IterMax
		1(a) – auto	Driver+ P&R auto legs	PeakF				
		2(c) – comm.	Commercial	≡1				
		3(a) – ext	External	≡1				

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 tat is applied for the first global iteration of integrated mode choice an assignment procedure described in **Subsection 3.8.1** 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 8) and final assignments is 80; 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.

3.9.2 Transit assignment and skimming

The TRANS 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 3.8**:
    - Total transit time,
    - In-vehicle time by transit mode (bus, rail),
    - Wait time,
    - Walk time,
    - Number of boardings by transit mode (bus, rail)),
    - Proportion of reliable services (Transitway, rail) in the total trip in-vehicle time/distance.
- 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.

Basic transit assignment algorithm implemented in EMME ("optimal strategies") is not sensitive to transit capacity constraints. Transit capacity constraint feedback can be introduced by means of an iterative procedure with shadow pricing applied for one of the transit time components (in-vehicle time or wait time). It has not been incorporated yet in the current version of the TRANS model. Thus, the transit skims are currently not dependent on the assigned demand. For this reason, the transit trip tables are not scaled to represent the peak hour and relate to the entire period (AM or PM). Also, for the same reason transit table construction within the mode choice loop can be simplified since for each intermediate global iteration transit assignments are needed for generating LOS skims only (see **Subsection 3.8.2** above). The ridership statistics are generated by the final assignment procedures after the last global mode choice iteration has been completed.

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:

- Bus assignment and skimming including regular bus, express bus, in both mixed traffic and on the guided Transitway; this allows to take into account combined headways across all bus services as well as to properly treat multiple cases where the same bus line has both mixed-traffic and Transitway segments; the specific attraction of Transitway in terms of reliability is taken into account in the mode choice model by having the proportion of guided distance in the total distance as a variable; bus mode path is considered valid (and the bus mode is considered available) if the in-vehicle time is positive (otherwise bus path deviates to walk only that is not a motorized mode); it should be taken into account that the EMME transit assignment algorithm allows for multiple paths of which some might deviate to walk only, in this case the bus mode is still considered available but some leakage of the assigned bus demand to walks is taking place.
- Rail assignment and skimming including all transit modes (rail, LRT, regular bus, express bus, Transitway, etc); this allows to take into account multiple trips where different transit modes are combined and bus serves as a feeder mode to rail; the specific attraction of the rail modes in terms of reliability is taken into account in the mode choice model by having the proportion of rail in-vehicle time in the total in-vehicle time as a variable; rail mode path is considered valid (and the rail mode is considered available) if the rail in-vehicle time is positive (otherwise rail path deviates to bus& walk only); it should be taken into account that the EMME transit assignment algorithm allows for multiple paths of which some might deviate to bus& walk only, in this case the rail mode is still considered available but some leakage of the assigned rail demand to bus & walk is taking place.

There are certain limitations of the skimming options of the existing EMME assignment algorithm with respect to the number and type of skims that can be saved at one assignment. In particular, only one additional attribute can be skimmed (in addition to the standard set of travel time components). Thus, if several additional attributes have to be skimmed (like total in-vehicle time and Transitway in-vehicle time for bus or total number of boardings and number of rail boardings for rail) the assignment procedure has to be repeated several times with one additional attribute saved at a time. For this reason, two bus assignments and two rail assignments are implemented at each global iteration of mode choice model that allows for skimming all necessary attributes.

Park & Ride and Kiss & Ride modes were modelled explicitly with each trip broken into an auto leg and transit leg each added to the corresponding demand matrix (auto or transit). Thus no specific bi-modal assignment is needed. The bi-modal LOS skims area created by convoluting the auto access/egress skims and transit skims through the available parking lots as described in the **Subsection 3.8.2** above.

The following transit assignment (path building) parameters were calibrated (and reconciled with the mode choice model to the extent possible):

- In-vehicle time, modelled by link speed functions (linked to the auto speed for mixed traffic bus) with a predefined dwelling time for each stop,
- Weighted walk access time,
- Weighted wait time,
- Transfer penalty specific to modes,
- Time equivalent of additional transit fare for transferring between lines (through node-specific boarding penalties).

The main features and parameters used in the transit assignment and skimming procedures are summarized in **Table 3-8** below.

Table 3-8 Transit Assignment and Skimming Procedures

Parameter / feature	Within mode choice model loop				Final ridership	
	For bus skimming		For rail skimming			
	Bus-1	Bus-2	Rail-1	Rail-2	Bus	Rail
New or add volumes	New	New	New	New	New	Add
Demand matrix	WB	WB	WR	WR	WB plus bus legs from P&R and K&R	WR plus rail legs from P&R and K&R
Total transit time	Skim		Skim			
Total in-vehicle time	Skim		Skim (rail and bus)	Skim (rail only)		
Walk time	Skim		Skim			
Total waiting time	Skim		Skim			
Total boardings	Skim		Skim (rail and bus)	Skim (rail only)		
Transit modes for path building	Bus (o,s)	Bus (o,s)	Rail (r), Bus (o,s)	Rail (r), Bus (o,s)	Bus (o,s)	Rail (r), Bus (o,s)
Auxiliary modes	Walk (p)	Walk (p)	Walk (p)	Walk (p)	Walk (p)	Walk (p)
Active modes for skimming	Same as for path	Same as for path	Same as for path	Rail (r)		
Source for wait time	Headway with max	Headway with max	Headway with max	Headway with max	Headway with max	Headway with max
Maximum	30 min	30 min	30 min	30 min	30 min	30 min
Source for boarding time:	Extra attributes:	Extra attributes:	Extra attributes:	Extra attributes:	Extra attributes:	Extra attributes:
- node-specific	@nboa	@nboa	@nboa	@nboa	@nboa	@nboa
- line specific	@tboa	@tboa	@tboa	@tboa	@tboa	@tboa
Wait time factor	0.5	0.5	0.5	0.5	0.5	0.5
Wait time weight	2.5	2.5	2.5	2.5	2.5	2.5
Walk time weight	2.0	2.0	2.0	2.0	2.0	2.0
Boarding time weight	1.0	1.0	1.0	1.0	1.0	1.0
Additional options	Yes	Yes	No	Yes	No	No
In-vehicle segment attribute	Length	Transit way length		Length		
Additional skim saved	Total in-vehicle distance	Transit way in-vehicle distance		Rail in-vehicle distance		

In future versions of the TRANS model, two additional specific features can be added to the transit assignment procedure, that are not parts of a standard EMME assignment (both require some equilibrating that can be effectively incorporated within the global mode choice iterations):

- Capacity-constrained assignment through wait time functions / boarding penalties defined as shadow prices for overloaded lines,
- Frequency adjustment procedures that are useful for future scenarios where exact line schedules are not known; with this procedure, line frequencies are iteratively adjusted to meet the travel demand on the peak link (with operational constraints on minimal allowable combined headways on each link).

The user will be allowed to turn these features on and off depending on the project. Logically, only one of these features makes sense at a time (but never both). Additional technical improvements that can be considered for the future versions of the model include 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, and using it in the mode choice model.

3.10 Time-of-Day Choice (Peak Spreading) Feedback

This sub-model has not been implemented yet but it could be added in future versions of the TRANS model. This sub-model requires all TOD periods to be modelled explicitly (though for simplicity, free-flow conditions could be assumed for all off-peak periods). If implemented, this option is enabled for future years where a significant overall growth of congestion is expected. This model represents an incremental logit model that is driven by differences in travel impedance (auto travel time in particular case) for the modelled year versus the base (calibration) year. The model is applied at the entire tour level and for each tour purpose independently. Since the basic TOD choice model is applied for tour production and attraction vectors, it is not sensitive to LOS changes, and specifically to growing congestion (see **Subsections 3.5.1** and **3.5.2** above). For this reason, the TOD feedback can be better implemented through the subsequent tour distribution in PA format (see **Subsection 3.6.2**).

The sub-model is placed after the integrated mode-choice-assignment procedures and assumes that additional global iterations are applied including the tour & trip distribution stage, mode choice & assignment, and TOD choice / peak spreading (see **Exhibit 3-2** above). The TOD choice feedback does not affect daily tour generation. The TOD choice feedback sub-model can be written in the following general form:

$$Z_{ij}^{ugh}(n+1)=\frac{Z_{ij}^{ugh}(n=0)\times\exp\left(\lambda^{u}\times\Delta L_{ij}^{gh}\right)}{\sum_{g'h'}\frac{Z_{ij}^{ug'h'}(n=0)}{Z_{ij}^{u}(n=0)}\times\exp\left(\lambda^{u}\times\Delta L_{ij}^{g'h'}\right)},$$

Equation 109

where:

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

u = tour purpose from 1 through 5,

g = outbound TOD period from 1through 5,

h = feasible inbound TOD periods from g through 5,

n = global iteration with TOD choice feedback,

$Z_{ij}^{ugh}(n=0)$ = tour tables by TOD slices produced before the first global iteration,

$Z_{ij}^{u}(n)=\sum_{gh} Z_{ij}^{ugh}(n)$ = total daily tour table produced before the first iteration,

$Z_{ij}^{ugh}(n+1)$ = tour tables by TOD slices for the next global iteration,

ΔL_{ij}^{gh} = difference in LOS between the current iteration and base-year scenario,

λ^{u} = estimated / calibrated dispersion coefficient (peak-spreading elasticity).

We suggest using a bi-direction entire-tour mode choice logsum as the LOS measure since it incorporates travel time/cost dynamic over years of all modes. In many practical cases, a simple auto travel time measure can be used instead. This simplification is justified if transit (bus) travel time is linked to auto travel time and no specific congestion pricing policy (through tolls and/or parking cost) is applied.

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 micro-simulation 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 micro-simulation 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 micro-simulation 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 ($d = 2$)
- Total employed labour force (number of workers by place of residence) (L_i).

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)
- From the person file:
  - Number of workers ($\widetilde{w}_n$)
  - 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 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, and dwelling type (H_i^{swd}). 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) is used in several travel models along with the household distribution.

The proposed household distribution includes the following 42 feasible combinations listed in **Table 3-9** below.

Table 3-9 Household Categories

Category	Household size	Number of workers	Dwelling type	Code
1	1	0	1	S1W0D1
2	1	0	2	S1W0D2
3	1	1	1	S1W1D1
4	1	1	2	S1W1D2
5	2	0	1	S2W0D1
6	2	0	2	S2W0D2
7	2	1	1	S2W1D1
8	2	1	2	S2W1D2
9	2	2	1	S2W2D1
10	2	2	2	S2W2D2
11	3	0	1	S3W0D1
12	3	0	2	S3W0D2
13	3	1	1	S3W1D1
14	3	1	2	S3W1D2
15	3	2	1	S3W2D1
16	3	2	2	S3W2D2
17	3	3	1	S3W3D1
18	3	3	2	S3W3D2
19	4	0	1	S4W0D1
20	4	0	2	S4W0D2
21	4	1	1	S4W1D1
22	4	1	2	S4W1D2
23	4	2	1	S4W2D1
24	4	2	2	S4W2D2
25	4	3+	1	S4W3D1
26	4	3+	2	S4W3D2
27	5	0	1	S5W0D1
28	5	0	2	S5W0D2
29	5	1	1	S5W1D1
30	5	1	2	S5W1D2
31	5	2	1	S5W2D1
32	5	2	2	S5W2D2
33	5	3+	1	S5W3D1
34	5	3+	2	S5W3D2
35	6+	0	1	S6W0D1
36	6+	0	2	S6W0D2
37	6+	1	1	S6W1D1
38	6+	1	2	S6W1D2
39	6+	2	1	S6W2D1
40	6+	2	2	S6W2D2
41	6+	3+	1	S6W3D1
42	6+	3+	2	S6W3D2

In the output file the number of households (H_i^{swd}) for each category is listed for each zone in the following format (**Table 3-10** below) with 1 key field (TAZ) and 42 data fields by household categories:

Table 3-10 Output file format for synthetic household distribution

TAZ	S1W0D1	S1W0D2	S1W1D1	…
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 further used as a seed in the balancing procedure. The OD survey provides a sample of 23,800 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 556 this leads to approximately 40 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 12 possible combinations of household size and dwelling type (assuming non-zero marginals for all size and dwelling type categories) as well as have representative persons in each age bracket $a = 1,2,...6$ and number of workers category (0,1,2,3+). Taking into account that we have 42 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 applied 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:

- 556 TAZs ($i \in I$),
- 94 aggregate zones ($j \in J$),
- 26 districts ($k \in K$).

The geographical hierarchy has been 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 majority of aggregate zones,
- ensuring a size of 20,000 inhabitants (8,000 households) in majority of districts,
- 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. For each combination (s, d) of non-zero marginals check if there is at least one household in this cell; if not go to 6,
5. If the zonal labour force marginal is positive ($L_i > 0$) check if there is at least one worker in the households; if not go to 6,
6. Identification of non-zero marginals by person age groups ($P_i^a > 0$),
7. 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,
8. If there is a problem, expand the geography to the next level up and go to 2,
9. 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 3-11** below (also convenient for the subsequent balancing procedure):

Table 3-11 Synthetic sample of households

TAZ	HHID	S1	S2	S3	S4	S5	S6	W	D1	D2	A1	A2	A3	A4	A5	A5	Exp
1	1				1			2	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 or 5 persons,

- Number of workers ($\widetilde{w}_n$); 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,
- 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):

$$\sum_{n \in N_i} s_n \times \omega_n = H_i^s , \qquad \text{Equation 110}$$

Matching controls by dwelling type:

$$\sum_{n \in N_i} d_n \times \omega_n = H_i^d , \qquad \text{Equation 111}$$

Matching the labour force control:

$$\sum_{n \in N_i} \widetilde{w}_n \times \omega_n = L_i , \qquad \text{Equation 112}$$

Matching the population controls by age brackets:

$$\sum_{n \in N_i} p_n^a \times \omega_n = P_i^a . \qquad \text{Equation 113}$$

The balancing algorithm represents an IPF procedure that loops over 5 controls by household type, 2 controls by dwelling type, 1 control for total labour force, 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:

$$f^1 = \frac{H_i^1}{\sum_{n \in N_i} 1_n \times \omega_n}, \qquad \text{Equation 114}$$

where $1_n = 0,1$ is a Boolean indicator if the household has a size 1 or not.

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

$$\omega_n = \omega_n \times f^1 \text{ for } 1_n = 1. \qquad \text{Equation 115}$$

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 matching labour force control (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:

$$H_i^{swd} = \sum_{n \in N_i} \omega_n \times s_n \times w_n \times d_n, \qquad \text{Equation 116}$$

where (w_n) denotes a categorized Boolean indicator for household number of workers tat is defined based on the absolute number of workers ($\tilde{w}_n$) in **Table 3-12** below:

Table 3-12 Categorized Number of Workers

Categorized Boolean indicators w_n	Number of workers in the household $\tilde{w}_n$			
	0	1	2	3+
0_n	1	0	0	0
1_n	0	1	0	0
2_n	0	0	1	0
3_n	0	0	0	1

4.0 Zones and Network Adjustments

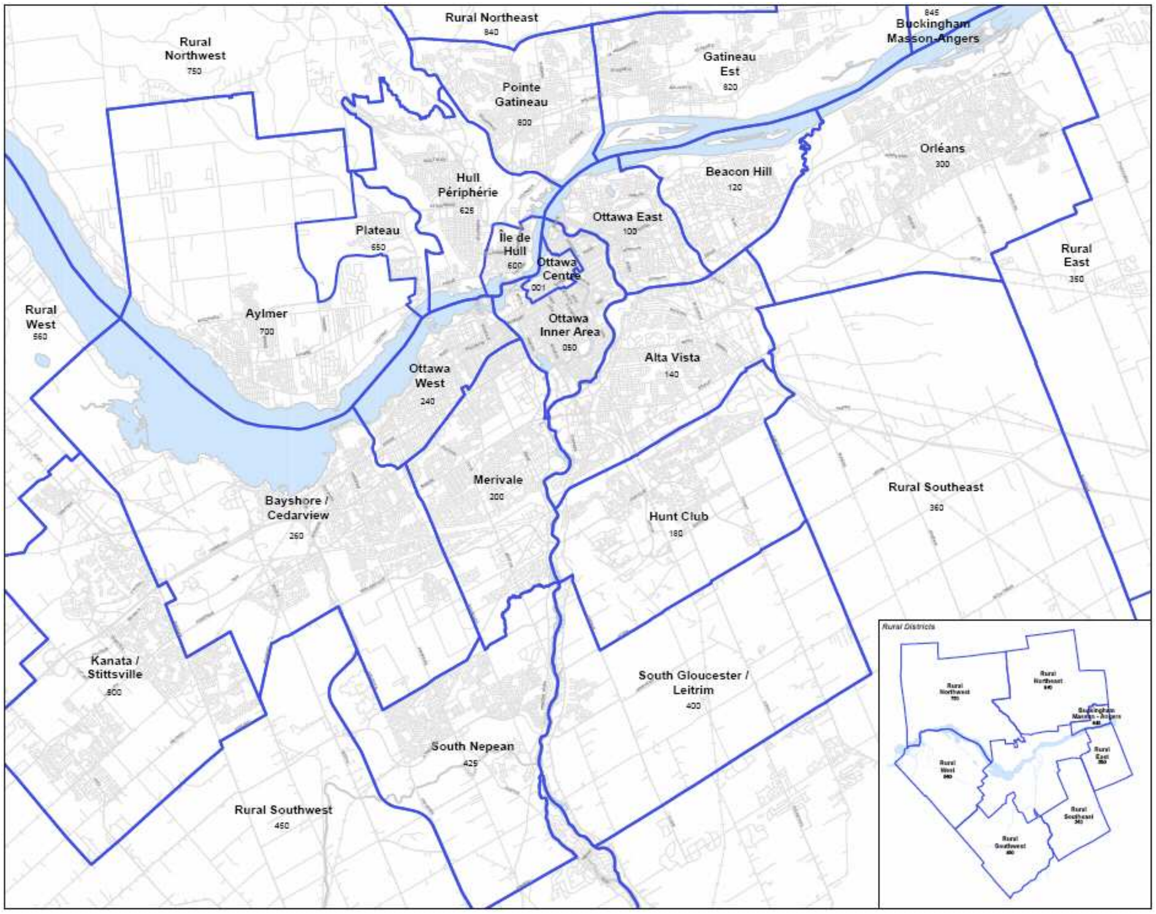
The TRANS Model traffic zone system and road and transit networks have undergone various levels of revision and updates in recent years. A primary outcome of this review was to ensure the zone structure and their connections to the underlying transportation networks were designed:

- 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 revise/add link characteristics to refine volume delay functions

4.1 Traffic Zone Review

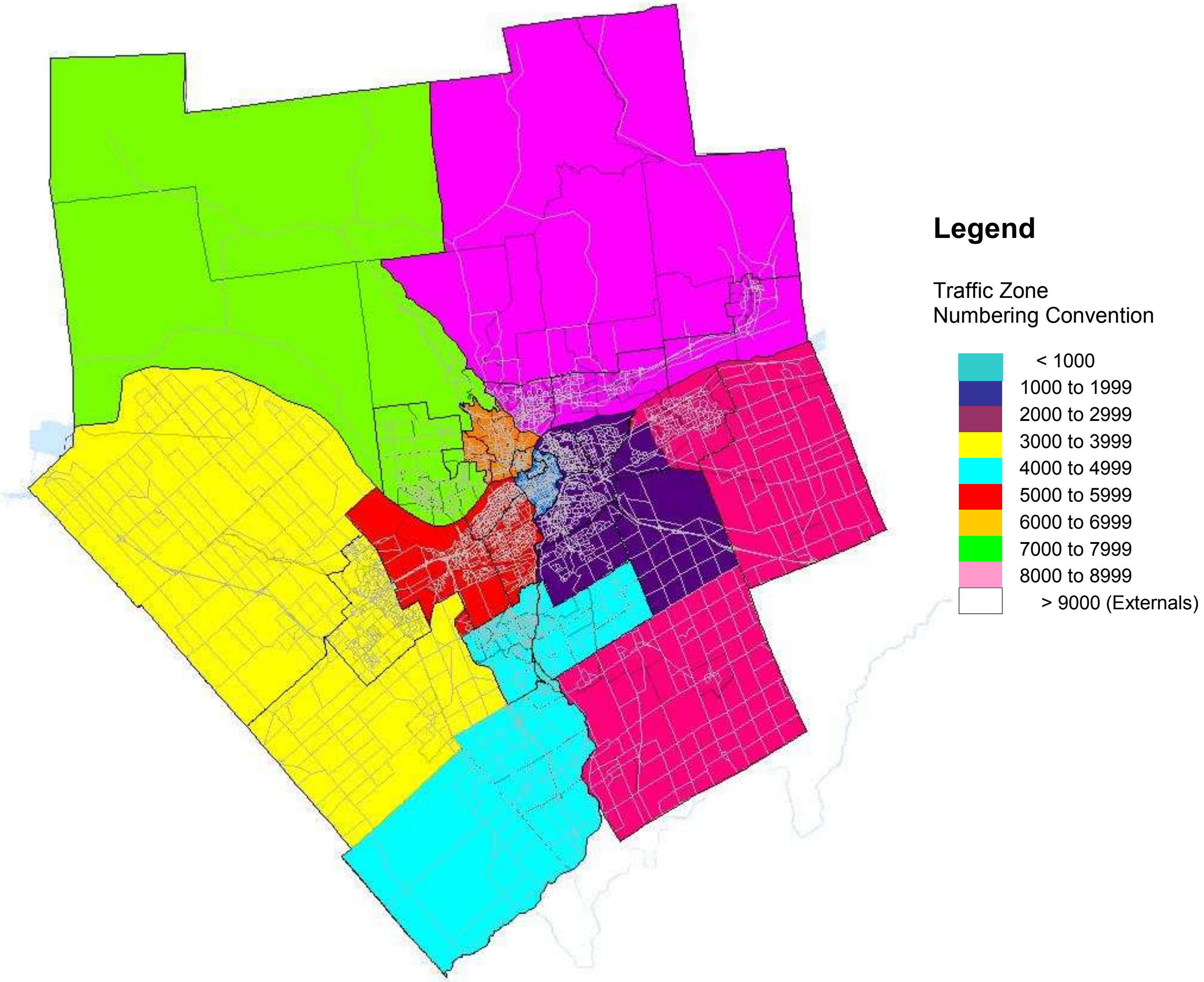
TRANS traffic zone system at the time of the 2005 OD survey was comprised 344 zones and for purposes of presenting aggregate OD results relied on a 20 district system (see Exhibit 4.1). A review of the 344 traffic zone system by TRANS Agencies during the model redevelopment study revealed that a need to refine/subdivide a number of existing traffic zones on both sides of the Ottawa River.

Exhibit 4.1 Revised TRANS District Map (2005)



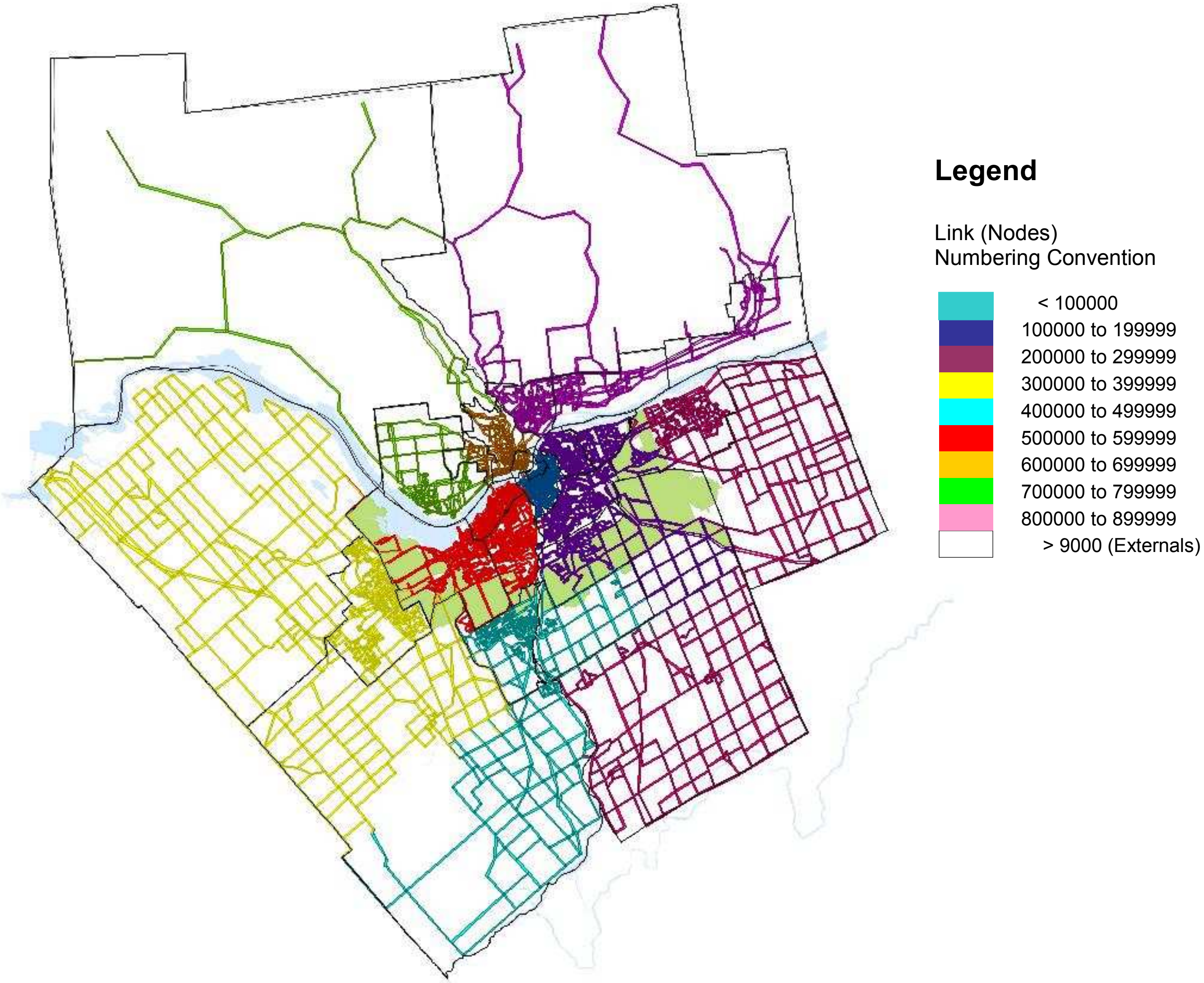
The result of this review and zone redefinition was a traffic zone system which was increased in number to approximately 600 zones. In addition, the traffic zone numbering convention adopted, provided improved spatial logic and consequently allowed for easier use and understanding by users, particularly those with limited familiarity with the traffic zone system. The four digit non-continuous numbering system as implemented by TRANS member agencies, also provided 9 clusters, traffic zones from 0 through to 8 thousand series with traffic zones greater than 9000 reserved for areas located outside the region or modelled area (externals zones). In addition, the traffic zone structure (four digit non-continuous numbering) provides considerable flexibility in accommodating future network expansion while maintaining the integrity/principles of the numbering convention. Exhibit 4.2 provides a general layout of the traffic zone numbering system with the less than 1000 series reserved for Ottawa's Inner Area and Gatineau's core area assigned the 6000 series zones. External zones were assigned the 9000 series set of zones numbers.

Exhibit 4.2 TRANS Traffic Zone Numbering Convention



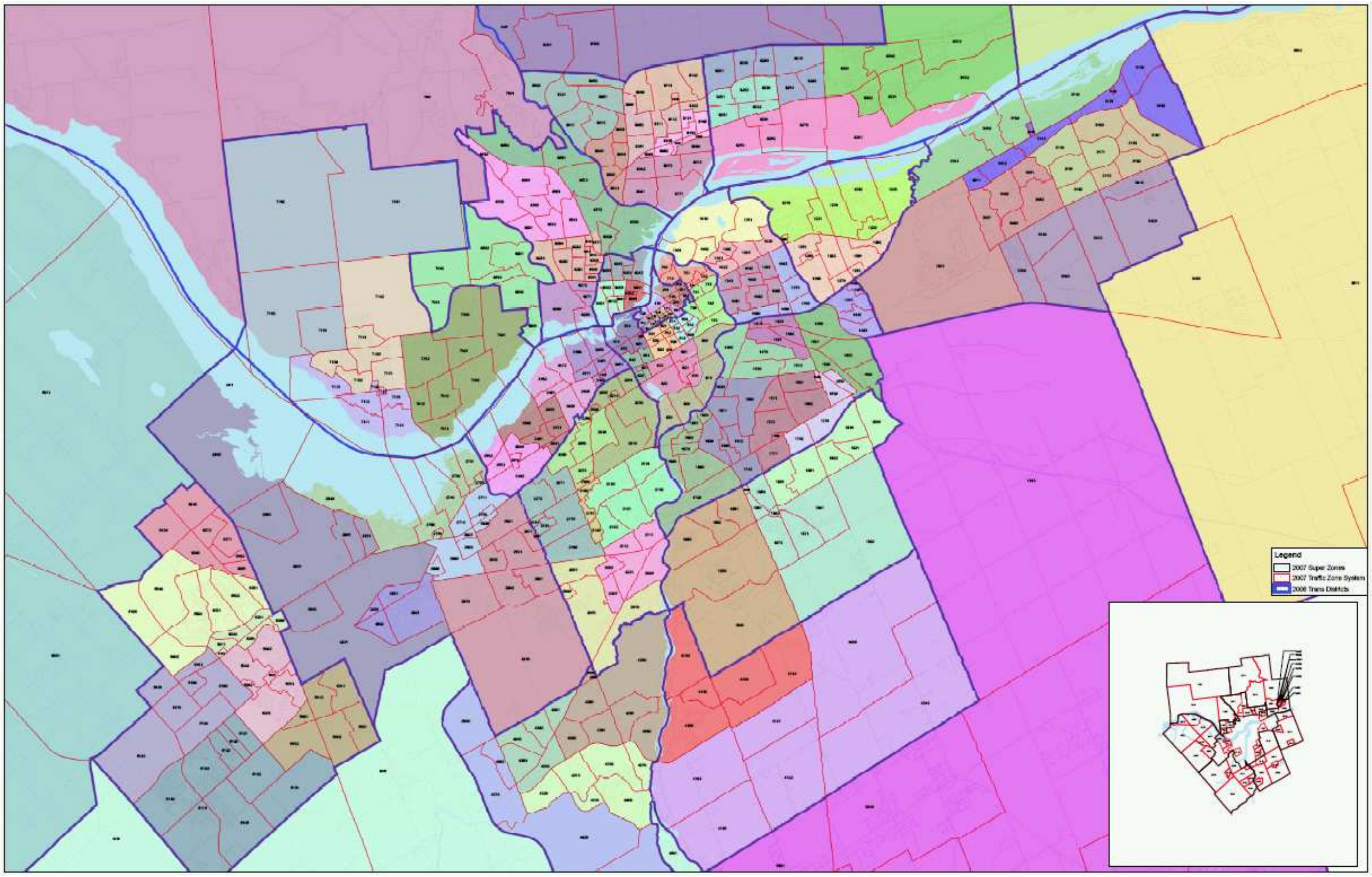
Also it is noted that the link-node numbering convention was also revised to be in conformity with the newly introduced traffic zone (node) numbering system. In this respect, link nodes were assigned six digits with the first four being associated with the neighbouring traffic zone, again providing spatial relationships not present in previous traffic zone systems and thereby significantly increasing the "user friendly" aspects of network editing often encountered with large complex road and transit networks.

Exhibit 4.3 Revised TRANS Link-Node Numbering Convention



The Exhibit 4.1 below illustrates the revised district system. 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 analysing model forecasts. To strengthening the analysis and to provide for opportunities to relate specific model parameters across groups of traffic zones an additional level of geography (super-zones with about 6 zones per super-zone; 3-4 super-zones per district) was introduced resulting in approximately 94 super-zones. These super-zones are illustrated by the Exhibit 4.4.

Exhibit 4.4 TRANS Super-zones Map



4.2 Network Review

4.2.1 Expanding Modelled Networks

The numbers of nodes and links have more increased substantially when compared with the previous model and consequently improvements anticipated with a finer road and transit network include both more accurate transit modelling and smoother loading of trips on the modelled road and networks.

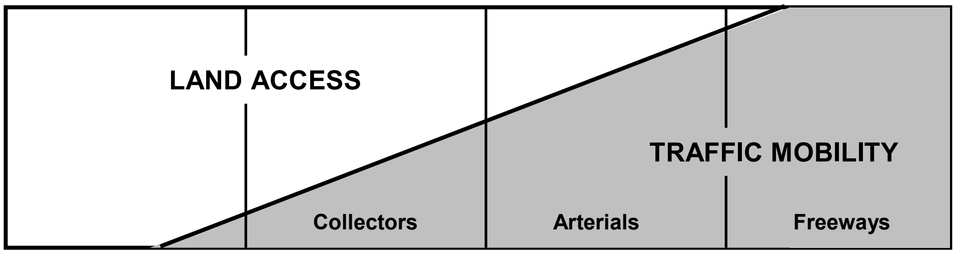
4.2.2 Link Characteristics

TRANS revised the road network classification system used in defining the transportation networks within the long range travel demand forecasting 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 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 recognises 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 4.2 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 (3) additional 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 validate cells in the matrix.

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

		Level of Interference					
ROAD TYPE		Rural / no interference 1	Low inteference 2	Medium interference 3	High interference 4	Ramp 5	Bridge 6
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		Transitway / Bus Only 1	Rail Transit 2
8	**Transit**	●	●

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

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 4-3 TRANS link type numbering system

ROAD TYPE	LEVEL OF FLOW		DESIGNATIONS	LINK TYPE (OLD)	Link Type (Lane-Km) POSTED SPEED LIMIT 30	40	50	60	70	80	90	100	Total Lane-km
#	#												
1	**Freeway (Autoroute)**												
	0	Rural / no interference	FW0U FW0S FWR	10 14 18								100 (470)	**470**
	1	Low inteference	FW1U FW1S	11 15					117 (3)			110 (211)	**215**
	2	Medium interference	FW2U FW2S	12 16			125 (5)		127 (7)			120 (117)	**129**
	3	High interference							137 (12)			130 (8)	**20**
	5	Ramp				154 (25)	155 (1)	156 (134)	157 (1)				**162**
	Subtotal												**997**
2	**Expressway (Route Express)**												
	0	Rural / no interference											
	1	Low inteference											
	2	Medium interference											
	3	High interference											
	5	Ramp											
	Subtotal												
3	**Arterial (Artère majeure)**												
	0	Rural / no interference	A0U A0S AR A0F HR	30 34 38 41 42			305 (113)	306 (256)	307 (212)	308 (1602)	309 (168)		**2,351**
	1	Low inteference	A1U A1S A1F	31 35 43			315 (64)	316 (123)	317 (67)	318 (63)	319 (22)	310 (0)	**339**
	2	Medium interference	A2U A2S	32 36	323 (3)	324 (1)	325 (244)	326 (265)	327 (48)	328 (3)			**564**
	3	High interference	A3U A3S	33 37		334 (3)	335 (258)	336 (143)					**404**
	5	Ramp				354 (3)	355 (5)	356 (15)					**24**
	6	Bridge	AB	40		364 (1)	365 (14)	366 (19)	367 (9)	368 (4)			**47**
	Subtotal												**3,729**
4	**Major Collector (Artère mineure)**												
	0	Rural / no interference	MJ0S MJR	54 58		404 (25)	405 (132)	406 (270)	407 (185)	408 (1973)	409 (163)		**2,747**
	1	Low inteference	MJ1U MJ1S	51 55		414 (11)	415 (97)	416 (24)	417 (15)				**145**
	2	Medium interference	MJ2U MJ2S	52 56	423 (3)	424 (25)	425 (110)	426 (10)	427 (22)			420 (0)	**169**
	3	High interference	MJ3U MJ3S	53 57	433 (1)	434 (10)	435 (59)	436 (4)					**75**
	Subtotal												**3,136**
5	**Minor Collector (Collectrice)**												
	0	Rural / no interference					505 (64)		507 (102)				**166**
	1	Low inteference	MN1U MN1S	61 65		514 (210)	515 (203)	516 (14)	517 (4)	518 (6)			**438**
	2	Medium interference	MN2U MN2S	62 66		524 (49)	525 (94)						**143**
	3	High interference	MN3U MN3S	63 67	533 (4)	534 (37)	535 (157)						**199**
	Subtotal												**946**
6	**Local (rue locale)**												
	0	Rural / no interference					605 (8)		607 (4)				**12**
	1	Low inteference											
	2	Medium interference					625 (1)						**1**
	3	High interference	LO	70		634 (491)	635 (1268)	636 (16)	637 (3)	638 (48)			**1,824**
	Subtotal												**1,837**
7	**Centroid Connector**						705 (1)					700 (1858)	**1,860**
8	**Transit**												
	1	Transitway/Bus Only	BO	71			815 (3)		817 (64)				**67**
	2	Rail Transit	RT	73								820 (114)	**114**
9	**Non motorized**												
	1	Multi-Use / Bike	PO	72								910 (17)	**17**
	2	Pedestrian Only	PO	72								920 (32)	**32**
	3	Transfer											
10	**Others**				911 (0)	912 (2)	930 (12)	995 (7)	997 (6)	999 (2)			**29**
													23,410 Lane Km

Notes:

"Arterial / no interference level" includes 50 "Highway Rural" links, 16 of which have 90 as posted speed limit.

911 and 912 are located at transit stations (p & b modes) 930 are pedestrian links in Gatineau 995, 997 and 999 represent the future connection between Lac des Fees and St Raymond in Gatineau

Roads coded with 0 or 9 lanes were assumed to be 1 lane only

4.2.3 Updating 2005 Transit Network

The transit route structure and associated transit itineraries were updated based on existing transit services provided on each side of the Ottawa River. TRANS Agencies rethread the transit itineraries based on the newly adopted link/node numbering system for both the existing AM and PM peak period transit service plans (OC Transpo and STO). As note in the previous table, transit only lanes were coded using a '8' with 2 sub-categories to distinguish between the technology used; Transitway and bus only lanes (bus operation) and rail transit (LRT operation).

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). It is also noted that the former TRANS model had identified a number of transit travel time functions for application based on different transit operating environments (i.e. Transitway links, Bus only Queensway lanes and O-Train line.)

4.3 Revised 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 focussed 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:

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

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

A review of the typical lane capacities for various roadway types is presented in Table 4-4. 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.

Table 4-4 Typical Lane Capacity Values from Literature Review

US FHA[1]	
Roadway Classification	Lane Capacity (pcphpl)
Freeway	2,100 - 2,100 - 2,100
Major Arterial	1,003 - 878 - 673
Minor Arterial	920 - 805 - 617
Major Collector	836 - 732 - 560
Minor Collector	669 - 585 - 448
Local	502 - 439 - 336

GTA [2] (Toronto)	
Roadway Classification	Lane Capacity (pcphpl)
Freeway (basic - ramps)	1,800 – 1,400
Controlled Access or Rural Hwy & Art	1,500 – 1,200
Major Urban Arterial	900
Medium Urban Arterial	700
CBD Arterial	500
Collector & Local	400

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)

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.

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[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 has been provided to allow for comparison with the FHA data) and reflects 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 4-5 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 4-4.

Table 4-5 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	limited 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 & Island Pky- Q. E. & Col 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 4-1 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 4-6 City of Ottawa Lane Capacities 2003 TMP

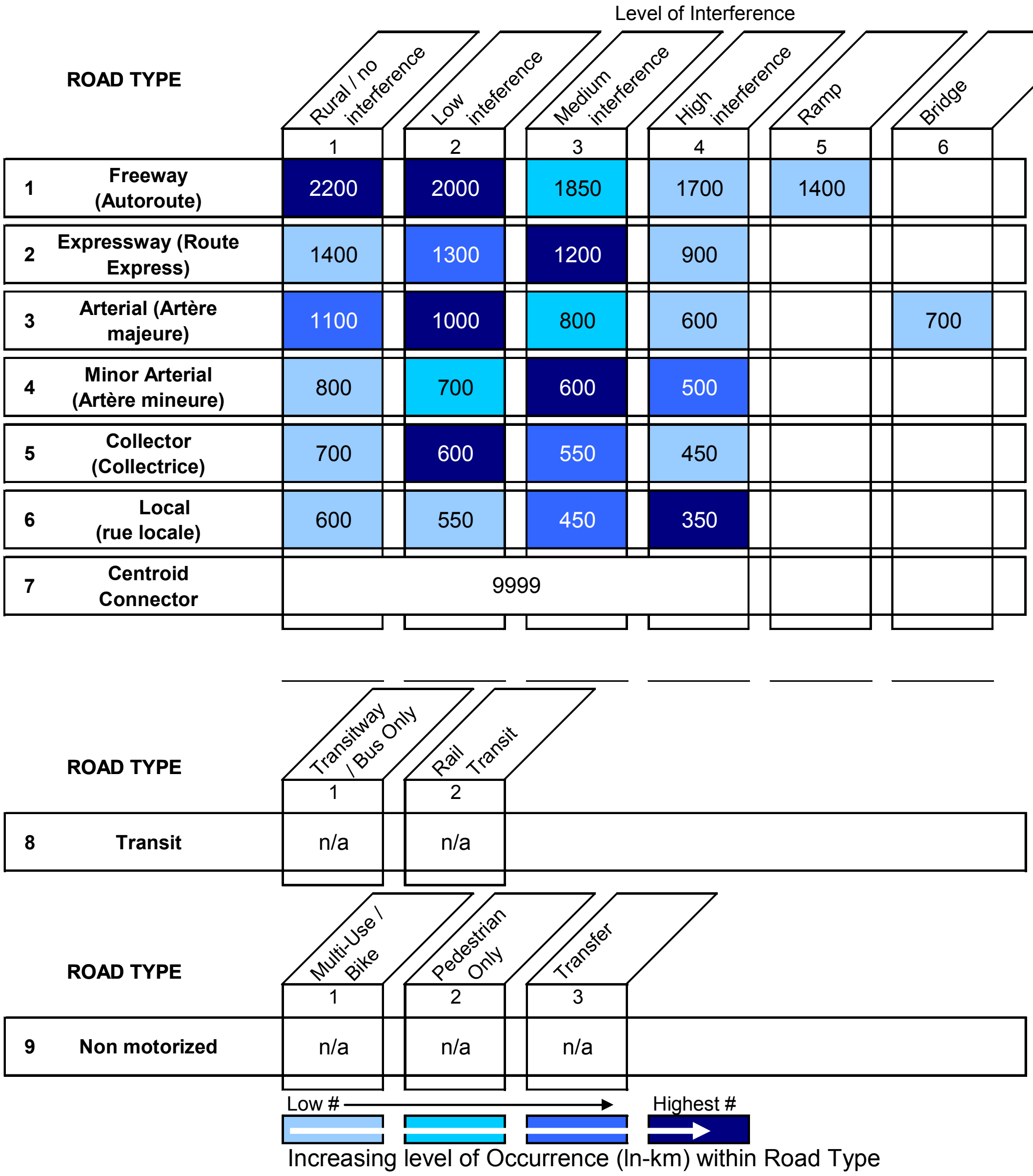
City of Ottawa Transportation Master Plan Background Report[5]

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,* The lane capacities indicated are in vehicles per hour per lane.

From the review of this data, lane capacities in vphpl were recommended for the National Capital Region as detailed in Table 4-7. 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 kilometres 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.

Table 4-7 Recommended lane capacity for TRANS NCR roadways



Level of Interference

	ROAD TYPE	Rural / no interference 1	Low inteference 2	Medium interference 3	High interference 4	Ramp 5	Bridge 6
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	Transitway / Bus Only 1	Rail Transit 2
8	**Transit**	n/a	n/a

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

Low # → Highest #

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

5.0 Model Estimation

5.1 Car Ownership Model

The car ownership model has been estimated as a choice model based on the disaggregate household data from the OD Survey and according to specifications noted in **Subsection 3.2** previously. The model estimation results are summarized in **Table 5-1** below. Detailed estimation results and statistics are provided in **Appendix B.1: 1st Progress Report**. 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 5-1 Estimation results for car ownership model

Variable Description	Utility coefficients by alternative			
	0 cars	1 car	2 cars	3+ cars
0 Workers in the Household		1.2051	-2.3246	-4.8932
1 Worker in the Household	-3.2436		-1.5813	-3.2280
2 Workers in the Household	-5.1656	-0.4856		-2.7232
3+ Workers in the Household	-5.7225	-1.9370	-0.2778	
# Non Workers if Workers=0		0.7952	1.7776	2.0753
# Non Workers if Workers =1		0.3551	0.9454	1.0155
# Non Workers if Worker >=2		0.6061	0.8363	1.0039
Detached House		1.8839	3.2146	3.7464
TAZ Population Density		-0.0025	-0.0137	-0.0262
TAZ % Low Income Households		-3.7801	-5.5634	-5.5934
TAZ % Detached Dwelling Units 1		0.5672	0.9728	0.6683
Superzone Population Density		-0.0041	-0.0065	-0.0031
District Population Density		-0.0294	-0.0550	-0.0677
Nesting coefficient (upper-level nests)	0.90	0.90		
Nesting coefficient (lower-level nests)		0.65	0.65	

The estimation results showed that the number of cars available to the household is strongly correlated with the number of workers in the household: for example, households with 2 workers are most likely to have two cars, a little less likely to have one car, and much less likely to have 3 cars or no car at all. The only notable exception is that households with no workers are much likely to have one car. This would reflect the situation of households made up of retirees, for instance.

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, population density of the area and the percentage of detached dwelling units in the traffic zone. The predicted number of cars available proved to be highly sensitive to the percentage of low-income households in the zone. The strong negative impact of this variable on multiple-car ownership categories is logical.

5.2 Daily Tour Generation Models

In this section, we provide summaries for the daily tour production and attraction models. The detailed estimation results and statistics for these models are included in **Appendix B.1: 1st Progress Report.** 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 556 TAZs while the production model was based on 23,868 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.

5.2.1 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 in **Subsection 3.3.1** previously. The model estimation results for 5 travel purposes are summarized in **Table 5-2** 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.

Table 5-2 Estimation results for household tour production model

Variable	Regression coefficients by travel purpose				
	Work	University	School	Maintenance	Discretionary
Zero cars – dummy		0.1058		-0.1994	-0.08492
Cars fewer than workers – dummy	-0.04147	-0.01702			
Cars greater than workers - dummy	0.03424	0.02452	-0.08885	0.05476	0.1352
1st worker in HH – dummy	0.8173		-0.03065	0.1773	0.2282
2nd worker in HH – dummy	0.8008	0.04711		0.04162	0.08983
3rd and further workers in HH (#)	0.7635	0.06724		0.07128	0.1250
1st non-worker in 0-worker HH - dummy		-0.04930		0.5023	0.3800
2nd and further non-workers (#) in 0-worker HH	0.05926	0.1769	0.1675	0.1661	0.1189
Non-workers (#) in 1-worker HH	0.02919	0.07962	0.2102	0.2194	0.1177
Non-workers (#) in 2-worker+ HH	0.02756	0.07332	0.3527	0.1689	0.1076
TAZ % of low income HHs in Ontario				-0.1086	
TAZ % of low income HHs in Quebec	-0.07792				-0.2015
Superzone % of low income HHs in Quebec				-0.3465	
Detached house – dummy		-0.04555		0.1040	0.07029
TAZ population density (persons/ha)	0.0004264	0.0005841			
Superzone retail+service density (emp/ha)		-0.002265			0.0022
Superzone % of detached HHs				0.07051	
District population density (persons/ha)		0.001083		0.003607	
District employment density (emp/ha)		0.0004922			
District % of detached HHs		-0.02944			

The data showed that the presence of workers in the household is a very strong explanatory variable for the number of work-related tours. 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.

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. 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 the forecast of employment. The latter would affect the population synthesis procedure and proportion between workers and non-workers in the synthesized households.

5.2.2 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 3.3.2** above. The model estimation results for 5 travel purposes are summarized in **Table 5-3** 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 5-3 Estimation results for zonal tour attraction model

Variable	Regression coefficients by travel purpose				
	Work	University	School	Maintenance	Discretionary
Total employment	0.6817				
Retail employment in Ontario				1.6901	0.6118
Retail employment in Quebec				1.8248	0.6224
Service employment					0.3760
Office (public and private) employment				0.02984	
Education employment				0.1678	
Health employment		0.1467		0.5075	
Shopping Gross Leasable Area in Ontario				0.003789	0.0004282
Total population	0.03061		0.02964	0.04446	
Number of detached households					0.2209
Number of apartment households					0.1613
University enrollment		0.7413			
School enrollment			1.1277	0.1520	0.2440
District employment density (emp/ha)	0.0003069				
District retail&service density (emp/ha)				-0.005120	

The data showed very robust relationships between the variables and the tour attractions, for all travel purposes except for discretionary trips. Work tours are very well explained by employment, with some addition of the population effect (work from home, telecommuting, etc.) and employment density. University tours are very well explained by university enrollment numbers (which suggests these are very reliable and are in agreement with the observed university tours in the OD Survey), as well as health employment, a proxy for health science programmes.

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 complemented by the Gross Leasable Area of stores, 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) and by dwelling types: discretionary tours (which include visiting friends and family) are more attracted to detached dwellings than they are to apartments.

5.3 Pre-Mode Choice Models (Motorized vs. Non-Motorized)

In this section, we provide summaries for the tour pre-mode choice (motorized vs. non-motorized) models for tour productions and attractions. The detailed estimation results and statistics for these models are included in **Appendix B.1: 1st Progress Report.**

5.3.1 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 3.4.2** above. The model estimation results for 5 travel purposes are summarized in **Table 5-4** below. All variables relate to the non-motorized utility while motorized 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 non-motorized. 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.

Share of non-motorized tours is explained by variables such as car sufficiency (the lower is car sufficiency the higher is the non-motorized travel probability), population age (people of age of 45 and older are more inclined to non-motorized travel), densities of population, employment and retail employment (higher densities produce more non-motorized travel), percentage of low-income households (more inclined to non-motorized travel) and percentage of detached houses (logical negative effect).

The share of non-motorized school and university tours proved, as expected, to be better explained by variables at the superzone level than at the TAZ level. Presence of university / school in the superzone logically creates more non-motorized travel produced by the residents. For university tours, it is also a manifestation of the residential self-choices of students living in rent apartments.

The low-income household coefficient differs between Quebec and Ontario but it is noted that the low-income threshold has been defined differently in each case (average vs. based on household size as was explained in **Subsection 2.2.4.4 above**).

Table 5-4 Estimation results for binary pre-mode choice model for tour productions

Variable	Non-motorized utility coefficients by travel purpose				
	Work	University	School	Maintenance	Discretionary
Non-motorized constant	-3.1665	-2.0593	-2.3559	-2.8112	-1.7515
Zero car household	1.1410	0.9320		1.6036	1.1100
At least one car, cars fewer than workers	0.6245			0.3815	0.3079
At least one car, cars greater than workers	-0.3331		-0.3270	-0.3663	-0.1281
TAZ % population of 45 years old or older	1.5465			1.1240	
TAZ population density	0.0038			0.0032	
TAZ retail & service density				0.0104	0.0057
Superzone population density		0.0165	0.0276	0.0098	0.0108
Superzone product of population and employment densities	0.0130				
Superzone % low-income HHs in Ontario	0.7495				
Superzone % low-income HHs in Quebec	0.1749				
Superzone % detached houses	-1.6443	-1.8715		-0.8618	-0.5328
Superzone university enrollment		0.0001			
Superzone school enrollment			0.0004		

5.3.2 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 3.4.3** above. The model estimation results for 5 travel purposes are summarized in **Table 5-5** below. As for the pre-mode choice model for tour production described in the previous subsection, all variables relate to the non-motorized 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 5-5 Estimation results for binary pre-mode choice model for tour attractions

Variable	Non-motorized utility coefficients by travel purpose				
	Work	University	School	Maintenance	Discretionary
Non-motorized constant	-2.6777	-3.0154	-1.5997	-2.8578	-2.1027
CBD dummy	0.2650				
TAZ population density		0.0065	0.0085	0.0155	0.0095
TAZ retail & service density				0.0015	
TAZ university enrolment		0.00001			
TAZ school enrollment			-0.00005		
Superzone population density		0.0165	0.0015	0.0063	0.0043
Superzone product of population and employment densities	0.0048				
Superzone retail & service density					0.0018
Superzone % detached houses	-0.6076			-0.2369	

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

The share of non-motorized school and university tours proved, as expected, to be affected by the enrollment variables at the TAZ level rather than at the superzone level, since for attractions, the modelled TAZ characteristics are important. (Contrary to that for the pre-mode choice model for productions discussed in the previous subsections, enrollment characteristics of the neighbouring TAZ have effect on the population behaviour in the given zone). Presence of university in the TAZ logically creates more non-motorized travel for university purpose attracted to this zone through the student residential self choice. School enrollment in the TAZ has a negative effect since large schools attract more motorized travel (having a bigger "catchment" radius).

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

In this section, we provide summaries for the time-of-day and stop frequency choice models for tour productions and attractions. The detailed estimation results and statistics for these models are included in **Appendix B.2: 2nd Progress Report.**

5.4.1 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 3.5.1** 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 5 travel purposes are summarized in **Tables 5-6** through **5-10** below.

Table 5-6 Estimation results for TOD & stop-frequency choice for work tour productions

Variables	TOD Outbound					TOD Inbound					Duration				Stops	
	Early	**AM**	**MD**	**PM**	**NT**	**Early**	**AM**	**MD**	**PM**	**NT**	**Very Short**	**Short**	**Med**	**Long**	**Outbound**	**Inbound**
Constant No Stop	0.0000	3.2124	2.5030	1.3277	3.3489	0.9567	-0.5278	1.3421	1.6918							
With Stop	-3.0297	0.8455	-0.1617	-2.0617	-0.1873	-999.0	-4.0098	-0.3610	0.0696							
Both Stop															1.6017	
Duration Dummy											0.0000	0.7855	1.9621	1.6815		
Zero Car HH	-999.0					-999.0	-0.8668	-0.5417	-0.4790						-0.8353	-0.1216
Car Sufficiency Low								-0.1473							0.0886	-0.1753
Car Sufficiency High		-0.0583	0.3110	0.3830	0.1060	0.9266	0.7626	0.0462	-0.1918						-0.3148	-0.2279
Zonal Characteristics																
Population Density		0.0041	0.0060	0.0076	0.0044											-0.0021
% Low Income HH in Ontario		-2.0351	-0.8720									0.8626	1.0343	1.2166		-0.2512
% Low Income HH in Quebec		-3.0469	-2.7922	-1.2458	-1.2458							0.7561	0.7961	0.9067		-0.8385
% Detached HH						-1.0569	-0.4346	-0.3196	-0.0214							
Super Zonal Characteristics																
% Detached HH		-1.2624	-1.5047	-1.0392	-1.5077											
District Characteristics																
Retail Density																0.0055

Table 5-7 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**	**Very Short**	**Short**	**Med**	**Long**	**Outbound**	**Inbound**
Constant No Stop		2.8656	2.2865	0.7154	1.1967	-2.0374	-3.9539	-0.5453	-0.1029							
With Stop	-1.4524	-0.0395	-0.9872	-2.5560	-2.5825	-999.000	-999.000	-3.3543	-2.1654							
Both Stop															1.1215	
Duration												0.2629	-0.1671	-1.0120		
Zero Car HH		-1.1905	-1.1019	-0.9836	-2.3975	-999.000	-999.000	0.4563	0.2741							
Car Sufficiency Low						-999.000										-0.7668
Car Sufficiency High								0.2954	0.3051							
Zonal Characteristics																
Population Density		0.0181	0.0224	0.0230	0.0202											
% Low Income HH in Ontario					-2.3934											
% Low Income HH in Quebec			-1.4465		-5.6908											
District Characteristics																
Retail Density																0.0095
% Low Income HH in Quebec				-0.9795	4.0752											

Table 5-8 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	Very Short	Short	Med	Long	Outbound	Inbound
Constant No Stop		3.9692	0.7324	-1.1492	-1.4030	-0.6346	-4.6508	1.0541	1.3093							
With Stop	-1.0585	-0.3334	-3.0110	-5.6208	-999.000	-999.000	-6.6700	-2.6651	-1.0356							
Both Stop															1.7847	
												0.1294	-0.5395	-2.0671		
Zero Car HH				-999.00	-999.000	-999.000	-999.000								-1.3272	
Car Sufficiency Low															-0.4714	
Zonal Characteristics																
Population Density		0.0109	0.0115			-0.0169										
Super Zonal Characteristics																
Retail Density															0.0130	0.0058
District Characteristics																
Population Density		0.0074	0.0195	0.0370	0.0420										0.0044	0.0097
% Low Income HH in Ontario								-1.9523								
% Low Income HH in Quebec								-3.5918								

Table 5-9 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	Very Short	Short	Med	Long	Outbound	Inbound
Constant No Stop		2.23739	3.75251	3.80565	4.59741	1.02440	0.90854	0.65897	0.05215							
With Stop	-1.85673	0.53048	2.04055	1.43887	1.90285	-2.81653	-1.65615	-0.74303	-1.25465							
Both Stop															0.65417	
Duration Dummy												0.00000	-1.14275	-1.14275		
Zero Car HH						-999.000	-1.35194	1.69128	1.09159						-0.35065	-0.44398
Car Sufficiency Low																
Car Sufficiency High						-0.66220	0.23923	1.56735	0.93389							
Zonal Characteristics																
Population Density							0.00247	0.00035	-0.00002							
% Low Income HH in Ontario															0.20952	0.13953
% Low Income HH in Quebec															-0.18014	-0.44815
District Characteristics																
School Enrollments		0.000134	0.000187	0.000192	0.000208	0.000166	0.000065									

Table 5-10 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	Long	Outbound	Inbound
Constant No Stop	0.0000	1.2947	2.8422	4.0041	5.3911	0.4168	0.3189	0.8666	-0.6809							
With Stop	-2.9294	-0.9707	0.2715	1.4268	1.9474	-999.000	-3.2714	-1.2474	-2.7626							
Both Stop															1.3083	
Duration Dummy												0.8928				
Zero Car HH	-999.000			-0.8786	-1.1155	-999.000	-1.3601	0.0446	0.5250						-0.2534	-0.1811
Car Sufficiency Low		-0.6430	-0.7378	-0.3628	-0.2233											
Car Sufficiency High		0.8229	1.0897				-0.1453	0.3349	0.3900							
District Characteristics																
Retail Density			0.01210	0.00345	0.00570											
School Enrollments		0.000059	0.000082	0.000093	0.000093		0.000055	0.000037	0.000037							

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. Foe 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 probability 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:

- Negative effect of high car sufficiency as well as percentage of low-income households and detached houses on outbound AM choice for work tours,

- Negative effect of zero-car and high car sufficiency as well as percentage of detached households on inbound PM choice for work tours,
- Positive impact of percentage of low-income households on the work activity duration,
- 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 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.

5.4.2 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 3.5.2** above. The model has 15 alternatives as feasible combinations of 5 outbound and 5 inbound time-of-day periods. The model estimation results for 5 travel purposes are summarized in **Tables 5-11** through **5-15** below.

Table 5-11 Estimation results for time-of-day choice model for work tour attractions

Variables	TOD Outbound					TOD Inbound					Duration			
	Early	AM	MD	PM	NT	Early	AM	MD	PM	NT	Very Short	Short	Med	Long
Constant		1.83550	1.16216	0.16603	1.52990	-0.13516	-1.00274	0.45003	1.05266			0.89629	2.03649	1.75471
CBD			4.25682				-1.14040	3.23887						
Zonal Characteristics														
% Public Offices		0.26488	-0.24428		-0.67971			0.37647	0.24668					
% Private Offices		0.52738	0.57993											
% Retail			0.85297	1.83582	1.07885			0.48855	-0.35072					
% Services			0.34952	1.37032	0.82035			0.39572	-0.30767					
% Industry														
% Health		0.27127	0.46909	0.59128	1.26656			0.49230						
%Education		0.83219	1.28425	1.99316	1.20881			0.92386						
Super Zonal Characteristics														
% Detached HH		-0.20387	-0.22671						0.22136					
District Characteristics														
Population Density			0.01255	0.01182										
Employment Density			-0.01094					-0.00823						
% Low Income HH in Ontario			-1.30304	-3.89777				0.35899	1.19441					
% Low Income HH in Quebec			-0.72432	-1.81041				0.58993	0.93900					

Table 5-12 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
Constant		3.23622	2.27653	1.63408	1.55341	-2.93503	-3.57255	-0.25648	0.09199					-0.73224
CBD														
Zonal Characteristics														
Population Density				-0.00629				0.00712						
School Enrollments								0.00038	0.00033					
Super Zonal Characteristics														
University Enrollments			0.00004				-0.00005	-0.00002	-0.00001					

Table 5-13 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
Constant		3.1775	0.6098	-1.5472	-1.8903	-3.4997	-7.0708	-2.2390	0.6345				-0.7889	-2.4536
CBD														
Zonal Characteristics														
School Enrollments		0.0008					0.0009	0.0001						
Super Zonal Characteristics														
Population Density									-0.0091					
District Characteristics														
% Detached HH								2.4548						

Table 5-14 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
Constant		2.86823	4.93444	5.36675	6.38370	2.51166	1.76047	2.11430	0.85438					
CBD		22.38260	31.55850	48.60966	59.84386		25.63548		0.45880					
Super Zonal Characteristics														
School Enrollments							0.000307	0.000037	0.000035					
District Characteristics														
Population Density		0.05494	0.06229	0.08318	0.10345		0.03341							
Retail Density		-0.17059	-0.23883	-0.36472	-0.44681		-0.18113							

Table 5-15 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
Constant		1.92872	3.71356	4.04563	5.41695	1.97426	0.75859	1.23739	-0.15737			0.92708		
CBD				-0.29080		-999.0	-1.37542	-0.86814	-0.42179					
Super Zonal Characteristics														
Retail Density								0.00412	0.00257					
School Enrollments		0.00024	0.00029	0.00031	0.00033			0.00006						
District Characteristics														
Population Density				0.00492	0.00576	-0.05170			-0.00459					

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 and Midday) while retail and service employees tend to leave workplaces earlier (in Midday rather than PM). Employees in CBD in general have a strong shift towards later starts (in Midday rather than AM). CBD proved also to be a strong generator of relatively late (from Midday through Night) maintenance tours

5.4.3 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 3.5.4** above. The model estimation results for 5 travel purposes with additional subdivision by half-tour direction are summarized in **Table 5-16** 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 except for the last five variables that relate to the superzone (four first of them) and district (the last one).

The strongest stop-attraction variables across all tour purposes and half-tour directions proved to be retail employment (as expected and in line with the tour-based models developed elsewhere) with the addition of shopping Gross Leasable Area. 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 school and university enrollment produced a significant number of stops on work, university, and school tours associated with dropping-off students at schools.

Table 5-16 Estimation results for zonal stop attraction model

Variable	Tour purpose and half-tour direction							
	Work		University		School		Mainte-nance	Discre-tionary
	Outbound	Inbound	Outbound	Inbound	Outbound	Inbound	Both	Both
Public offices employment	0.02760	0.03432	0.00255					
Retail employment / Ontario	0.12826	0.46941	0.03008	0.08494	0.01405	0.10463	0.38811	0.15450
Retail employment / Quebec	0.09259	0.36720		0.03100			0.62303	0.18018
Service employment	0.05093	0.08699					0.05456	0.03877
Health employment	0.06334	0.10926	0.00890	0.01092			0.08883	
Education employment						0.01698		
Shopping GLA / Ontario	0.00014	0.00087		0.00006			0.00155	0.00026
School enrollment	0.08277	0.05969	0.00508		0.00978	0.02623	0.07680	0.02389
University enrollment	0.02466	0.02766	0.00312	0.01131				
Detached houses	0.05689	0.06628			0.00324	0.01581	0.08030	0.03240
Apartments	0.03612	0.03802						0.02184
Retail density				0.09943				
Employment density / superzone	0.20481							
Retail density / superzone		0.50622						
Share of low-income households / superzone				22.6945				
University enrollment / superzone				0.00163				0.00244
Population density / district		2.05747				0.19028	2.71922	1.05155

5.5 Mode Choice for Motorized Trips

In this section, we provide summaries for the trip mode choice model estimated separately for AM and PM periods and by 5 travel purposes. The model ha 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 3.8.1**. The model has 9 alternatives that correspond to the modelled motorized modes groped into 4 nests. The detailed estimation results and statistics for these models are included in **Appendix B.3: 3rd Progress Report.**

5.5.1 Summary of Coefficients for Level-of-Service Variables

The model estimation results with respect to the Level-of-Service (LOS) variables like travel time an cost for 5 travel purposes are summarized in **Tables 5-17** (non scaled coefficients before nesting) and **5-18** (scaled coefficients after nesting) below. 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 (9 modes) before nesting. They reflect on the elasticities of lower-level choices between six transit modes in the transit nets (all other nests have one mode each). Scaled coefficients correspond to composite utilities of 4 nests. 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 mane 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 two innovative variables introduced in the model that relate to travel time reliability (congestion delay separated from the free-flow time for auto and the share of Transitway / rail time in the total in-vehicle time for transit) 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 though these ratios are not used in the model application per se. The following derived model parameters are of primary importance (highlighted in green 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,

- 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,

Table 5-17 Summary of estimated coefficients for LOS variables (unscaled)

Variable	**Unscaled coefficient value (lower-level choice)**				
	AM Work	**AM Univ**	**AM Scho**	**AM Main**	**AM Disc**
Free flow auto time	-0.0666	-0.0918	-0.0600	-0.0478	-0.0528
Auto delay	-0.1282	-0.0918	-0.0600	-0.0478	-0.0528
Auto & parking cost	-0.1800	-0.5500	-0.7000	-0.2668	-0.3500
Auto VOT, $/h	22.2	10.0	5.1	10.7	9.0
Auto VOR, $/h	42.7	10.0	5.1	10.7	9.0
Transit IVT	-0.0300	-0.0472	-0.0400	-0.0382	-0.0300
Fare & auto access / egress cost	-0.1800	-0.5500	-0.7000	-0.2668	-0.3500
Wait time	-0.0961	-0.1245	-0.0865	-0.1300	-0.0900
Walk time	-0.0831	-0.0732	-0.0800	-0.0587	-0.0600
# of boardings	-0.2710	-0.3000	-0.2500	-0.1500	-0.2000
Auto access time	-0.0666	-0.0918	-0.0600	-0.0478	-0.0528
Wait time weight	3.20	2.64	2.16	3.40	3.00
Walk time weight	2.77	1.55	2.00	1.54	2.00
Transfer penalty, min	9.03	6.36	6.25	3.92	6.67
Transit VOT	10.0	5.1	3.4	8.6	5.1
Bus Transit Way share	0.5684	1.5868	2.0000	0.7547	1.7508
Nesting scale	0.7311	0.5500	0.5500	0.9659	0.4601
	Unscaled coefficient value (lower-level choice)				
	PM Work	**PM Univ**	**PM Scho**	**PM Main**	**PM Disc**
Free flow auto time	-0.0685	-0.0716	-0.0600	-0.0363	-0.0570
Auto delay	-0.1411	-0.0716	-0.0600	-0.0363	-0.2972
Auto & parking cost	-0.2116	-0.3900	-0.7000	-0.1800	-0.3000
Auto VOT, $/h	19.4	11.0	5.1	12.1	11.4
Auto VOR, $/h	40.0	11.0	5.1	12.1	59.4
Transit IVT	-0.0330	-0.0458	-0.0450	-0.0208	-0.0427
Fare & auto access / egress cost	-0.2116	-0.3900	-0.7000	-0.1800	-0.3000
Wait time	-0.1018	-0.1024	-0.1297	-0.0508	-0.1297
Walk time	-0.0570	-0.0570	-0.0919	-0.0398	-0.0829
# of boardings	-0.1320	-0.2700	-0.3000	-0.0879	-0.2515
Auto access time	-0.0200	-0.0521	-0.0600	-0.0363	-0.0300
Wait time weight	3.08	2.24	2.88	2.45	3.04
Walk time weight	1.73	1.24	2.04	1.92	1.94
Transfer penalty, min	4.00	5.90	6.67	4.24	5.89
Transit VOT	9.4	7.0	3.9	6.9	8.5
Bus Transit Way share	0.1981	1.7968	2.0000	1.1300	1.2093
Nesting scale	0.8627	0.5500	0.5500	0.8834	0.4735

- 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 5-18 Summary of estimated coefficients for LOS variables (scaled)

Variable	**Scaled coefficient value (upper-level choice)**				
	AM Work	**AM Univ**	**AM Scho**	**AM Main**	**AM Disc**
Free flow auto time	-0.0487	-0.0505	-0.0330	-0.0462	-0.0243
Auto delay	-0.0937	-0.0505	-0.0330	-0.046162	-0.0243
Auto & parking cost	-0.1316	-0.3025	-0.3850	-0.2577	-0.1611
Auto VOT, $/h	22.2	10.0	5.1	10.7	9.0
Auto VOR, $/h	42.7	10.0	5.1	10.7	9.0
Transit IVT	-0.0219	-0.0260	-0.0220	-0.03693	-0.0138
Fare & auto access / egress cost	-0.1316	-0.3025	-0.3850	-0.2577	-0.1611
Wait time	-0.0702	-0.0685	-0.0476	-0.125569	-0.0414
Walk time	-0.0607	-0.0403	-0.0440	-0.056692	-0.0276
# of boardings	-0.1981	-0.1650	-0.1375	-0.1449	-0.0920
Auto access time	-0.0487	-0.0505	-0.0330	-0.0462	-0.0243
Wait time weight	3.20	2.64	2.16	3.40	3.00
Walk time weight	2.77	1.55	2.00	1.54	2.00
Transfer penalty, min	9.03	6.36	6.25	3.92	6.67
Transit VOT	10.0	5.1	3.4	8.6	5.1
Bus Transit Way share	0.4156	0.8727	1.1	0.728943	0.8056
Nesting scale	0.7311	0.5500	0.5500	0.9659	0.4601

	Scaled coefficient value (upper-level choice)				
	PM Work	**PM Univ**	**PM Scho**	**PM Main**	**PM Disc**
Free flow auto time	-0.0591	-0.0394	-0.0330	-0.0321	-0.0270
Auto delay	-0.1218	-0.0394	-0.0330	-0.0321	-0.1407
Auto & parking cost	-0.1825	-0.2145	-0.3850	-0.1590	-0.1421
Auto VOT, $/h	19.4	11.0	5.1	12.1	11.4
Auto VOR, $/h	40.0	11.0	5.1	12.1	59.4
Transit IVT	-0.0285	-0.0252	-0.0248	-0.0183	-0.0202
Fare & auto access / egress cost	-0.1825	-0.2145	-0.3850	-0.1590	-0.1421
Wait time	-0.0878	-0.0563	-0.0713	-0.0449	-0.0614
Walk time	-0.0492	-0.0314	-0.0505	-0.0352	-0.0393
# of boardings	-0.1139	-0.1485	-0.1650	-0.0777	-0.1191
Auto access time	-0.0173	-0.0287	-0.0330	-0.0321	-0.0142
Wait time weight	3.08	2.24	2.88	2.45	3.04
Walk time weight	1.73	1.24	2.04	1.92	1.94
Transfer penalty, min	4.00	5.90	6.67	4.24	5.89
Transit VOT	9.4	7.0	3.9	6.9	8.5
Bus Transit Way share	0.1709	0.9882	1.1000	0.9982	0.5726
Nesting scale	0.8627	0.55	0.55	0.8834	0.4735

Enforced values

Pooled values

Coefficients and values for auto LOS are shared between auto driver and passenger modes. Cost variables (operating and parking) for the auto passenger modes are halved. Coefficients and values for most transit LOS variables are shared between six transit modes.

The estimation results are similar between AM and PM periods and consistent for both of them. 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.

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 1.2-2.8 minutes of in-vehicle time depending on travel purpose and TOD,
- 1 minute of wait time is perceived as 2.3-3.4 minutes of in-vehicle time depending on travel purpose and TOD,
- 1 transfer adds 4.0-9.0 minutes of perceived extra penalty to the calculated transit time.

Overall, the choice of auto modes (driver and passenger) is more sensitive to travel time changes than that of transit since the auto time coefficient is large (in absolute terms) than the transit in-vehicle time coefficient for all purposes and TOD periods. 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.

A rail bias was observed for work trips and modelled through alternative (mode) specific constants and other coefficients (for example differential car ownership impacts). Currently those constants are very different; this however might be a consequence of the limited dataset associated with the existing rail service operating in the region. In the model application for large-scale rail projects several adjustments will be made including a re-estimation of the combined Transitway and rail reliability index.

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 cost 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 $12/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) except for work purpose (where it was allowed to take a higher value) and school purpose (where a lower value was assumed).

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, Transitway 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 university, school, and discretionary purposes have a strong nesting coefficient close to 0.5. This indicates that the mode considerations of transit sub-modes are different from the preferences between transit and other modes. It means, that if anew 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 and maintenance purposes.

5.5.2 Mode Choice Estimation Results for AM period

The model estimation results with all mode utility coefficients for 5 travel purposes for AM period are summarized in **Tables 5-19** through **5-23** below.

Table 5-19 Estimation results for mode choice model for work trips in AM period

AM Work	**Driver**	**Passenger**	**Bus**			**Rail**			**School Bus**
			Walk	**PNR**	**KNR**	**Walk**	**PNR**	**KNR**	
ASC	0.0000	-3.7582	-1.1593	-4.6124	-4.9030	-2.6892	-4.6600	-4.9045	0.0000
Driving Modes									
Free Flow Time	-0.0666								
Hwy Delay	-0.1282								
Hwy Cost ($) + Parking Cost	-0.1800								
Transit									
IVTT			-0.0300						
Fare + Drive Access Cost ($)			-0.1800						
Wait Time			-0.0961						
Walk Time			-0.0831						
# Boardings			-0.2710						
Access Time			-0.0666						
Bus TWShare			0.5684						
Rail Path Ratio							-0.8491		
Car Ownership									
Zero	-999.0000	0.0000	2.4341	-999.0000	2.4341	4.0618	-999.0000	4.0618	
Low		1.9008	1.7287		2.3290	2.3991		3.2701	
High		-0.4647	-0.3638			-0.3638			
Zonal									
% Low Income HH			1.0902						
Superzonal									
% Detached HH				1.6230			1.6230		
Employment Density		0.0013	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	
Nesting Coefficient	0.7311	0.7311	0.7311						
Likelihood at Zero Coefficients	-64,402.3								
Likelihood at Constants	-14,060.4								
Likelihood of MNL	-11,771.5								
Final Likelihood	-11,754.6								

In addition to the LOS variables discussed in **Subsection 5.5.2** above, for work trips in the AM period, a strong car-sufficiency impact should be mentioned. Zero-car households strongly favour transit, while low-car-sufficiency households favour transit and auto passenger modes. Additionally, low-income households logically favour walk-to-bus mode and low-density residential areas (with a high percentage of detached houses) favour Park-and-Ride. Higher employment density at the destination (workplace) end logically has a positive impact on propensity to use all transit modes and auto passenger mode compared to the auto driver mode.

Table 5-20 Estimation results for mode choice model for university trips in AM period

Model Results	Driver	Passenger	Bus			Rail			School Bus
			Walk	PNR	KNR	Walk	PNR	KNR	
ASC	0.0000	-2.1439	3.0809	0.3775	-8.4476	3.6378	2.1954	-999.0000	0.0000
Driving Modes									
Free Flow Time	-0.0918								
Hwy Delay	-0.0918								
Hwy Cost ($)	-0.5500								
Parking Cost ($)	-0.5500								
Distance									
Transit									
IVTT			-0.0472						
Fare ($)			-0.5500						
Wait Time			-0.1245						
Walk Time			-0.0732						
# Boardings			-0.3000						
Access Time			-0.0918						
Transit Way Share			1.5868						
Rail Path Ratio							-2.0000		
Car Ownership									
Zero	-999.0000			-999.0000			-999.0000		
Low		1.7835	1.5485						
High		-1.4773	-1.6054						
Zonal									
% Detached HH					8.7657				
University Enrollments			0.000049						
District									
Population Density			0.0187	-0.1092					
Nesting Coefficient									
All Nests - level1	0.5500	0.5500	0.5500						
Likelihood at Zero Coefficients	-4273.2								
Likelihood at Constants	-1206.5								
Final Likelihood	-1112.9								

In addition to the LOS variables discussed in **Subsection 5.5.2** above, for university trips in the AM period, a strong car-sufficiency impact should be mentioned. Zero-car households cannot use auto driver and park-and-ride modes. Low-car-sufficiency households favour transit and auto passenger modes. Low-density residential areas (with a high percentage of detached houses) strongly favour Park-and-Ride. 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-bus mode. Logically, travel behaviour of university students is not dependent on the household income.

In addition to the LOS variables discussed in **Subsection 5.5.2** above, for school trips in the AM period, 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 rail) are not observed and hence excluded. Low-car-sufficiency households favour walk-to-bus, auto passenger, and school bus modes while high-car-sufficiency households strongly disfavour them. Additionally, low-income households prefer school bus and rarely give an auto ride to children. Residential population density has a certain positive impact on use of the auto passenger mode. Logically, households living in detached houses (presumably in low-density areas) strongly rely on school bus.

Table 5-21 Estimation results for mode choice model for school trips in AM period

AM School	Driver	Passenger	Bus			Rail			School Bus
			Walk	PNR	KNR	Walk	PNR	KNR	
ASC	0.0000	4.3746	8.3687	0.8381	5.8193	9.0375	-999.0000	12.5757	0.2936
Driving Modes									
Free Flow Time	-0.0600								
Hwy Delay	-0.0600								
Hwy Cost ($)	-0.7000								
Parking Cost ($)	-0.7000								
Distance									-0.0936
Transit									
IVTT			-0.0400						
Fare ($)			-0.7000						
Wait Time			-0.0865						
Walk Time			-0.0800						
# Boardings			-0.2500						
Access Time			-0.0600						
Transit Way / Rail Share			2.0000						
Rail Path Ratio							-4.9289		
Car Ownership									
Zero	-999.0000			-999.0000					
Low		0.8462	1.4955						1.3880
High		-2.9005	-3.4412		-3.3437				-3.1454
Zonal									
% Low Income HH		-5.0467							0.4474
School Enrollments		0.0005	0.0013						0.0011
Superzonal									
Population Density									-0.0078
District									
Population Density		0.0547							
% Detached HH									5.2780
Nesting Coefficient									
All Nests - level1	0.5500	0.5500	0.5500						
Likelihood at 0 Coefficients	-13765.2								
Likelihood at Constants	-4311.1								
Final Likelihood	-4183.5								

Table 5-22 Estimation results for mode choice model for maintenance trips in AM period

AM Maintenance	Driver	Passenger	Bus			Rail			School Bus
			Walk	PNR	KNR	Walk	PNR	KNR	
ASC	0.0000	-2.8670	-2.9695	-5.1600	-999.0	-999.0	-999.0	-999.0	-999.0
Driving Modes									
Free Flow Time	-0.0478								
Hwy Delay	-0.0478								
Hwy Cost ($) + Parking Cost	-0.2668								
Distance									0.0000
Transit									
IVTT			-0.0382						
Fare + Drive Access Cost ($)			-0.2668						
Wait Time			-0.1300						
Walk Time			-0.0587						
# Boardings			-0.1500						
Access Time			-0.0478						
Bus TWShare			0.7547						
Rail Path Ratio									
Car Ownership									
Zero	-999.0	-	3.2375	-999.0			-999.0		
Low			0.8387						
High									
Zonal									
% Low Income HH			2.2305						
Employment Density		0.00057							
Nesting Coefficient	0.9659	0.9659	0.9659						
Likelihood at 0 Coefficients	-9710.8								
Likelihood at Constants	-1017.7								
Likelihood of MNL	-862.01								
Final Likelihood	-862.01								

In addition to the LOS variables discussed in **Subsection 5.5.2** above, for maintenance trips in the AM period, a strong car-sufficiency impact should be mentioned. Zero-car households cannot use auto driver and park-and-ride modes. They strongly favour walk-to-bus mode. Low-car-sufficiency households also somewhat favour walk-to-bus mode. Low-income households strongly prefer walk-to-bus mode. Higher employment density at the trip destination enhances propensity to use auto passenger mode. In general, there is very low frequency of using Park-and-Ride and Kiss-and-Ride modes because of comparatively short trip distances and other factors common for shopping and escorting trips in all metropolitan regions.

Table 5-23 Estimation results for mode choice model for discretionary trips in AM period

AM Discretionary	**Driver**	**Passenger**	**Bus**			**Rail**			**School Bus**
			Walk	**PNR**	**KNR**	**Walk**	**PNR**	**KNR**	
ASC	0.00	-3.4198	-3.4286	-5.8275	-5.5185	-999.0	-999.0	-999.0	0.0
Driving Modes									
Free Flow Time	-0.0528								
Hwy Delay	-0.0528								
Hwy Cost + Parking ($)	-0.3500								
Distance									0.0000
Transit									
IVTT			-0.0300						
Fare and Drive Access Cost ($)			-0.3500						
Wait Time			-0.0900						
Walk Time			-0.0600						
# Boardings			-0.2000						
Access Time			-0.0528						
Bus TW / Rail Share			1.7508						
Rail Path Ratio									
Car Ownership									
Zero	-999.0		1.5063	-999.0	-999.0		-999.0		
Low (Including Zero)									
High		-0.7794	-2.9864		-2.5138				
Zonal									
% Low Income HH			4.4778						
Superzonal									
Employment Density			0.0031	0.0031	0.0031				
District									
Population Density				-0.1898					
Nesting Coefficient	0.4601	0.4601	0.4601						
Likelihood at 0 Coefficients	-4168.4								
Likelihood at Constants	-740.8								
Likelihood of MNL	-669.7								
Final Likelihood	-664.5								

In addition to the LOS variables discussed in **Subsection 5.5.2** above, for discretionary trips in the AM period, a strong car-sufficiency impact should be mentioned. Zero-car households cannot use auto driver and park-and-ride modes. They strongly favour walk-to-bus mode. High-car-sufficiency households strongly disfavour walk-to-bus and Kiss-and-Ride bus modes. Low-income households have a very strong propensity to use the walk-to-bus mode. There is a certain positive impact of employment density at the trip destination end on use of all bus-based modes. Similar to maintenance trips, there is a low observed frequency of using Park-and-Ride and Kiss-and-Ride options in general.

5.5.3 Mode Choice Estimation Results for PM period

The model estimation results with all mode utility coefficients for 5 travel purposes for PM period are summarized in **Tables 5-24** through **5-28** below.

Table 5-24 Estimation results for mode choice model for work trips in PM period

PM Work	Driver	Passenger	Bus			Rail			School Bus
			Walk	PNR	KNR	Walk	PNR	KNR	
ASC	0.0000	-3.1667	-1.1886	-5.1176	-5.7302	-2.8078	2.5051	3.4865	0.0000
Driving Modes									
Free Flow Time	-0.0685								
Hwy Delay	-0.1411								
Hwy Cost ($) + Parking Cost	-0.2116								
Distance									0.0000
Transit									
IVTT			-0.0330						
Fare + Drive Access Cost ($)			-0.2116						
Wait Time			-0.1018						
Walk Time			-0.0570						
# Boardings			-0.1320						
Access Time			-0.0200						
Bus TW / Rail Share			0.1981						
Rail Path Ratio							-6.8229		
Car Ownership									
Zero	-999.0	0.0000	2.1993	-999.0000	2.4041	3.5569	-999.0000	2.4041	
Low		1.4990	1.5660		1.8900	2.1776			
High		-0.39880	-0.34304	-0.4089	-0.4591	-0.34304	-0.4089	-0.4591	
Zonal									
% Low Income HH			0.4535						
Superzonal									
Population Density			0.0035						
% Detached HH				1.5080			1.5080		
Employment Density		0.00103	0.00127	0.00127	0.00127	0.00127	0.00127	0.00127	
Nesting Coefficient	0.8627	0.8627	0.8627						
Likelihood at 0 Coefficients	-69053.4								
Likelihood at Constants	-14493.3								
Likelihood of MNL	-12046.0								
Final Likelihood	-12044.0								

In addition to the LOS variables discussed in **Subsection 5.5.2** above, for work trips in the PM period, a strong car-sufficiency impact should be mentioned. Zero-car households strongly favour transit, while low-car-sufficiency households favour transit and auto passenger modes. Additionally, low-income households logically favour walk-to-bus mode and low-density residential areas (with a high percentage of detached houses) favour Park-and-Ride. Higher employment density at the origin (workplace) end logically has a positive impact on propensity to use all transit modes and auto passenger mode compared to the auto driver mode. All these effects are symmetric to the factors driving mode choice for work trips in the AM period. Additionally, there is a direct positive effect of population density at the destination (residential) end on use of walk-to-bus mode.

Table 5-25 Estimation results for mode choice model for university trips in PM period

Model Results	Driver	Passenger	Bus			Rail			School Bus
			Walk	PNR	KNR	Walk	PNR	KNR	
ASC	0.0000	-2.5364	1.9216	-1.5909	-2.7968	1.8215	4.5356	-999.0000	0.0000
Driving Modes									
Free Flow Time	-0.0716								
Hwy Delay	-0.0716								
Hwy Cost ($)	-0.3900								
Parking Cost ($)	-0.3900								
Distance									
Transit									
IVTT			-0.0458						
Fare ($)			-0.3900						
Wait Time			-0.1024						
Walk Time			-0.0570						
# Boardings			-0.2700						
Access Time			-0.0521						
Transit Way Share			1.7968						
Rail Path Ratio							-5.9806		
Car Ownership									
Zero	-999.0000			-999.0000					
Low		1.2700	1.5170		1.7875				
High		-1.8763	-1.7167		-1.9059				
Zonal									
% Detached HH					1.5417				
University Enrollments			0.000075						
District									
Population Density			0.0211	-0.0276					
Nesting Coefficient									
All Nests	0.5500	0.5500	0.5500						
Likelihood at Zero Coefficients	-4712.2								
Likelihood at Constants	-1249.4								
Final Likelihood	-1120.1								

In addition to the LOS variables discussed in **Subsection 5.5.2** above, for university trips in the PM period, a strong car-sufficiency impact should be mentioned. Zero-car households cannot use auto driver and park-and-ride-bus modes. Low-car-sufficiency households favour transit, auto passenger and Kiss-and-Ride bus modes. Low-density residential areas (with a high percentage of detached houses) strongly favour Park-and-Ride. Higher population density at the trip destination (residential) end and the size of the university at the trip origin end positively enhance propensity to use walk-to-bus mode. Logically, travel behaviour of university students is not dependent on the household income. All these effects are symmetric to the factors driving mode choice for university trips in the AM period.

In addition to the LOS variables discussed in **Subsection 5.5.2** above, for school trips in the PM period, 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 rail) are not observed and hence excluded. Low-car-sufficiency households favour walk-to-bus, auto passenger, and school bus modes while high-car-sufficiency households strongly disfavour them. Additionally, low-income households prefer school bus and rarely give an auto ride to children. Residential population density has a certain positive impact on use of the auto passenger mode. Logically, households living in detached houses (presumably in low-density areas) strongly rely on school bus and also pick-up children from school more frequently. All these effects are symmetric to the factors driving mode choice for school trips in the AM period.

Table 5-26 Estimation results for mode choice model for school trips in PM period

Model Results	Driver	Passenger	Bus			Rail			School
			Walk	PNR	KNR	Walk	PNR	KNR	Bus
ASC	0.0000	2.1359	8.8188	2.6712	5.0252	9.0278	-999.0000	12.8482	-1.7033
Driving Modes									
Free Flow Time	-0.0600								
Hwy Delay	-0.0600								
Hwy Cost ($)	-0.7000								
Parking Cost ($)	-0.7000								
Distance									
Transit									
IVTT			-0.0450						
Fare ($)			-0.7000						
Wait Time			-0.1297						
Walk Time			-0.0919						
# Boardings			-0.3000						
Access Time			-0.0600						
Transit Way Share			2.0000						
Rail Path Ratio							-4.9453		
Car Ownership									
Zero	-999.0000			-999.0000					
Low		1.7348	2.5448						2.5432
High		-2.6403	-3.5178		-2.7762				-3.0252
Zonal									
% Low Income HH		-2.0967							0.8885
School Enrollments		0.0006	0.0018						0.0017
District									
Population Density		0.0428							
% Detached HH		1.9089							4.5375
Nesting Coefficient									
All Nests	0.5500	0.5500	0.5500						
Likelihood at Zero Coefficients	-8052.7								
Likelihood at Constants	-2646.5								
Final Likelihood	-2649.6								

Table 5-27 Estimation results for mode choice model for maintenance trips in PM period

PM Maintenance	Driver	Passenger	Bus			Rail			School
			Walk	PNR	KNR	Walk	PNR	KNR	Bus
ASC	0.0000	-1.5684	-2.8097	-7.0552	-7.9553	-999.0000	-999.0000	-999.0000	-999.0000
Driving Modes									
Free Flow Time	-0.0363								
Hwy Delay	-0.0363								
Hwy Cost ($) + Parking Cost	-0.1800								
Distance									0.0000
Transit									
IVTT			-0.0208						
Fare + Drive Access Cost ($)			-0.1800						
Wait Time			-0.0508						
Walk Time			-0.0398						
# Boardings			-0.0879						
Access Time			-0.0363						
Bus TW / Rail Share			1.1300						
Rail Path Ratio							0.0000		
Car Ownership									
Zero	-999.0000	0.0000	3.8346	-999.0000			-999.0000		
Low		0.1049	0.4776	-999.0000					
High									
Superzonal									
Population Density		-0.0058							
% Detached HH		-0.5935	-0.9487						
District									
Employment Density			0.0043	0.0043	0.0043				
Nesting Coefficient	0.8834	0.8834	0.8834						
Likelihood at 0 Coefficients	-28174.36								
Likelihood at Constants	-4131.34								
Likelihood of MNL	-3659.21								
Final Likelihood	-3659.12								

In addition to the LOS variables discussed in **Subsection 5.5.2** above, for maintenance trips in the PM period, a strong car-sufficiency impact should be mentioned. Zero-car households cannot use auto driver and park-and-ride modes. They strongly favour walk-to-bus mode. Low-car-sufficiency households also somewhat favour walk-to-bus (and auto passenger) mode. Higher employment density at the trip destination enhances propensity to use all bus-based modes. In general, there is very low frequency of using Park-and-Ride and Kiss-and-Ride modes because of comparatively short trip distances and other factors common for shopping and escorting trips in all metropolitan regions. Most of these effects are symmetric to the factors affecting mode choice for maintenance trips in the AM period. In addition to that, there is a strong negative impact of low population density (percentage of detached houses) at the trip destination (residential) end on use of auto passenger mode (somewhat offset by the direct negative impact of population density.

Table 5-28 Estimation results for mode choice model for discretionary trips in PM period

PM Discretionary	**Driver**	**Passenger**	**Bus**			**Rail**			**School**
			Walk	**PNR**	**KNR**	**Walk**	**PNR**	**KNR**	**Bus**
ASC	0.0000	-3.9090	-2.0180	-5.5003	-7.0964	-2.3485	4.5151	3.9804	0.0000
Driving Modes									
Free Flow Time	-0.0570								
Hwy Delay	-0.2972								
Hwy Cost + Parking ($)	-0.30000								
Distance									0.0000
Transit									
IVTT			-0.0427						
Fare +Drive Access Cost ($)			-0.3000						
Wait Time			-0.1297						
Walk Time			-0.0829						
# Boardings			-0.2515						
Access Time			-0.0300						
Bus TW / Rail Share			1.2093						
Rail Path Ratio							-9.8		
Car Ownership									
Zero	-999.0000	-	3.5695	-999.0000	3.4436	3.8131	-999.0000	3.4436	
Low		1.3088	1.9685	0.7297	2.2670	1.9725	4.0938	4.6285	
High			-0.6995	-0.8635	-0.8491			-0.8491	
Zonal									
% Low Income HH			1.5203						
Superzonal									
Population Density			0.0051			0.0114			
Employment Density		0.0002	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	
Nesting Coefficient	0.4735	0.4735	0.4735						
Likelihood at 0 Coefficients	-124885.6								
Likelihood at Constants	-27614.0								
Likelihood of MNL	-24718.0								
Final Likelihood	-24589.4								

In addition to the LOS variables discussed in **Subsection 5.5.2** above, for discretionary trips in the PM period, a strong car-sufficiency impact should be mentioned. Zero-car households cannot use auto driver and park-and-ride modes. They strongly favour walk-to-bus, walk-to-rail, and Kiss-and-Ride modes. Similar preferences are observed for low-car-sufficiency households with the addition of auto passenger and kiss-and-ride modes. Low-income households have a very strong propensity to use the walk-to-bus mode. Population density at the trip destination (residential) end additionally enhances propensity to use walk-to-bus mode. There is a certain positive impact of employment density at the trip origin end on use of all transit modes.

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.

The following components of the tour/trip distribution require calibration of dispersion factors:

- Dispersion coefficients used in the auxiliary gravity component in the smoothing procedure for seed matrices (explained in **Subsection 3.6.1** above),
- Dispersion coefficients used in the gravity component of the hybrid gravity-balancing model for construction of tour end matrices (explained in **Subsection 3.6.2** above),
- Dispersion coefficients used to regulate route deviation from the shortest path for stop location on chained half-tours (explained in **Subsection 3.7.3** 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 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 target values of average tour length and the corresponding values of dispersion coefficients are shown in **Table 5-29** below (including both direct and chained tours).

Table 5-29 Targets and calibrated dispersion coefficients for the gravity model components

Travel purpose	Average tour length (min of free-flow auto time)	Dispersion coefficient
Work	14.5	-0.105
University	11.2	-0.125
School	11.7	-0.235
Maintenance	9.8	-0.205
Discretionary	11.8	-0.135

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.

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 **Table 5-30** 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 5-30 Targets and calibrated dispersion coefficients for the stop-location model

Travel purpose	Average tour length (minutes of free-flow auto time)	Observed route deviation for stops		Dispersion Coefficient			
				Outbound		Inbound	
		Outbound	Inbound	Home end	Destine end	Home end	Destine end
Work	14.5	1.51	1.54	-0.200	-0.080	-0.190	-0.070
University	11.2	1.63	1.68	-0.140	-0.070	-0.130	-0.060
School	11.7	1.57	1.95	-0.220	-0.140	-0.170	-0.090
Maintenance	9.8	1.86	1.74	-0.190	-0.110	-0.190	-0.110
Discretionary	11.8	1.67	1.63	-0.190	-0.110	-0.190	-0.110

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 Trip Assignment

5.7.1 Auto assignment

Auto assignment procedures used at different stages of the integrated "mode choice – assignment" model are described in **Subsection 3.9.1** above. The auto assignment algorithm ("static user equilibrium") is built-in in the EMME package and does not require any specific parameters except for specification of the volume-delay functions 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 stopping criteria applied according to the strategy described in **Subsection 3.9.1** 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 link volumes. As the result, the auto assignment loop normally terminates having achieved the pre-specified gap.

5.7.2 Transit assignment

Transit assignment procedures used at different stages of the integrated “mode choice – assignment” model are described in **Subsection 3.9.2** above. The transit assignment algorithm (“optimal strategies”) is built-in in the EMME package. It requires several path-building parameters (weights applied for walk and wait time as well as boarding/transit penalties) as well as sources for calculation of in-vehicle, walk, and wait times. The parameters of transit assignment and sources for there calibration are summarized in **Table 5-31** below. Transit assignments are distinguished between bus-only assignment and rail-with-bus 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 5.5.1** above.

Table 5-31 Transit Assignment Parameters

Parameter	Bus	Rail	Calibration source
In-vehicle time for bus modes (o,s)	Transit Time Function (TTF) as function of auto time (mixed traffic) or predetermined (for Transitway)	Transit Time Function (TTF) as function of auto time (mixed traffic) or predetermined (for Transitway)	Prevailing practice, TRANS calibration
In-vehicle time for rail mode (r)		Predetermined TTF	Prevailing practice
Auxiliary pedestrian mode (p)	Speed 5 km/h	Speed 5 km/h	Prevailing practice
Source for wait time	Headway with max	Headway with max	Prevailing practice
Maximum	30 min	30 min	Prevailing practice
Source for boarding time:	Extra attributes:	Extra attributes:	
- node-specific	@nboa	@nboa	TRANS calibration
- line specific	@tboa	@tboa	TRANS calibration
Wait time factor	0.5	0.5	Prevailing practice
Wait time weight	2.5	2.5	Average across travel purposes (estimated in Section 5.5.1)
Walk time weight	2.0	2.0	Average across travel purposes (estimated in Section 5.5.1)
Boarding time weight	1.0	1.0	Not required since boarding time is specified directly

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.

5.8 Validation of Model Estimates

After implementation, each component of the model system was validated against the observed statistics from the OD Survey across multiple relevant dimensions. The validation process is documented in the following appendices, as part of the model redevelopment process:

- **Appendix B.4** (The 4th Progress Report) includes validation statistics for the car ownership, tour production, and tour attraction models.
- **Appendix B.5** (The 5th Progress Report) includes validation statistics for the time-of-day choice and stop-frequency models.
- **Appendix B.6.** (The 6th Progress Report) includes validation statistics for the tour/trip distribution and trip mode choice models.

While opportunities exist to compare the model results 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 summarised form the OD survey at a regional level. This comparison is summarised in **Table 5-32 Regional Travel Demand Comparisons for the AM and PM peak Periods** 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 (-1% and -4%) and transit trips (-7% and -5%) 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. 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.

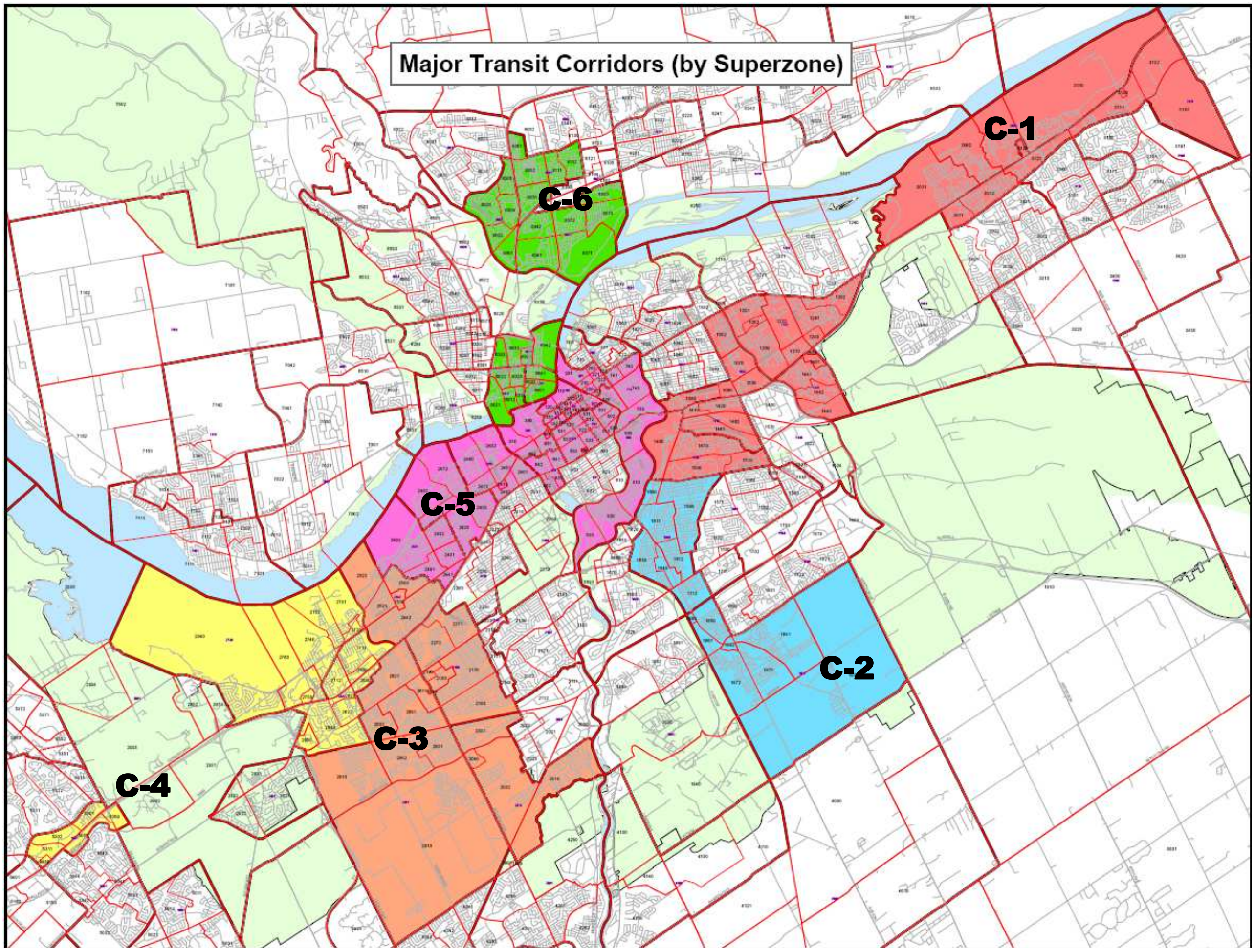
Table 5-32 Regional Travel Demand Comparisons for the AM and PM Peak Periods

Regional System-wide Travel Demands*	AM Peak Period (6:30 to 9:29 AM)			PM Peak Period (15:30 to 18:29 AM)		
	EMME Model	OD Survey	% Difference	EMME Model	OD Survey**	% Difference
Total Auto Drivers	298,400	300,700	-1%	431,800	448,800	-4%
Total Auto Passengers	68,700	62,200	11%	92,000	96,500	-5%
Average Car Occupancy	*1.23*	*1.21*		*1.21*	*1.21*	
Total Transit Trips	103,900	111,500	-7%	117,800	124,500	-5%
Transit Mode Split	*22.1%*	*23.5%*		*18.4%*	*18.6%*	

* Numbers rounded to nearest 100 trips.
** OD survey results for PM (15:30 to 18:00 PM) were factored to reflect the modelled period of 15:30 to 18:29 PM.

Model results were also aggregated and scrutinised across a number of screenline and travel corridors. The six 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. In general, OD pairs for traffic zones within each of the corridors and traffic zones within the downtown core areas (Ottawa and Gatineau) were used to provide a validation of modelled with reported travel characteristics by various travel modes. The six corridors are highlighted in the following map:

Exhibit 5.1 Major Transit/Screenline Corridors



The identification of these corridors allowed for the calibration efforts to be focused initially on a broader set of travel corridors. Also for the base year, comparisons of the modelled results with the base year data were carried out with a view of confirming key parameters to be applied within the modelling framework as part of the overall calibration efforts of the model. The two factors are briefly described as follows:

- **Scaling coefficient for congested auto assignment** which allows for the scaling of the peak period to represent the peak hour auto demand within the peak period auto demand. A number of model runs were initiated for both the AM and PM and the results analysed until the overall results reported compared well against the general travel (reported OD survey and observed traffic count statistics available at the regional level). Based on the model runs, the scaling factors identified for the 2.5 hour AM peak period to AM peak hour was 2.1 and the 3 hour PM peak period to PM peak hour was 2.5.

- **Mode-corridor-specific statistics** which facilitate calibration of travel within each of the distinct corridors previously identified as having significant transit shares. The six corridors were defined in terms of specific OD pairs within the corridors. It is note that the “other category” while not a corridor as such represents all travel not falling within any of the six corridors pre-established corridors. Also the modes analysed included access modes and therefore included Auto driver, Auto passenger, Walk to bus, P&R to bus, K&R to bus, Walk to rail, P&R to rail, K&R to rail and School bus for each of the six corridors. Several runs were undertaken for both AM and PM periods to adjust these coefficients until the modelled results within each corridor and overall become consistent with the counts and general statistics available at a regional level. The comparison of the mode specific final validation statistics for both the AM and PM peak periods are highlighted in **Table 5-33 and Table 5-34** below. As noted previously, the summary report compares modelled trips versus the OD survey reported trips by mode for each of the 6 corridors (defined in terms of Origin-Destination pairs) while the other category refers to trips not defined within any of the six predefined corridors.

  Overall the modelled travel demands remain within approximately 5% of reported travel demands for most of the corridors with the notable exception of corridors 3 and 6 for the PM peak period summary. This comparison of modelled demand and OD survey results indicates the model slightly underestimates trips within corridor from the core area (Ottawa-Gatineau CBD) to the North-South corridor (i.e. the corridor centered on Bank Street).

Table 5-32 AM Peak Mode Choice Validation- AM Peak Period

AM Peak Period Corridors*		Travel Mode with Access										Ratio Model to OD Survey
		Driver	Auto Passenger	Walk to bus	P&R Bus	K&R Bus	Walk to Rail	P&R Rail	K&R Rail	School bus	Total	
1	Model	9,800	2,900	6,100	110	250	150	1	7	235	19,500	**1.04**
	OD Survey	9,300	2,200	6,450	35	57	265	0	0	185	18,750	
2	Model	21,150	5,500	11,850	1,100	525	150	1	1	3,800	44,050	**0.97**
	OD Survey	20,850	5,500	15,350	540	425	0	0	0	2,350	45,250	
3	Model	3,050	665	1,700	120	88	140	5	2	245	5,950	**0.94**
	OD Survey	2,800	1,100	1,650	95	91	265	55	0	240	6,300	
4	Model	6,800	2,050	3,750	365	250	175	1	1	765	14,100	**0.97**
	OD Survey	7,800	2,300	3,900	135	86	130	0	0	260	14,600	
5	Model	8,350	2,150	4,200	405	230	220	0	0	1,800	17,300	**1.05**
	OD Survey	7,850	3,000	4,150	175	165	230	0	0	945	16,500	
6	Model	3,250	965	1,650	93	80	2	0	0	655	6,700	**1.06**
	OD Survey	3,150	1,100	1,550	125	20	0	0	0	390	6,350	
Other	Model	246,100	54,650	62,300	4,200	3,000	915	25	59	33,050	404,150	**1.00**
	OD Survey	243,950	46,350	67,700	4,050	2,700	730	73	100	34,950	403,150	

*Data rounding based on value; >1000 to nearest 50, >100 nearest 5, less than 100 no rounding)

Table 5-33 PM Peak Mode Choice Validation – PM Peak Period

PM Peak Period Corridors*		Travel Mode with Access										Ratio Model to OD Survey
		Driver	Auto Passenger	Walk to bus	P&R Bus	K&R Bus	Walk to Rail	P&R Rail	K&R Rail	School bus	Total	
1	Model	15,100	4,450	8,650	105	200	130	0	2	225	28,750	1.00
	OD Survey	15,350	3,800	8,350	0	41	295	0	0	77	28,750	
2	Model	32,350	6,850	13,550	550	175	85	0	1	2,100	55,650	0.98
	OD Survey	32,400	8,550	14,050	630	145	0	0	0	665	56,600	
3	Model	4,850	1,100	1,950	56	31	150	3	6	200	8,250	0.93
	OD Survey	5,400	1,200	1,900	18	15	180	21	36	125	8,900	
4	Model	9,700	2,400	4,300	160	79	96	0	5	515	17,250	0.95
	OD Survey	11,050	2,600	4,200	79	16	53	0	0	105	18,200	
5	Model	13,550	2,850	4,950	160	68	130	0	1	1,050	22,650	1.04
	OD Survey	13,150	3,500	4,350	210	21	69	0	0	455	21,750	
6	Model	4,950	1,350	2,250	87	60	2	0	0	425	9,050	0.86
	OD Survey	6,200	2,100	1,750	36	0	0	0	0	365	10,550	
Other	Model	351,450	73,150	74,250	3,350	1,700	755	23	53	20,300	524,900	0.98
	OD Survey	355,300	75,150	71,550	3,850	1,600	1,050	115	55	20,250	533,000	

*Data rounding based on value; >1000 to nearest 50, >100 nearest 5, less than 100 no rounding)

- **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 2005 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 summarised in **Table 5-34 and Table 5-35** respectively. This summary focuses on the observed (from traffic and APC counts) vs. modelled trips for auto driver (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).

Table 5-34 Regional Cordon Validation Existing Counts - AM

AM Peak Hour Inbound (peak direction) - Regional Cordons*	Auto Vehicles			Transit Riders		
	Model	Count	Ratio	Model	Count	Ratio
Interprovincial	12,500	11,800	**1.06**	5,050	4,300	**1.17**
Greenbelt	34,300	34,900	**0.98**	11,300	8,250	**1.37**
Rideau River	21,500	22,200	**0.97**	13,800	11,800	**1.17**
Ottawa Inner Area	31,700	28,100	**1.13**	22,300	18,200	**1.23**
Gatineau Inner Area	14,400	11,000	**1.31**	6,100	n/a	**n/a**
Gatineau River	11,300	7,450	**1.52**	3,600	n/a	**n/a**

*Data rounded to nearest 100
"Inbound" refers to the Peak travel direction and is in reference to Parliament Hill
"n/a" indicates observed transit counts were not available at time of review

Table 5-35 Regional Cordon Validation - PM

PM Peak Hour Outbound (peak direction) **- Regional Cordons***	**Auto Vehicles**			**Transit Riders**		
	Model	**Count**	**Ratio**	**Model**	**Count**	**Ratio**
Interprovincial	11,300	10,700	**1.06**	5,850	4,800	**1.22**
Greenbelt	33,100	32,700	**1.01**	9,000	7,050	**1.28**
Rideau River	22,200	19,400	**1.14**	11,700	8,900	**1.31**
Ottawa Inner Area	30,400	24,900	**1.22**	19,500	15,000	**1.30**
Gatineau Inner Area	9,700	6,800	**1.43**	7,100	n/a	**n/a**
Gatineau River	9,400	8,500	**1.11**	3,950	n/a	**n/a**

*Data rounded to nearest 100
"Outbound" refers to the Peak travel direction and is in reference to Parliament Hill
"n/a" indicates observed transit counts were not available at time of review

In general, the comparison of observed traffic volumes with the modelled results appear to be within acceptable ranges however, it is noted that the numbers of transit riders estimated from APC data when compared against modelled ridership shows higher differences. Further review of the previous comparison of OD Survey results and reported transit mode splits confirmed that the modelled demands were generally not as high as the travel demands reported in the OD survey yet, significantly higher than the reported observed travel form 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 (Oct to Nov) and consequently would therefore tend to represent average conditions for the Fall period.

It was also noted that the modelled travel demand is estimated for the full morning and evening peak periods and both the transit and auto travel demands then dimensioned to the peak hour based on the application of scaling factors for each of the AM and PM hour as identified in the previous sections.

A more detailed screenline validation of the modelled travel demands was also carried out and is summarised in Appendix C.1 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.

6.0 EMME User Guide for TRANS Model

6.1 Programming Implementation

The core model was implemented as an EMME/3 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 14,
    - 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 9-12 can be run multiple times (for example for testing or calibration purposes). In a similar way, sub-macros 1-12 can be run to construct trip matrices and then, the mode choice sub-macros 13 and 14 can be run multiple times (for testing different network scenarios).
    - 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 13 (for the AM period) and 14 (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. However, the matrix-related results (LOS skims and mode trip matrices) 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. Thus, if it is essential to save all LOS and mode matrices for both AM and PM period, two separate databanks should be used.

Table 6-1 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. ***CarOwner.mac*** – calculate car ownership choice	
	3. ***TourProd.mac*** – calculate total (motorized & non-motorized) tour productions	
	4. ***TourAttr.mac*** – calculate total (motorized & non-motorized) tour attractions	
	3-4. ***BalanTot.mac*** – balance total tour productions and attractions	
	5. ***NonMProd.mac*** – calculate share of motorized tour productions	
	6. ***NonMAttr.mac*** – calculate share of motorized tour attractions	
	5-6. ***BalanMot.mac*** – balance motorized productions and attractions	
	7. ***TODProd.mac*** – call time-of-day & stop-frequency choice subroutine for tour productions for each purpose	7.1. ***TODProd1.mac*** – for work
		7.2. ***TODProd2.mac*** – for university
		7.3. ***TODProd3.mac*** – for school
		7.4. ***TODProd4.mac*** – for maintenance
		7.5. **TODProd5.mac** – for discretionary
	8. ***TODAttr.mac*** – call time-of-day choice subroutine for tour attractions for each purpose	8.1. ***TODAttr1.mac*** – for work
		8.2. ***TODAttr2.mac*** – for university
		8.3. ***TODAttr3.mac*** – for school
		8.4. ***TODAttr4.mac*** – for maintenance
		8.5. ***TODAttr5.mac*** – for discretionary
	7-8. ***BalanTOD.mac*** – balance productions and attractions for each time-of-day period	
	9. ***SeedMatr.mac*** – prepare seed matrices for tour ends (call ***MatSmoot.mac*** for each purpose)	9. ***MatSmoot.mac*** – smooth up observed matrices from OD Survey
	10. ***TourDist.mac*** – calculate tour-ends distribution (call ***MatConst.mac*** for each purpose, outbound time-of-day periods, and inbound time-of-day period)	10. ***MatConst.mac*** – construct tour-end matrices by gravity-balancing method using seed matrices
	11. ***StopAttr.mac*** – calculate stop-attraction size variables for stop-location choice	
	12. ***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)	12. ***ChainDis.mac*** – calculate convoluted trip matrices for chained half-tour matrices based on stop-location choice
	13. ***ModeAM.mac*** – calculate mode choice for AM period	
	14. ***ModePM.mac*** – calculate mode choice for PM period	

- Sub-macros 1-8 operate only with vectors (mo, md) and are independent of the network scenario. Sub-macros 9-12 operate with vectors (mo, md), full matrices (mf), and use simple free-flow auto assignment. Thus they are only slightly dependent on the network scenario. Sub-macros 13-14 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 should be set in *TRANSMod.mac* batch prior to sub-macro 13 and sub-macro 14.
- The following dimensions and components must be set for the EMME databank in order to run the entire model system:
    - The maximum number (999) of matrices for all matrix types (ms, mo, md, mf); this requirement make it essential to use EMME/3 version of the package.
    - Network scenarios for AM and PM periods including auto and transit networks with VDF and TTF functions ready for assignments.
    - Auto link extra-attributes for storage of multi-call 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:
        - @driv (peak hour auto driver vehicle volume),
        - @pass (peak hour auto passenger volume),
        - @comm (peak hour commercial vehicle volume),
        - @exte (peak hour external traffic volume).
    - Line-specific (@tboa) and node-specific (@nboa) 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).

6.2 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 car ownership and tour/trip 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 1-14.
- **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 9-14. It is assumed that a full daily run with a population synthesis procedure and sub-models 1-8 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/trip 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 13 or 14. It is assumed that a full run including tour/trip distribution stage (sub-models 1-12) have already been implemented for the socioeconomic / land-use scenario. If both AM and PM runs (or 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. If only the final network assignment results (auto and transit) are of interest, the runs can be implemented back-to-back in the same databank but using different network scenarios. The demand and LOS mode matrices of the first runs will be overridden by the last run.

- **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 1-13/14) have already been implemented for the socioeconomic / land-use / network scenario. This option is specified by the user using standard EMME/3 assignment procedures with the following assignable matrices by modes (see **Subsections 3.9.1-3.9.2** above for details):
    - Auto assignment (multi-class):
        - mf"AutAss" (peak period auto drivers/vehicles scaled by the peak-hour factor),
        - mf"ComAM" or mf"ComPM" (peak hour trucks/commercials),
        - mf"ExtAM" or mf"ExtPM" (peak hour external traffic),
        - mf"PasAss" (peak hour auto passengers) as additional demand.
    - Transit assignment:
        - mf"BusAss" (peak period bus demand),
        - mf"RaiAss" (peak period rail demand).

6.3 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.

6.3.1 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 that 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/3 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 that inputs number of households by TAZ jointly distributed by size, number of workers, and dwelling/housing type. The program loops over household size categories 1-6, number-of-worker categories 0-3, housing types 1-2, and reads the external files created by the population synthesizer listed in **Table 6-2** below.
- Section 1.3 that 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 6-3** below.
- Section 1.4 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 6-4** below.
- Section 1.5 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 6-5** below.
- Section 1.6 that converts geographic aggregations from vectors into group partitions (*gs*, *gd*, *gc*, *gp*, and *gr* for superzones, districts, corridors, provinces, and rings 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 (provided for Ontario only), share of low-income households (provided for Quebec only). Finally, the program calculates various derived zonal

characteristics (share of population of age 45 and older, population density, share of low-income households, share of detached houses) at different levels of geographic aggregation (TAZ, superzone, district). The created vectors are listed in **Table 6-6** below.

- Section I.7 inputs zonal data items that relate to employment (total and by 6 branches – retail, service, public offices, private offices, education institutions, and health institutions), shopping Gross Leasable Area (provided for Ontario only), university and school enrolment, as well as parking cost estimates for long (daily) and short (2-hour) parking. 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 6-7** 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 1-5 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 6-8** below.
- Section 1.8 inputs observed matrices from the OD Survey. The program loops over travel purposes (1-5) 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 9 modelled modes) for AM and PM period. The created matrices are listed in **Table 6-9** below.
- Section 1.9 inputs additional matrices needed for mode choice model and assignment procedures. They include transit fare matrices (specified for regular bus, express bus, and rural expressed bus separately), 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 hour. The created matrices are listed in **Table 6-10** below.
- Section 1.10 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.

All input data items except for trip matrices for external zones relate to internal TAZs. Cells that relate to external zones obtain a default zero value in all other vectors/matrices.

Table 6-2 Input Components (Joint Household Distribution)

Type	No	Name		Source	
		Short	Long (description)	File name	Created by
mo	1	H101	HHs Size=1 Workers=0 Dwelltype=1	H101.in	PopSyn/out
mo	2	H102	HHs Size=1 Workers=0 Dwelltype=2	H102.in	PopSyn/out
mo	3	H111	HHs Size=1 Workers=1 Dwelltype=1	H111.in	PopSyn/out
mo	4	H112	HHs Size=1 Workers=1 Dwelltype=2	H112.in	PopSyn/out
mo	5	H201	HHs Size=2 Workers=0 Dwelltype=1	H201.in	PopSyn/out
mo	6	H202	HHs Size=2 Workers=0 Dwelltype=2	H202.in	PopSyn/out
mo	7	H211	HHs Size=2 Workers=1 Dwelltype=1	H211.in	PopSyn/out
mo	8	H212	HHs Size=2 Workers=1 Dwelltype=2	H212.in	PopSyn/out
mo	9	H221	HHs Size=2 Workers=2 Dwelltype=1	H221.in	PopSyn/out
mo	10	H222	HHs Size=2 Workers=2 Dwelltype=2	H222.in	PopSyn/out
mo	11	H301	HHs Size=3 Workers=0 Dwelltype=1	H301.in	PopSyn/out
mo	12	H302	HHs Size=3 Workers=0 Dwelltype=2	H302.in	PopSyn/out
mo	13	H311	HHs Size=3 Workers=1 Dwelltype=1	H311.in	PopSyn/out
mo	14	H312	HHs Size=3 Workers=1 Dwelltype=2	H312.in	PopSyn/out
mo	15	H321	HHs Size=3 Workers=2 Dwelltype=1	H321.in	PopSyn/out
mo	16	H322	HHs Size=3 Workers=2 Dwelltype=2	H322.in	PopSyn/out
mo	17	H331	HHs Size=3 Workers=3 Dwelltype=1	H331.in	PopSyn/out
mo	18	H332	HHs Size=3 Workers=3 Dwelltype=2	H332.in	PopSyn/out
mo	19	H401	HHs Size=4 Workers=0 Dwelltype=1	H401.in	PopSyn/out
mo	20	H402	HHs Size=4 Workers=0 Dwelltype=2	H402.in	PopSyn/out
mo	21	H411	HHs Size=4 Workers=1 Dwelltype=1	H411.in	PopSyn/out
mo	22	H412	HHs Size=4 Workers=1 Dwelltype=2	H412.in	PopSyn/out
mo	23	H421	HHs Size=4 Workers=2 Dwelltype=1	H421.in	PopSyn/out
mo	24	H422	HHs Size=4 Workers=2 Dwelltype=2	H422.in	PopSyn/out
mo	25	H431	HHs Size=4 Workers=3 Dwelltype=1	H431.in	PopSyn/out
mo	26	H432	HHs Size=4 Workers=3 Dwelltype=2	H432.in	PopSyn/out
mo	27	H501	HHs Size=5 Workers=0 Dwelltype=1	H501.in	PopSyn/out
mo	28	H502	HHs Size=5 Workers=0 Dwelltype=2	H502.in	PopSyn/out
mo	29	H511	HHs Size=5 Workers=1 Dwelltype=1	H511.in	PopSyn/out
mo	30	H512	HHs Size=5 Workers=1 Dwelltype=2	H512.in	PopSyn/out
mo	31	H521	HHs Size=5 Workers=2 Dwelltype=1	H521.in	PopSyn/out
mo	32	H522	HHs Size=5 Workers=2 Dwelltype=2	H522.in	PopSyn/out
mo	33	H531	HHs Size=5 Workers=3 Dwelltype=1	H531.in	PopSyn/out
mo	34	H532	HHs Size=5 Workers=3 Dwelltype=2	H532.in	PopSyn/out
mo	35	H601	HHs Size=6 Workers=0 Dwelltype=1	H601.in	PopSyn/out
mo	36	H602	HHs Size=6 Workers=0 Dwelltype=2	H602.in	PopSyn/out
mo	37	H611	HHs Size=6 Workers=1 Dwelltype=1	H611.in	PopSyn/out
mo	38	H612	HHs Size=6 Workers=1 Dwelltype=2	H612.in	PopSyn/out
mo	39	H621	HHs Size=6 Workers=2 Dwelltype=1	H621.in	PopSyn/out
mo	40	H622	HHs Size=6 Workers=2 Dwelltype=2	H622.in	PopSyn/out
mo	41	H631	HHs Size=6 Workers=3 Dwelltype=1	H631.in	PopSyn/out
mo	42	H632	HHs Size=6 Workers=3 Dwelltype=2	H632.in	PopSyn/out

Table 6-3 Input Components (Household Distribution by Size)

Type	No	Name		Source	
		Short	Long (description)	File name	Created by
mo	43	H1	HHs Size=1	H101.in	PopSyn/inp
mo	44	H2	HHs Size=2	H102.in	PopSyn/inp
mo	45	H3	HHs Size=3	H111.in	PopSyn/inp
mo	46	H45	HHs Size=4 or 5	H112.in	PopSyn/inp
mo	47	H6	HHs Size=6	H201.in	PopSyn/inp

Table 6-4 Input Components (Households by Dwelling, Labour Force, and Population by Age)

Type	No	Name		Source	
		Short	Long (description)	File name	Created by
mo	48	HHDet	HHs Dwelltype=1 (detached)	D1.in	PopSyn/inp
mo	49	HHApt	HHs Dwelltype=2 (apts)	D2.in	PopSyn/inp
mo	50	LF	Pop Labour Force	LF.in	PopSyn/inp
mo	51	P0_4	Pop age group 0-4 years	P0_4.in	PopSyn/inp
mo	52	P5_14	Pop age group 5-14 years	P5_14.in	PopSyn/inp
mo	53	P15_24	Pop age group 15-24 years	P15_24.in	PopSyn/inp
mo	54	P25_44	Pop age group 25-44 years	P25_44.in	PopSyn/inp
mo	55	P45_64	Pop age group 45-64 years	P45_64.in	PopSyn/inp
mo	56	P65	Pop age group >=65 years	P65.in	PopSyn/inp

Table 6-5 Input Components (Geographic Aggregations, TAZ Area, and Total Population)

Type	No	Name		Source	
		Short	Long (description)	File name	Created by
mo	57	Quebec	Quebec province dummy	Quebec.in	User
mo	58	Superz	Superzone ID (1-94)	Superz.in	User
mo	59	Distri	District ID (1-26)	Distri.in	User
mo	60	CBD	CBD dummy (district=1)	N/A	Derived
mo	61	Ring	Ring ID (1-4)	Ring.in	User
mo	62	Corrid	Corridor ID (1-6)	Corrid.in	User
mo	63	Area	TAZ Area in ha	Area.in	User
mo	64	PopTot	Total population	PopTot.in	PopSyn/inp

Table 6-6 Input Components (Population Density and Other Derived Characteristics)

Type	No	Name		Source	
		Short	**Long (description)**	**File name**	**Created by**
mo	65	PS45+	Population share of age 45+	N/A	Derived
mo	66	PopDe1	TAZ population density	N/A	Derived
mo	67	PopDe2	Superzone population density	N/A	Derived
mo	68	PopDe3	District population density	N/A	Derived
mo	75	LowIn1	TAZ share of low-income population	N/A	Derived
mo	76	LowIn2	Superzone share of low-income population	N/A	Derived
mo	77	LowIn3	District share of low-income population	N/A	Derived
mo	78	Detac1	TAZ share of detached houses	N/A	Derived
mo	79	Detac2	Superzone share of detached houses	N/A	Derived
mo	80	Detac3	District share of detached houses	N/A	Derived
mo	81	HHTot	Total number of households	HHTot.in	PopSyn/inp
mo	82	PopLow	Low-income population in Ontario	PopLow.in	User
mo	83	HHLow	Low-income households in Quebec	HHLow.in	User

Table 6-7 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	ShoGLA	Shopping Gross Leasable Area	ShoGLA.in	User
md	9	EnUni1	Taz university enrolment	EnUni1.in	User
md	10	EnUni2	Superzone university enrolment	N/A	Derived
md	11	EnUni3	District university enrolment	N/A	Derived
md	12	EnSch1	Taz school enrolment	EnSch1.in	User
md	13	EnSch2	Superzone school enrolment	N/A	Derived
md	14	EnSch3	District school enrolment	N/A	Derived
md	15	ParkLo	Cost for long parking, $	ParkLo.in	User
md	16	ParkSh	Cost for short parking, $	ParkSh.in	User
mo	69	EmpDe1	TAZ employment density	N/A	Derived
mo	70	EmpDe2	Superzone employment density	N/A	Derived
mo	71	EmpDe3	District employment density	N/A	Derived
mo	72	RetDe1	TAZ retail+service density	N/A	Derived
mo	73	RetDe2	Superzone retail+service density	N/A	Derived
mo	74	RetDe3	District retail+service density	N/A	Derived

Table 6-8 Input Components (Observed Tour Generation from OD Survey)

Type	No	Name		Source	
		Short	**Long (description)**	**File name**	**Created by**
mo	931	Prod1v	Total tour production Purp=1 observed	Prod1v.in	User
mo	932	Prod2v	Total tour production Purp=2 observed	Prod2v.in	User
mo	933	Prod3v	Total tour production Purp=3 observed	Prod3v.in	User
mo	934	Prod4v	Total tour production Purp=4 observed	Prod4v.in	User
mo	935	Prod5v	Total tour production Purp=5 observed	Prod5v.in	User
mo	936	PrMo1v	Motorized tour production Purp=1 observed	PrMo1v.in	User
mo	937	PrMo2v	Motorized tour production Purp=2 observed	PrMo2v.in	User
mo	938	PrMo3v	Motorized tour production Purp=3 observed	PrMo3v.in	User
mo	939	PrMo4v	Motorized tour production Purp=4 observed	PrMo4v.in	User
mo	940	PrMo5v	Motorized tour production Purp=5 observed	PrMo5v.in	User
md	931	Attr1v	Total tour attraction Purp=1 observed	Attr1v.in	User
md	932	Attr2v	Total tour attraction Purp=2 observed	Attr2v.in	User
md	933	Attr3v	Total tour attraction Purp=3 observed	Attr3v.in	User
md	934	Attr4v	Total tour attraction Purp=4 observed	Attr4v.in	User
md	935	Attr5v	Total tour attraction Purp=5 observed	Attr5v.in	User
md	936	AtMo1v	Motorized tour attraction Purp=1 observed	AtMo1v.in	User
md	937	AtMo2v	Motorized tour attraction Purp=2 observed	AtMo2v.in	User
md	938	AtMo3v	Motorized tour attraction Purp=3 observed	AtMo3v.in	User
md	939	AtMo4v	Motorized tour attraction Purp=4 observed	AtMo4v.in	User
md	940	AtMo5v	Motorized tour attraction Purp=5 observed	AtMo5v.in	User

Table 6-9 Input Components (Seed Tour & Trip Matrices from OD Survey)

Type	No	Name		Source	
		Short	Long (description)	File name	Created by
mf	1	Purp1	Work tours in PA format from OD	Purp1.in	User
mf	2	Purp2	University tours in PA format from OD	Purp1.in	User
mf	3	Purp3	School tours in PA format from OD	Purp1.in	User
mf	4	Purp4	Maintenance tours in PA format from OD	Purp1.in	User
Mf	5	Purp5	Discretionary tours in PA format from OD	Purp1.in	User
mf	6	MotAM	Motorized trips AM period from OD	MotAM.in	User
mf	7	MotPM	Motorized trips PM period from OD	MotPM.in	User
mf	8	DrivAM	Auto driver trips AM period from OD	DrivAM.im	User
mf	9	DrivPM	Auto driver trips PM period from OD	DrivPM.im	User
mf	10	PassAM	Auto passenger trips AM period from OD	PassAM.im	User
mf	11	PassPM	Auto passenger trips PM period from OD	PassPM.im	User
mf	12	WbusAM	Walk-to-bus trips AM period from OD	WbusAM.im	User
mf	13	WbusPM	Walk-to-bus trips PM period from OD	WbusPM.im	User
mf	14	Dbu1AM	P&R bus trips AM period from OD	Dbu1AM.im	User
mf	15	Dbu1PM	P&R bus trips PM period from OD	Dbu1PM.im	User
mf	16	Dbu2AM	K&R bus trips AM period from OD	Dbu2AM.im	User
mf	17	Dbu2PM	K&R bus trips PM period from OD	Dbu2PM.im	User
mf	18	WraiAM	Walk-to-rail trips AM period from OD	WraiAM.im	User
mf	19	WraiPM	Walk-to-rail trips PM period from OD	WraiPM.im	User
mf	20	Dra1AM	P&R rail trips AM period from OD	Dra1AM.im	User
mf	21	Dra1PM	P&R rail trips PM period from OD	Dra1PM.im	User
mf	22	Dra2AM	K&R rail trips AM period from OD	Dra2AM.im	User
mf	23	Dra2PM	K&R rail trips PM period from OD	Dra2PM.im	User
mf	23	SchbAM	School bus trips AM period from OD	SchbAM.in	User
mf	25	SchbPM	School bus trips PM period from OD	SchbPM.in	User
mf	26	Pur1AM	Trips on work tours AM period from OD	Pur1AM.in	User
mf	27	Pur1PM	Trips on work tours PM period from OD	Pur1PM.in	User
mf	28	Pur2AM	Trips on university tours AM from OD	Pur2AM.in	User
mf	29	Pur2PM	Trips on university tours PM from OD	Pur2PM.in	User
mf	30	Pur3AM	Trips on school tours AM period from OD	Pur3AM.in	User
mf	31	Pur3PM	Trips on school tours PM period from OD	Pur3PM.in	User
mf	32	Pur4AM	Trips on maintenance tours AM from OD	Pur4AM.in	User
mf	33	Pur4PM	Trips on maintenance tours PM from OD	Pur4PM.in	User
mf	34	Pur5AM	Trips on discretionary tours AM from OD	Pur5AM.in	User
mf	35	Pur5PM	Trips on discretionary tours PM from OD	Pur5PM.in	User

Table 6-10 Input Components (Additional Matrices)

Type	No	Name		Source	
		Short	Long (description)	File name	Created by
mf	36	RegFar	2007 AM regular bus fare	AM_RegularFare.in	User
mf	37	ExpFar	2007 AM express bus fare	AM_ExpressFare.in	User
mf	38	RuExFa	2007 AM Rural express bus fare	AM_RuralExpressFare.in	User
mf	39	ComAM	Commercials and trucks AM	CVS_AM_FinalMatrix.in	User
mf	40	ComPM	Commercials and trucks PM	CVS_PM_FinalMatrix.in	User
mf	41	ExtAM	External trips AM	External_Matrix_AM	User
mf	42	ExtPM	External trips PM	External_Matrix_PM	User

6.3.2 Sub-Macro “2. CarOwner”

Sub-Macro 2 (*CarOwner*) calculates car-ownership choice probabilities for each household segment. The model specification is described in **Section 3.2** above and the estimated model coefficients are reported in **Section 5.1** 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 2.1 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), and dwelling type (1-2).
- Section 2.2 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), and dwelling type (1-2).
- Section 2.3 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), 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), dwelling type (1-2), and car sufficiency (0-3) constitute the primary output of this sub-model used by the subsequent sub-models (*mo”H1010”-mo”H6323”*).
- Section 2.4 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 2.5 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 2.7 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.

6.3.3 Sub-Macro "3. TourProd"

Sub-Macro 3 (*TourProd*) calculates total (including motorized and non-motorized) tour productions for each household segment. The model specification is described in **Subsection 3.3.1** above and the estimated model coefficients are reported in **Section 5.2.1** 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 3.1 contains household tour production rates by purpose 1-5 as function of car sufficiency, household composition, 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 3.2 calculates zonal tour productions accumulated for each car-sufficiency group (0-3) and purposes (1-5) from the household variables. The program loops over car-sufficiency group (0-3), purpose (1-5), household size (1-6), number of workers (0-3), and dwelling type (1-2).
- Section 3.3 adds zonal tour productions accumulated for each car-sufficiency group (0-3) and purposes (1-5) from the zonal variables. The program loops over car-sufficiency group (0-3), purpose (1-5), household size (1-6), number of workers (0-3), and dwelling type (1-2).
- Special subsections add impacts of university enrolment on university tour production (effect of students living in rent apartments in the vicinity of large universities) and manual corrections for selected high-density districts.
- Section 3.4 contains individual TAZ 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 3.5 aggregate tour production for each purpose (1-5) 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 (1-5) (*mo"Prod01"-mo"Prod35"*) as well as aggregate tour production vectors by purpose (1-5) (*mo"Prod1"-mo"Prod5"*).
- Section 3.6 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.

6.3.4 Sub-Macro “4. TourAttr”

Sub-Macro 4 (*TourAttr*) calculates total (including motorized and non-motorized) tour attractions. The model specification is described in **Subsection 3.3.2** above and the estimated model coefficients are reported in **Section 5.2.2** 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 4.1 contains zone tour attraction rates by purpose 1-5 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 4.2 calculates zonal tour attractions for each purpose (1-5) in a loop.
- Section 4.3 contains individual adjustments for selected TAZs 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”Attr5”*).
- Section 4.4 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.

6.3.5 Sub-Macro “3-4. BalanTot”

Sub-Macro 3-4 (*BalanTot*) balances total regional tour productions and attractions. The algorithm is described in **Subsection 3.3.3** 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 (1-5). The switches are currently set in the following way:
    - 3 (by average) for Work (purpose=1),
    - 2 (by attractions) for University (purpose=2),
    - 1 (by productions) for School, Maintenance, and Discretionary (purposes=3,4,5).
- 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“Prod5”* and *md”Attr1” – md“Attr5”*.
- Section that summarizes and outputs balancing (correction factors) applied for the total productions and attractions for each purpose.

6.3.6 Sub-Macro “5. NonMProd”

Sub-Macro 5 (*NonMProd*) calculates share of motorized tour productions for each household car-sufficiency segment. It is based on binary (pre-mode) choice between motorized and non-motorized travel at the tour production end (household residence). The model specification is described in **Subsection 3.4.2** 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 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 5.1 calculates utilities for non-motorized travel (motorized 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 (1-5).

- Section 5.2 calculates non-motorized probabilities based on the binary logit choice model. The program loops over car-sufficiency groups (0-3) and travel purposes (1-5).

- Section 5.3 calculates motorized production vectors based on the total productions and non-motorized share for each segment. The program loops over car-sufficiency groups (0-3) and travel purposes (1-5). The resulted vectors (*mo"PrMo01"-mo"PrMo35"*) constitute the primary output of this sub-model.

- Section 5.4 aggregates the motorised tour production vectors across car-sufficiency groups (0-3) and creates motorized tour production vectors by purpose (1-5) (*mo"PrMo1"-mo"PrMo5"*).

- Section 5.5 summarizes and outputs main statistics on motorized tour production by purpose compared to the observed motorized tour production in OD survey for the entire region. Section 5.6 does the same for urban rings 1 and 2. Section 5.7 does 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.

6.3.7 Sub-Macro "6. NonMAttr"

Sub-Macro 6 (*NonMAttr*) calculates share of motorized tour attractions based on binary (pre-mode) choice between motorized and non-motorized travel at the tour attraction end (primary destination). The model specification is described in **Subsection 3.4.3** 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 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 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 6.1 calculates utilities for non-motorized travel (motorized utilities are all set to zero as the reference case) for each segment. The program loops over travel purposes (1-5). Additional subsection allows for utility adjustments for selected traffic zones (several of them currently used for large schools).

- Section 6.2 calculates non-motorized probabilities based on the binary logit choice model. The program loops over travel purposes (1-5).

- Section 6.3 calculates motorized attraction vectors based on the total attractions and non-motorized share for each segment (purpose). The program loops over travel purposes (1-5). The resulted vectors (*md"AtMo1"-mo"AtMo5"*) constitute the primary output of this sub-model.
- Section 6.4 summarizes and outputs main statistics on motorized tour attraction by purpose compared to the observed motorized tour attraction in OD survey for the entire region. Section 6.5 does the same for urban rings 1 and 2. Section 6.6 does 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.

6.3.8 Sub-Macro "5-6. BalanMot"

Sub-Macro 5-6 (*BalanMot*) balances regional motorized tour production and attraction totals. The algorithm is described in **Subsection 3.4.4** 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 (1-5). The switches are currently set in the following way and in line with the balancing principles applied for total (motorize & non-motorized) tour generation:
    - 3 (by average) for Work (purpose=1),
    - 2 (by attractions) for University (purpose=2),
    - 1 (by productions) for School, Maintenance, and Discretionary (purposes=3,4,5).
- 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"PrMo5"* and *md"AtMo1" – md"AtMo5"*.
- Section that summarizes and outputs balancing (correction factors) applied for the motorized productions and attractions for each purpose.

6.3.9 Sub-Macro "7. TODProd"

Sub-Macro 7 (*TODProd*) calls subroutines (*TODProd1-5*) 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 3.5.1** above and the estimated model coefficients are reported in **Section 5.4.1** 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 7.1-7.5 (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 1-5) 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"Pr544"*) represent the <u>primary aggregate output</u> 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.

6.3.10 Sub-Macro "8. TODAttr"

Sub-Macro 7 (*TODAttr*) calls subroutines (*TODAttr1-5*) 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 3.5.2** above and the estimated model coefficients are reported in **Section 5.4.2** 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 8.1-8.5 (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"At544"*) 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.

6.3.11 Sub-Macro "7-8. BalanTOD"

Sub-Macro 5-6 (*BalanMot*) balances regional motorized tour production and attraction totals. The algorithm is described in **Subsection 3.5.3** 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 (1-5). 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),
    - 2 (by attractions) for University (purpose=2),
    - 1 (by productions) for School, Maintenance, and Discretionary (purposes=3,4,5).
- 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"Pr544"* and *md"At111" – md"At544"*.
- Section that summarizes and outputs balancing (correction factors) applied for productions and attractions for each purpose and TOD slice.

6.3.12 Sub-Macro "9. SeedMatr"

Sub-Macro 9 (*SeedMatr*) prepares seed matrices for tour ends (residential and primary destination). This sub-macro serves as a shell for multiple calls for subroutine 9 (*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 (1-5) and calls subroutine *MatSmoot* (described in the next subsection) for each purpose. As the result, smoothed daily tour-end matrices (*mf"Purp1s"-mf"Purp5s"*) are prepared.
- Section that scales the daily purpose-specific matrices for each TOD demand slice. The program loops over travel purposes (1-5), 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"See544"*) constitute the primary output of the sub-model. These matrices are used as seeds in the subsequent matrix construction procedure.

6.3.13 Subroutine "9. MatSmoot"

Subroutine 9 (*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 3.6.1** 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 9.1 calculates original (raw/observed) matrix marginals (production and attraction totals),
- Section 9.2 implements an auxiliary gravity model with the calculated marginals and specified impedance function.
- Section 9.3 aggregates the original matrix and auxiliary gravity-based matrix according to the specified partition.
- Section 9.4 calculates final smooth matrix that replicates the original matrix at the aggregate level but follows the gravity model for internal / disaggregate proportions.

6.3.14 Sub-Macro "10. 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 10 (*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 (1-5) 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"Tou544"*) constitute the primary output of the sub-model. These matrices are used as tour-end controls in the PA format in the subsequent trip matrix construction procedure.

6.3.15 Subroutine "10. MatConst"

Subroutine 10 (*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 3.6.2** 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),
- 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"Tou544"*.
- 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.

6.3.16 Sub-Macro "11. StopAttr"

Sub-Macro 11 (*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 3.5.4** above and the estimated model coefficients are reported in **Section 5.4.3** 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 11.1 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 (1-5). The resulted vectors (*md"StAt1o"-md"StAt5o"*) constitute the sub-model output. It is used in the subsequent trip matrix construction procedure for outbound chained half-tours.
- Section 11.2 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 11.3 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.

6.3.17 Sub-Macro "12. TripDist"

Sub-Macro 12 (*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 12 (*ChainDis*). The algorithm is described in **Section 3.7** 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 12.1 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 (1-5). 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 12.2 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 (1-5). 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 12.3 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 (1-5). 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"TrAM35"* for the AM period,
    - *mf"TrPM01"-mf"TrPM35"* 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.

6.3.18 Subroutine “12. 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 3.7.3** 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.

6.3.19 Sub-Macros “13. ModeAM” and “14. ModePM”

Sub-Macros 13 (*ModeAM*) and 14 (*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 3.8.1** with the assignment procedures as described in **Subsection 3.8.2**. 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 and K&R (as explained in **Subsection 3.8.2**). The sub-macro script has the following sections:

- Control section of input parameters specified by the user:
    - 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),

  - 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 6),
  - 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 8 that produces a good level of convergence in a reasonable time frame (20 min). A smaller number of iterations (3-4) will suffice for a crude analysis with a large number of alternatives (10 min each run).
  - 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 80 iterations at the last global iteration),
  - Scaling coefficient for the peak hour auto demand within the peak period auto demand; it is currently set to the following values (based on the observed peak patterns):
    - For 2.5-hour AM period: 2.1
    - For 3.0-hour PM period: 2.5
  - Transit and auxiliary mode definitions (can be extended for future projects):
    - Currently *"osp"* for bus assignment,
    - Currently *"rp"* for rail assignment (includes bus modes also),
  - List of P&R lots for bus and rail (should be defined by the user for each run according to the network scenario).

- Section 13.0 / 14.0 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,

- Section 13.1 / 14.1 (located within the global equilibrium loop) includes assignments and skimming procedures (described in **Subsections 3.9.1** and **3.9.2** above):
  - Free-flow assignment,
  - Congested multi-class auto assignment,
  - Averaging of congested time skims and calculation of delays,
  - 1st walk-to-bus assignment to skim time components and total in-vehicle distance,
  - 2nd walk-to-bus assignment to skim Transitway in-vehicle distance,
  - Building drive-to-bus skims by station choice and skim convolution,
  - 1st walk-to-rail assignment to skim generic time components,
  - 2nd walk-to-rail assignment to skim rail specific time components,
  - Building drive-to-rail skims by station choice and skim convolution,

- Section 13.2 / 14.2 (located within the global equilibrium loop) calculates exponentiated mode-specific utilities for each segment (car-sufficiency category and purpose). For each mode (1-9), 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 13.3 / 14.3 (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 (1-5) and applies a nested logit model to calculate probabilities for modes (1-9). A special sub-section implements a logical check (sum of all mode probabilities for ach 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 13.4 / 14.4 (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 and K&R modes. For these modes, demand matrices are split into auto 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 9 modes and 6 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 (auto driver, commercials, externals),
    - Final bus assignment with P&R and K&R transit components,
    - Final rail assignment with P&R and K&R transit components.

6.4 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.

6.4.1 Software and Installation Procedures

- Minimum OS
    - Windows 2000 or XP: Basic Installation with Service Pack updates

- Microsoft Office
    - Microsoft Office 2000 or later version (at least MS Access is required)

- JAVA
    - jdk-1_5_0_06-windows-i586-p.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\ jdk1.5.0_06\

- Setting environmental variables
    - In Windows 2000 or Windows XP, The environmental variables PATH needs to be edited as below:
        - In Windows 2000 or Windows XP, use Control Panel to access System→Advanced→Environmental Variables.
        - Edit the PATH variable under 'System Variables' to also include the location of the jdk bin directory, for example "C:\Program Files\Java\jdk1.5.0_06\bin".

6.4.2 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.

6.4.3 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

i. ZSED : This file should contain the Zonal Socio Economic data for all internal 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 6-11**.

Table 6-11 Zonal Socio-Economic Controls for Population Synthesis

Field Number	Field Name	Description
1	taz	Traffic analysis zone number
2	superzone	Super zone 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 fiver 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 labour force

Note: ZSED table should have at least the above 19 fields with the exact same field names. It can have more fields and that wouldn't affect results. These 19 fields can be in any sequence.

ii. 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 6-12** below. All other fields could be left in the file.

Table 6-12 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

iii. 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 6-13** below. All other fields could be left in the file.

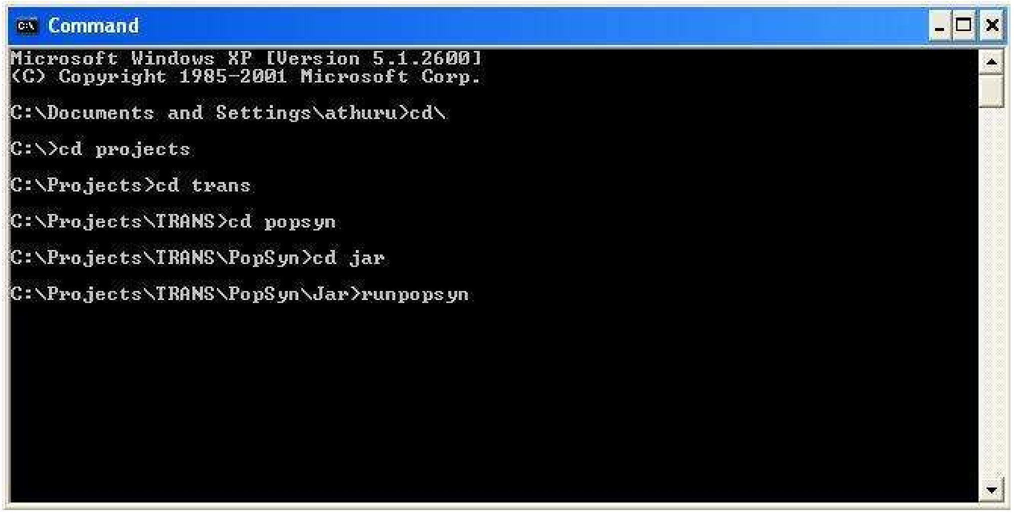
Table 6-13 Seed Person File for Population Synthesis

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

6.4.4 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 6-1** below.

Exhibit 6.1 Run Window for Population Synthesizer



```
Microsoft Windows XP [Version 5.1.2600]
(C) Copyright 1985-2001 Microsoft Corp.

C:\Documents and Settings\athuru>cd\

C:\>cd projects

C:\Projects>cd trans

C:\Projects\TRANS>cd popsyn

C:\Projects\TRANS\PopSyn>cd jar

C:\Projects\TRANS\PopSyn\Jar>runpopsyn
```

6.4.5 Output Files

The Population Synthesis process takes about 100 minutes to complete the run and create all the required output files. The following three sets of output files are created.

1. 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

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.

2. 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.

3. EMME Input Matrices:

The final set of outputs is EMME matrices that are inputs to the TRANS model in EMME. These matrices are written out in a certain format so that the EMME software can read them (see **Subsecton 6.3.1** above).

Location: C:\Projects\TRANS\PopSyn\EMMET\
List of EMME matrices:

i. 42 matrices (H101 to H632) are written out from SyntheticHH table in SynPop.mdb access database
ii. 14 matrices (H1, H2, H3, H45, H6, D1, D2, LF, P0_4, P5_14, P15_24, P25_44, P45_64, and P65) are written out from ZSEDN table in SynPop.mdb access database.

7.0 Future Model Enhancements

The redevelopment of the TRANS model focused on opportunities to improve the model's ability to replicate observed travel behaviour. In this respect the modelling framework includes an advanced tour based modelling structure model for daily tour generation and spatial distribution. The model also relies on traditional trip based structure for mode choice and traffic/transit assignments for both the AM and PM periods. The redevelopment of the TRANS model in this fashion can therefore be considered to have taken significant and deliberate steps forward toward a future tour based model for the region. The redeveloped model framework therefore leaves considerable flexibility for TRANS as part of its ongoing annual programme to further develop and refine key elements of its modelling framework based on both data availability and funding constraints. TRANS Agencies recognise that the very nature of travel demand modelling requires an ongoing continuum of updating and revision to ensure the model remains current and relevant to both its users and city planners. Consequently the focus of this section of the report is to identify key model enhancements which TRANS may wish to explore in the context of ensuring increased use while at the same time ensuring specific data collection efforts to support further model development are recognised and implemented within reasonable timelines. Potential model enhancements have been identified as follows:

- Further enhancement of the core demand model structure
- GHG emissions modelling procedures
- Sub area modelling
- External based travel and commercial vehicles

7.1 Further Enhancements of the Core Demand Model

The core demand model described in **Sections 3, 5, and 6** above is implemented in a modular way and allows for various extensions, refinements, and modifications in the future. In particular, the following optional extensions may be of particular interest for TRANS, as they continue to improve and enhance modelling practises for area planning agencies:

- Model system extension to address all periods of the day in addition to AM and PM (Midday, Night) that would cover a complete daily forecast; this might be essential for environmental studies as well as toll road traffic and revenue studies
- Addition of a time-of-day (peak spreading model); this is an integral element in ensuring long term forecasts adequately consider congestion management policies,
- Implementation of a full system equilibrium including the dependency of trip distribution on mode choice logsums as part of the impedance function; this is essential for congestion pricing and other congestion management policies;
- Introduction of capacity constraints for Park and Ride lots; this is important for rapid transit studies (BRT, LRT, commuter rail) where Park and Ride might represent a significant share of the transit ridership,
- Introduction of capacity-constrained transit assignment through shadow pricing; this is important for more realistic ridership distribution by transit lines in dense urban areas;
- Introduction of frequency adjustment mechanism for selected transit lines; this enhancements makes long-term forecasts more reasonable since exact line frequencies are not known and cannot be coded with certainty,
- Separation of rail modes in the mode choice nested structure; this is needed for analysing various rail projects; since the current O-D Survey cannot support estimation of these nests, a stated preference

survey will be required. Alternatively, the nesting structure and parameters could be transferred from other regional models.

All optional improvements listed above have been successfully implemented and tested elsewhere. The core structure of the redeveloped TRANS model and software allows for a straightforward incorporation of these additional features without a requirement to significantly modify key elements of the main model framework.

7.2 GHG Emissions Modelling Procedures

The consideration of environmental implications and benefits of various transportation policies and infrastructure investments has become a critical consideration in urban transportation planning across North America. Due to concerns about smog, pollution and greenhouse gas emissions, urban municipalities are being asked to demonstrate how their policies and investments address growing air quality concerns. **Table 7-1** summarizes the GHG emissions in Ontario by Transportation mode for the years 1990, 2000 and 2005, based on estimates developed by Natural Resources Canada.

Table 7-1 Ontario GHG Emissions by transportation Mode 1990-2005

Ontario GHG Emissions by Transportation Mode	**1990**	**2000**	**2005**
Total GHG Emissions Excluding Electricity (Mt of CO_2e)	**45.3**	**56.4**	**60.2**
Passenger Transportation	30.7	34.5	36.0
Freight Transportation	13.2	20.0	21.6
Off-Road	1.5	2.0	2.6

Source: Natural Resources Canada, Office of Energy Efficiency website, Table 8: GHG Emissions by Transportation Mode

While the rate of increase in overall emissions in the transportation sector slowed between 2000 and 2005 compared to the previous 10 year period, the growth in CO_2 equivalents is still increasing by over 1% per year. Approximately 60% of the total emissions are attributed to passenger transportation, and much of that travel occurs in Canada's largest urban centres. Increasingly, transportation authorities are being asked to identify or evaluate polices and/or infrastructure investments in terms of their effectiveness in reducing GHG emissions.

There are many sources of GHG emissions due to transportation, ranging from personal auto travel to rail travel and even air travel. While urban travel demand models are typically not capable of forecasting all of this travel activity, the largest modes of travel that typically contribute to GHG emissions are frequently included in demand forecasting. **Table 7-2** summarizes the estimated GHG emission by mode of travel for Ontario for the years 1990, 2000, and 2005. Approximately 51% of all CO_2 equivalents are emitted by personal automobiles and light trucks. This component of vehicle demand is represented in virtually all urban travel demand models, although modelling does not typically differentiate between size of vehicle or mix of auto / light truck / or SUV. A further 32% of annual emissions are generated by commercial vehicles including light, medium, and heavy freight trucks. While these vehicle classes are less commonly represented in urban travel demand models, many jurisdictions are attempting to account for this increasingly important mode of travel. Urban transit, representing about 1% of annual emissions is represented is some of the models in larger municipalities, including the TRANS model.

Together, large multi-modal transportation models have the capability of representing in the order of 85% of the travel that produces GHG emissions within their jurisdictions. Incorporating a methodology to estimate GHG emissions related to future transportation scenarios, can provide a very representative picture of how proposed initiatives may affect future air quality.

Table 7-2 Ontario GHG Emissions by Transportation Mode and Vehicle Type 1990-2005

GHG Emissions by Transportation Mode (Mt of CO2e)	1990	2000	2005
Small Cars	9.6	8.9	8.8
Large Cars	11.3	10.1	10.3
Passenger Light Trucks	4.9	9.3	11.5
Freight Light Trucks	1.8	3.2	3.9
Medium Trucks	3.2	4.2	2.9
Heavy Trucks	4.8	9.8	12.3
Motorcycles	0.1	0.1	0.1
School Buses	0.4	0.4	0.4
Urban Transit	0.5	0.6	0.6
Inter-City Buses	0.2	0.2	0.2
Passenger Air	3.7	4.9	4.1
Freight Air	0.1	0.2	0.1
Passenger Rail	0.1	0.1	0.1
Freight Rail	1.7	1.7	1.5
Marine	1.6	1.1	0.9
Off-Road	1.5	2.0	2.6

Source: Natural Resources Canada, Office of Energy Efficiency website, Table 8: GHG Emissions by Transportation Mode

7.2.1 Tools Used to Estimate GHG

There has been significant research over the past decade on the relationships between transportation and air quality, particularly in the development of methodologies to predict emissions of various pollutants related to motorized travel. The US Environmental Protection Agency has developed a sophisticated computer program to calculate the emissions generated by transportation activities at various levels of geographic resolution. The MOBILE program has evolved over the past 29 years to be one of the leading macroscopic emission modelling tools used by practitioners to estimate the emissions of various air pollutants and GHG from transportation projects. The latest release of the MOBILE software, version 6.2, was designed to "estimate hydrocarbon (HC), carbon monoxide (CO), oxides of nitrogen (NOx), exhaust particulate matter (which consists of several components), tire wear particulate matter, brake wear particulate matter, sulfur dioxide (SO2), ammonia (NH3), six hazardous air pollutant (HAP), and carbon dioxide (CO2) emission factors for gasoline-fueled and diesel highway motor vehicles, and for certain specialized vehicles such as natural-gas-fueled or electric vehicles that may replace them"[1].

The MOBILE6 outputs generate emission rates in grams or milligrams of pollutant per vehicle mile traveled (g/mi or mg/mi). Database output can be reported as g/mi or grams per vehicle per unit time (day or hour). Emission rates from MOBILE6 can be combined with estimates of travel activity (total vehicle miles traveled, or VMT) from a travel demand model to develop vehicle emission inventories expressed in terms of tons per hour, day, month, season, or year. There are numerous inputs that MOBILE uses to calculate the emission rates, however many of them have standard default values based on US nationwide average values. For a number of the inputs, the program does allow the user to replace the default data with custom data obtained from a travel demand model or based on local conditions (i.e. Vehicle Miles Traveled by roadway type, vehicle fleet composition, atmospheric temperature ranges, trip length distribution, etc). Environment Canada has developed a Canadian version of the MOBILE program, called MOBILE 6.2C that utilizes updated input data from Canadian sources.

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[1] User's Guide to MOBILE6.1 and MOBILE6.2, Office of Transportation and Air Quality, U.S. Environmental Protection Agency, August 2003

Transport Canada has also developed an emissions calculator that can be found on its website at http://www.tc.gc.ca/programs/environment/UTEC/menu-eng.htm. The Urban Transportation Emissions Calculator (UTEC) has been developed as web based tool for estimating annual greenhouse gas (GHG) and other air pollutant emissions from passenger, commercial, and urban transit vehicles. The primary input required is vehicle kilometres traveled (VKT) for road vehicles and passenger kilometres travelled (PKT) for rail vehicles. These inputs are standard outputs from many multi-modal travel demand models. Other inputs relating to average travel speeds, hourly to daily expansion factors, and vehicle fuelling characteristics can be modified from default values to reflect local conditions or, in the case of speeds, incorporate outputs from the strategic modelling process.

The UTEC estimates GHG and Criteria Air Contaminants (CAC) emissions for the following vehicles:

- Light-duty passenger vehicles (automobiles, light trucks)
- Light-duty commercial vehicles
- Heavy-duty commercial vehicles
- Public transit buses
- Public transit trolley buses
- Light rail/Metro (electric and diesel)
- Heavy rail (diesel)

Similar to MOBILE6, the UTEC uses a series of default values based on provincial averages that can be adjusted by the user. Vehicle-kilometres of travel are the primary input variable by vehicle class. The user can utilize default values for the trip distribution inputs (based on amount of travel by road type, average speeds, and vehicles class distribution by road type), expansion factors (hourly/daily/annual) and overall vehicle fleet characteristics (share of each vehicle class, and share of each vehicle class by fuel type).

The UTEC outputs GHG emissions in terms of CO2 equivalents for direct (tailpipe GHG emissions of CO2, N2O, and CH4 from urban transportation fuel use) and indirect (estimate the ‘upstream’ GHG emissions associated with fuel combustion including fuel refining and transportation emissions by vehicle class. CO2 equivalents are a single measurement unit describing the global warming potential of all GHG emissions. In addition estimates of CO, NOx, S02, VOC, TPM, PM10, and PM2.5 are generated based on forecasts of emission factors from MOBILE6.2C. MOBILE 6.2C was developed by Environment Canada, and reflects the Canadian version of the MOBILE 6.2 program, with default data reflective of Canadian conditions.

7.2.2 Integration with Modelling Activities

Software packages such as MOBILE6 can be used outside of the travel demand forecasting model as a “post processing” tool, using assignment results at a corridor or area wide level to assess changes to GHG emissions other air pollutants as a result of transportation improvement initiatives. Some travel demand forecasting software packages, such as TransCad, have incorporated routines to estimate GHG emissions within their software environment. The TransCad software has a function within the program software that utilizes model outputs, prepares the necessary input files for MOBILE6, launches the program and runs the emissions model, and then summarizes the output of the MOBILE6 run results.

INRO, the developers of EMME/3 transportation planning software used by the TRANS model does not have GHG emission modelling functions built into their software, although custom macro programming could be undertaken to develop this capability. One such example is the emission calculator that was developed by J. Armstrong[2] at Carleton University to work with the previous TRANS model. An EMME macro was developed to extract VKT, travel speeds, and trip length distribution from a model run. An ‘emissions calculator’ was developed to import this data, prepare the data in the format required to run MOBILE5 (the previous version of MOBILE6), run the MOBILE5 model, and extract the results. Input data specific to

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[2] Development of a Methodology for Estimating Vehicle Emissions, J. Armstrong, Thesis Presentation, 2000

Ottawa-Gatineau was collected, including estimates of intra-zonal travel, temperature, operating mode fractions, fleet characteristics, and commercial vehicle traffic.

A similar type of application was developed by Y. Noriega and M. Florian[3] (INRO) in conjunction with Environment Canada, Ministère des Transports du Québec, and the Centre for Transportation Research. This application utilizes MOBILE 6.2C and EMME to calculate vehicle emissions for the Montreal area. Emission rates are initially calculated for each vehicle type using the MOBILE 6.2C software. A user interface was developed to assist in preparing the MOBILE 6.2C data files and for running the model. The resulting emission rates by vehicle type were then coded into functions used by EMME. EMME macros were subsequently written to run the assignments, and calculate the emissions for each link and each centroid connector based on volumes, speeds, and VKT. An area wide grid system was set up to illustrate the GHG emissions within each grid area, showing the concentrations of emissions in proximity to major transportation corridors.

7.2.3 Considerations for Model Development

There are essentially two ways to incorporate GHG emissions modelling capabilities into the TRANS model update. Emissions modelling can be undertaken as a separate ‘post assignment’ process, utilizing assignment results on a global basis or in a specific area, to generate forecasts of emissions. A second approach would be the development of a GHG module within the TRANS model architecture to automate the processes required to generate GHG emissions forecasts. Each approach is discussed in further detail below.

Post Assignment Process of GHG Emissions Modelling

The “post assignment” process to forecast GHG emissions essentially involves the use of two separate software platforms and two separate modelling work streams. The traditional EMME model software (used by the TRANS model) would continue to be used to provide travel forecasts in the National Capital Region (NCR) for each mode of travel covered by the model. Currently the model is being structured to forecast auto and transit trips. Commercial vehicle trips are planned to be treated explicitly as a separate demand matrix based on observed truck counts and commercial vehicle trip matrices. The commercial vehicle demands could then be assigned to the road network and estimates of commercial vehicle VKT can be derived from the assignment results.

The emission model (MOBILE 6.2C software or equivalent) would then be used to generate standard emission rates for GHG and other air pollutants by speed range, vehicle class, and roadway type. Ideally, these emission rates would be based on customized data reflecting conditions in the Ottawa-Gatineau area such as local ambient temperatures, barometric pressure and relative humidity, vehicle fleet composition (type, age, and fuel type), etc., and could be generated for annual average conditions or specified for each month of the year. A forecast of the emissions produced could then be provided on a project specific basis.

This approach would benefit from consistent application of the base assumptions that go into the emissions forecasts that are not related to transportation model outputs. Consistent assumptions with respect to vehicle fleet composition, average temperatures, and other ‘non usage’ factors would minimize the variations between several different analysts applying a wider range of assumptions in undertaking air quality analysis.

A ‘post assignment’ process has been used by the NYSDOT[4], where emission rate tables were developed for use in localized and area-wide air quality analysis. The tables provide emission rates for each

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[3] The Computation of Emissions with MOBILE 6, Yolanda Noriega, University of Montreal and Michael Florian, INRO Consultants Inc., Montréal, QC, Canada, 2005-10-21, 19th International EMME/2 Users' Conference

[4] NYSDOT Environmental Procedures Manual, Chapter 1.1, Environmental Analysis Bureau, January, 2001

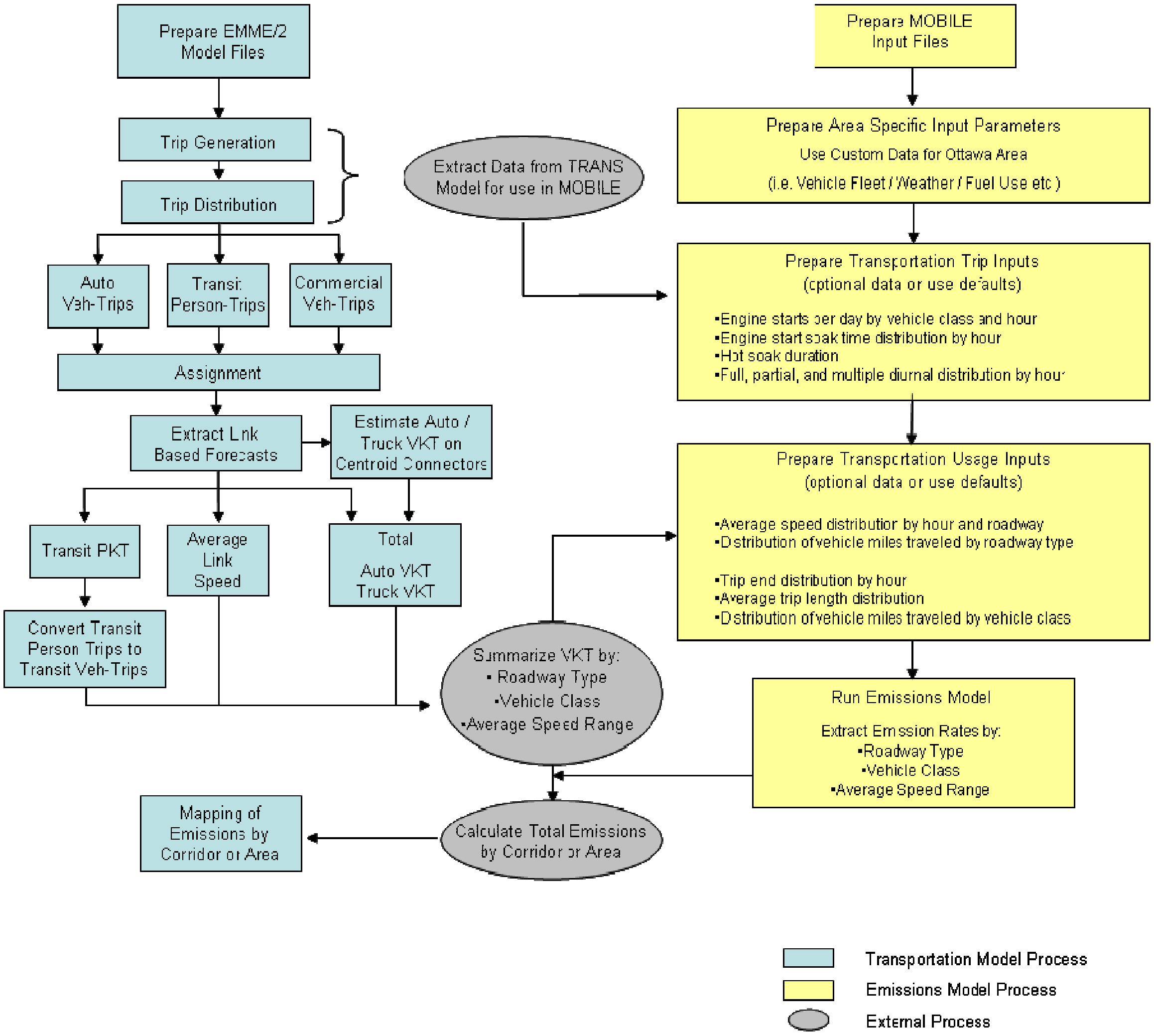
compound in grams/mile by road class and by speed range, allowing the analyst to estimate the total emissions of each compound by calculating the number of vehicle miles traveled on each type of road facility, in each speed range. Custom tables are provided for each County in the State, allowing the assessment to reflect local weather conditions as well as vehicle fleet composition.

Development of a GHG Module within the TRANS Model

The development of a GHG module within the TRANS Model architecture should be relatively straightforward, based on a review of the past work by J. Armstrong and M. Florian in the Ottawa-Gatineau and Montreal areas respectively. Both studies, discussed above, have implemented custom designed data entry programs and/or EMME macros to extract travel demand forecasting results for use in emissions modelling.

There are a number of different approaches to structuring a process that integrates travel demand forecasting with the estimation of GHG emissions. One possible approach is illustrated in **Exhibit 7.1**, below.

Exhibit 7.1 Generic Process for Integration of Transportation Model & Emission Model.



Emissions Forecasting Process

There are a number of different processes that may need to be undertaken at various stages of the emissions forecasting process, depending on the degree that the user wishes to customize the MOBILE 6.2C data inputs. Some of these steps could be omitted if the default data in the emissions model is representative of local data, or if reliable local data is not available. A brief discussion of some of these processes is provided below.

Treatment of Engine Starts, Soaks, and Diurnal Assumptions

Engine starts refers to the number of trips that are made in a given period. The use of transportation model can readily provide this data for use in emissions modelling. If the model is not structured to provide 24 hour forecasts, hourly trip departure assumptions or peak hour to daily conversion factors will need to be provided.

Soaking refer to emissions that are released during periods when a vehicle is not running, and are categorized as soaks or hot soaks (referring to a vehicle that has just been turned off). The emissions are highest immediately after the engine is shut down and decrease over time, reaching a baseline level in about an hour.

Diurnal emissions vary with the length of time a vehicle has been soaking (the length of time it has been parked). Diurnal soak time distributions represent the distribution of the length of time that vehicles have been soaking during the analysis period.

The MOBILE software relies on default values to replicate the distribution of travel over the course of a typical day which may be suitable for use in many emissions modelling applications, although results from a tour or activity based transportation model may be able to provide forecasts of these parameters that better reflect future local conditions in the study area.

Vehicle Class Distributions

The MOBILE software calculates emissions for 28 different vehicle classes. While information on the proportion of each vehicle type registered in the study area (NCR) may be available from the provincial transport ministries (Ontario and Québec), the TRANS model will not have the ability to predict vehicle demands for each of the 28 vehicle classes.

The Urban Transportation Emissions Calculator (UTEC), developed by Transport Canada, developed emission rates for 5 on-road vehicle types and 3 rail based types, based on a weighted average of the related MOBILE6.2C vehicle classes. The UTEC requires inputs of light duty automobiles (including trucks, SUV's and Vans), Light Duty Commercial Vehicles, Heavy Duty Commercial Vehicles, Urban Buses and Trolley Buses, in addition to 3 classes of rail vehicles.

At best, the model will be able to provide forecasts for three aggregate classes: auto, truck and transit vehicles[5]. The use of multi-class assignment techniques may improve emission forecasting results by allowing the transportation model to provide the estimates of vehicle demands that use each different class of road, by vehicle type (auto, truck). By doing this, the estimates can better reflect the projected mix of traffic using different types of roadways. Thus, roadways that attract a greater share of truck traffic would be expected to generate more emissions than roads with similar operating conditions that are dominated by cars.

Generating transportation forecasts at this level of detail would require well developed commercial vehicle demand matrices capturing both local truck movements and interregional truck movements operating within

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[5] Transit vehicles will need to be estimated based on service parameters and occupancy factors as the model forecasts transit person-trips rather than vehicle trips.

the NCR. Some data on commercial vehicle movements in the NCR may be available from the provincial transport ministries (Ontario and Québec Commercial Vehicle Surveys), recently undertaken in 2006 / 2007. The TRANS committee participated in that survey, which included O-D surveys of trucks using highways around the Ottawa-Gatineau region, and some of the major river crossings between Québec and Ontario.

In the absence of detailed commercial vehicle Origin-Destination flows, general assumptions with respect to commercial vehicle percentages by roadway type may need to be developed to estimate the emissions related to truck traffic. These can be link specific, to reflect observed truck shares from traffic count data. The inherent drawback of this approach is that the commercial vehicle demands are assumed to increase at the same rate as auto traffic on the link, irrespective of network improvements or increased levels of congestion.

Treatment of Intra-Zonal Trips and Centroid Connectors

Centroid connectors are intended to represent the travel undertaken on the local road network between the centroid of a traffic zone and the major road network represented in the model. For emissions modelling, the travel that is undertaken on the local road network is important to recognize as part of forecasting overall emissions in the NCR.

Often where the model is being used to compare alternative transportation improvements or evaluating policy options, the determination of emission levels due to traffic volumes on local roadways may be ignored, i.e. assumed to remain constant between the scenarios being evaluated.

However, in estimating travel on the local road network, two key factors need to be considered:

- **VKT on Centroid Connectors** - Auto and truck traffic using the centroid connectors represents traffic that is occurring on the local road network within the underling traffic zone system. An estimate of the veh-km traveled on these local roads therefore, needs to developed along with the average speed of this traffic. The most common approach to estimating VKT on centroid connectors in the US, utilizes a VKT adjustment factor. The adjustment factor is typically based on local estimates of VKT within a zone (sum of segment volumes x segment lengths for all local roads in zone) compared to the VMT represented on the centroid connectors in the model. This is a factor calibrated for the base year, which is generally applied for all forecast years, assuming the ratio of local travel to centroid travel remains constant over time. Average speeds for the portion of VKT using centroid connectors are typically assumed to be the same as the average posted speed limit on the local network. This approach of course assumes that the local road network is not affected by congestion.
- **VKT for Intra-zonal Trips** – Auto and truck demands that start and end within the same zone are not assigned by the model to the road network, although this component of local travel still occurs on the local roads (for auto and truck trips). Estimating the VKT for this component of the travel demand can be completed using an approach similar to the "nearest neighbour" technique used to estimate intra-zonal travel times. Intra-zonal travel time is typically calculated as one-half the average travel time to the adjacent zones. By using distance in this application, the intra-zonal travel distance can be calculated as one-half of the average travel distance to the adjacent zones. Multiplying this average distance by the intra-zonal demand can provide an estimate of the VKT for intra-zonal trips. The average speed for these trips can be calculated based on the average intra-zonal distance divided by the average intra-zonal travel time.

Treatment of Transit Trips

Most travel demand models forecast transit person trips or ridership as opposed to transit vehicle demands. For the purpose of emissions modelling, the VKT generated by transit vehicles needs to be estimated rather than the Passenger-Kilometres of Travel (PKT). The UTEC, developed by Transport Canada, is one exception, where the input for rail travel use is based on PKT. The documentation for the program does not indicate how the passenger demand is converted to rail based emissions.

Transit vehicle usage can be estimated outside of the modelling process by reviewing transit route and schedule information. In many cases, the route and schedule would not change in response to ridership demand, except on the busiest routes or express routes. Therefore the estimate of transit vehicle travel should also include a check of demands by route to determine in higher frequencies or additional vehicles would be required to serve projected demands.

7.2.4 Implementing GHG Modelling Procedures

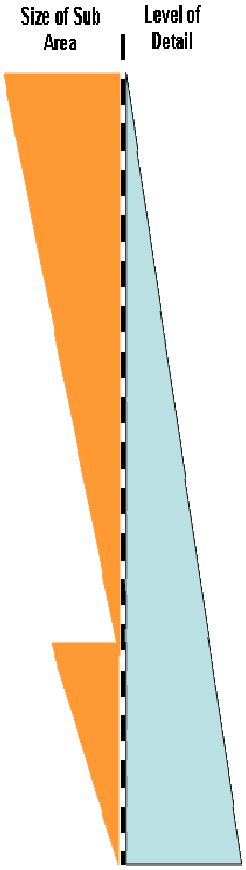
The development of a process for forecasting GHG emissions for the NCR may be best suited to a phased approach that incrementally builds towards a fully integrated system, as follows:

- Develop NCR specific inputs and default assumptions for use in GHG emissions modelling that reflect local data and conditions and produce emission rate tables by road type, speed range, and vehicle class using the MOBILE6.2C or the UTEC applications. Emissions would be calculated using a 'post model' processing approach. This would promote the use of consistent assumptions and application throughout the region;
- Develop an interface application (program or macro) to automate the calculation of total emissions based on transportation model outputs of VKT and emission model outputs, and include some capabilities to graphically summarize and/or display the results;
- Enhance the interface application to integrate with the transportation modelling process; using outputs from trip generation, trip distribution and mode split phases to generate or update the input files used by the emissions model prior to calculation of emission rates. This would ideally coincide with the development of full activity based modelling capabilities;
- Fully integrate the emissions modelling process into the travel demand forecasting process through the development of macros, scripts or programming routines.

7.3 Sub Area Modelling

The TRANS Model was developed and designed to provide regional strategic level forecasts of travel demand in the NCR. The model currently forecasts demands for three modes of travel including auto driver, auto passenger and transit modes. The traffic zone system, as redefined, is comprised of approximately 600 homogeneous zones that vary in size, with very small dense zones in the urban core areas, and large sparse zones in the suburban and external rural areas. The travel demand model is typically calibrated and validated at a screenline level of detail and forecasts of future travel demands and network performance results are also typically extracted and reported at a screenline level of detail.

Regional forecasting models are seldom designed or calibrated to undertake detailed forecasting of travel demands on individual road segments (links) or in smaller, detailed study areas. Consequently, the application of a regional scale model to examine localized roadway system performance, particularly in the outlying suburban areas of the NCR for example would require considerable additional validation and refinement. The updating of the TRANS model does, however, present opportunities to extend the capabilities of the travel demand model provided that the appropriate design considerations are incorporated into the model development so that future subarea modelling can be undertaken within a more reasonable framework for analysis.



7.3.1 Applications for Sub Area Modelling

Sub area modelling, or the modelling of discrete localized areas within a broader urban context, has a number of applications to planners and traffic engineers. The ability to utilize the model to estimate the future travel demands in a localized area, or a specific corridor, are critical components to many planning and engineering studies today. Some of the typical projects and applications for sub area modelling are listed below:

- **Transportation Network Improvement Studies (Master Plans) –** where the model is used to examine travel demands within an existing built up area at a more refined level of detail so as to test the effectiveness of different network improvements, policy applications, or land use scenarios;
- **Secondary Plan Studies –** forecasting localized transportation demands within a new development area and testing the effects of different land use / transportation policies, or road / transit network scenarios on forecasted travel demands and resulting infrastructure needs;
- **Corridor Environmental Assessment Studies –** utilizing the model to forecast the projected increase in demand for auto / transit travel within individual corridors under various land use, demographic, policy, and transportation network scenarios;
- **Corridor Traffic Operations Studies –** utilizing the model to forecast corridor growth rates used to adjust base year traffic counts to undertake detailed intersection traffic analysis for future conditions;
- **Micro-simulation Studies –** using model inputs / outputs to build micro simulation models of a localized corridor or broader area to undertake detailed simulations of alternative traffic control and infrastructure design scenarios.

The level of forecasting detail can also vary depending on the type and complexity of the individual study, although some general usage parameters can be summarized as shown in **Table 7-3**.

Table 7-3 Level of Forecasting Detail by Type of Study

Study Focus	Size of Study Area	Scope of Forecasting Work	Modes Typically Considered	Level of Detail
TMP	Broad – Citywide	• Road & Transit Demand to Support Infrastructure Needs • Policy Assessment	• Auto • Transit • Non Motorized	• Screenline / key corridor • Major Transit Lines
Secondary Plan	Larger New Development Areas	• Road & Transit Demand to Support Infrastructure Needs	• Auto • Transit - sometimes	• Key road / transit corridors • Major internal roads / intersections
Corridor EA Study	Narrow corridor plus parallel facilities	• Road or Transit Demand to Support Infrastructure Needs	• Auto or Transit (sometimes both)	• Road / transit corridor plus parallel routes • Crossing Roads / intersections • Station boarding / alighting
Traffic Operations	Single Corridor	• Road Demand to support operational analysis and infrastructure needs	• Auto	• Detailed corridor / intersection turning movements
Micro-simulation	Can range from a broad area to a narrow corridor	• Road Demand to support operational analysis and infrastructure needs (sometimes combined with transit veh demand to assess implications on roadway operations)	• Usually Auto	• Very detailed (simulation of individual vehicles or groups of vehicles) • Beyond capabilities of travel demand models

7.3.2 Considerations for Model Development

There is an underlying assumption with sub area analysis that "*conditions within the sub area will have no influence on conditions outside of the sub area*". Before proceeding with sub area analysis, it must be confirmed that this assumption is valid for the type of study being undertaken. This can affect all stages of the modelling process.

For example, testing various land use alternatives within the sub area, may impact population or employment allocations in other areas of the region, assuming that region wide or municipal control totals are being used. Using the same example, trip distribution patterns within and outside of the sub area may be affected by this same land use scenario. Other changes to trip distribution patterns may occur where major infrastructure improvements are included / tested within the sub area. Land use patterns may impact mode choice within and beyond the sub area, or the introduction and infrastructure within the sub area may also have a similar affect. Finally, trip assignment may be dramatically impacted by changes within the sub area, particularly where new infrastructure is provided to reduce the level of congestion which then results in drawing additional traffic into the sub area.

Before proceeding with extensive work on creating and validating a sub area model, it is recommended that this assumption be tested and confirmed within the region wide modelling framework. Through undertaking this test, the nature of the changes within the sub area can be better understood at a broad level, and the effective boundary of the sub area can be defined where the changes are found to have limited impact on model results.

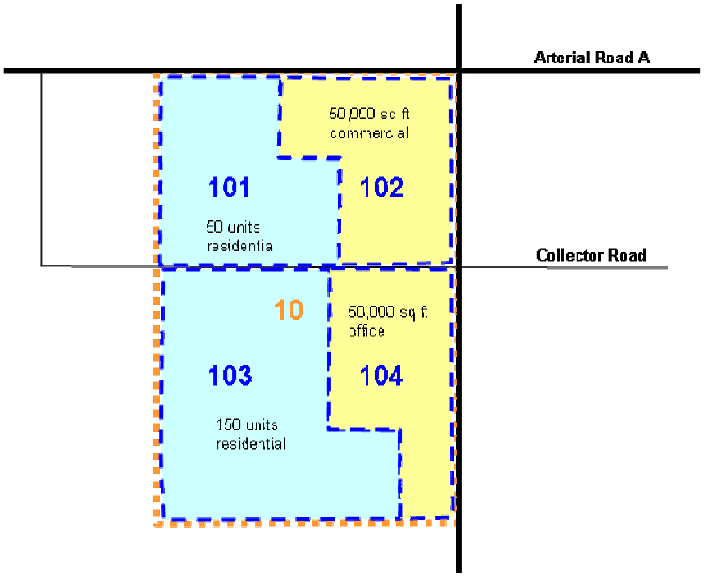
Considering the above caution, there are two main approaches that have been used for sub area analysis and planning; the "isolation" approach and the "focusing" approach. The isolation approach essentially isolates part of the network and creates external zones (or gates) at the boundaries of the sub area to reflect flows to and from the sub area. The creation of a sub area trip matrix (known as the Computation of Traversal Matrices in EMME) is completed to reflect the travel demands within the sub area. In addition, to the previous assumption about changes to the flows to and from the sub area discussed above, sub area matrices will be required to be developed for each horizon year using the regional model as a basis, as the trip patterns into and from the sub area may change with other changes in the overall model for the new horizon year. All procedures must be repeated from the beginning/initial steps if the user decides to change the definition of a sub area or to change an initial demand matrix. Third, the number of 'sub area gateways' that can be created in EMME is limited, which can affect the size of the sub area that can be analyzed.

The most common method to implement a focusing approach is to create a separate model with larger (aggregated) traffic zones and higher capacity links in areas remote from the sub area of interest, while improving the level of detail within the sub area. In reality this approach requires the creation, validation and calibration of another network with a corresponding databank. This process is time consuming and requires considerable care in the selection of appropriate detail and in the calibration efforts necessary to ensure it reasonably reflects the existing and future conditions and travel behaviours. The practical result is that when an aggregated system is prepared and calibrated it can only be applied to the sub area it was designed for and it tends to be difficult to change the boundaries of the sub area later.

Regardless of which approach is used, there are a number of issues to consider when attempting to improve the ability of a strategic model to undertake sub area analysis studies.

Zone Structure

The size and density of traffic zones within an area can certainly influence the approach and potential for improved accuracy that can be yielded through sub area analysis. The average zone density used in large urban Transportation Models in the US ranges between 0.9-0.5 Traffic Zones per square mile[6].



Within areas that have a relatively dense and small geographic zone structure, a reasonable sub area can usually be defined that allows for a more detailed modelling approach while respecting the homogenous nature of existing zones. For example, a sub area analysis of the downtown core area could yield more detailed model outputs without changes to the underlying traffic zone structure than a sub area within the greenbelt area, where the traffic zones are geographically large and have sparse activity levels (in terms of population and / or employment).

Where the zone system is relatively dense, changes to the location and number of centroid connectors for zones within the sub area could be used to provide a more refined loading of traffic onto the adjacent road network. Current practice typically includes unlimited capacity on the zone connectors, which can have the affect of all trips being loaded onto the network at one location, making local calibration of the road network flows in that area difficult. By using a reasonable capacity constraint on the zone connectors, and a VDF that encourages shifts to alternate connectors without skewing the overall travel time on the connector, may be effective at improving the network loading within the localized area of the network. Building these additional zone connectors into the overall model as it is being developed and calibrated would allow for the zone connectors to be properly established as part of the overall model development.

Where the zone system is geographically large or there are a large number of intra-zonal trips, simply changing the zone connectors may not be enough to yield more detailed modelling results. In this case, zone splitting may need to be considered prior to the assignment stage. Care must taken during this process to determine an appropriate zone system for the split zones that will achieve the desired improvements in modelling detail while providing a logical and practical basis for proportioning the trips from the larger zone to the sub area zones.

Ideally, the proportioning of trips from the original zones to the associated sub area zones should be done separately for different trip purposes, which can be tied to the land use characteristics within each of the new, smaller zones. Estimates of the sub area zone population and employment characteristics may be readily available from the City, although use of Census data (household / population counts and Place of Work data) may also provide a basis for splitting the existing population and employment into the sub zones. This could be achieved by:

- using the trip generation rates previously calibrated for the model for different trip purposes and the estimated population and employment within each of the sub zones to predict the number of trips from each of the sub zones (using the original zone productions and attractions as a control total), or

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[6] METROPOLITAN TRAVEL FORECASTING - Current Practice and Future Direction, Special Report 288, Transportation Research Board, 2007

- use of other types of trip generation rates (such as ITE Trip rates) to calculate the expected number of trips produced and attracted to each sub area zone and using these estimates to determine the appropriate proportion of the original zone productions and attractions to assign to each zone.

Where the land uses within the sub area are not particularly well matched to the trip generation rates established for the overall model (such as retail areas where employment levels are low relative to the intensity of trip making to / from these land uses) the later approach may improve the accuracy of the zone splitting estimates. Care will need to be taken to translate the intra-zonal demands from the original zone into O-D flows between the subzones based on a rational process that includes consideration of the trip productions and attractions within each sub zone.

Link / Network Coding Attributes

Typically in strategic area wide models, the level of detail for the road network or transit network represented is less than exists in reality. Local roads are typically omitted from large area models and minor and major collector roads may be omitted as well, depending on their role and function in the network. Similarly, local transit routes are usually omitted in large area planning models, with emphasis placed on major transit routes and higher order transit routes.

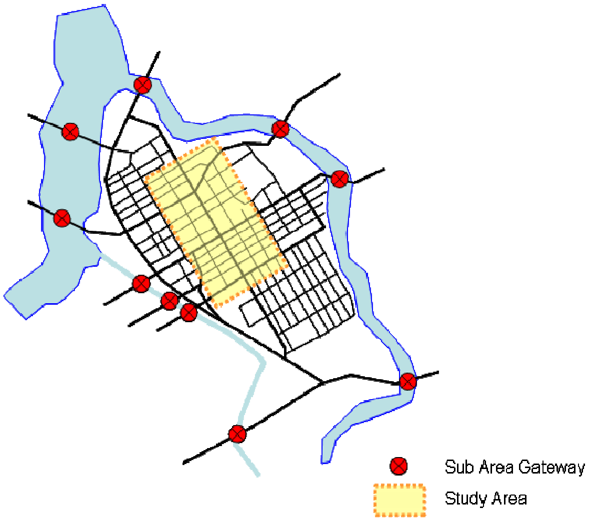
More recently, the increased governmental use and related sophistication of modern GIS systems within most municipalities combined with increased computational power of desktop computers has provided increased opportunities to include finer road network detail than would have been contemplated in the past. The lower travel speeds associated with the collector and local road network often limits the traffic assignment results at a network wide level while offering some opportunities to correct historical issues with respect to over-assignment to the major road network.

Within a sub area, a finer level of road network detail can be used to further improve the network loading characteristics within a sub area by providing a closer representation of the local street network. Rather than connecting centroid connectors to the major arterial road intersections, centroid connectors can be designed to connect to major or even minor collector roads, which allows for the model to more naturally load trips onto the road network. This approach may improve the ability to calibrate a sub area model at a link level of detail. Turning movements simulated by the model, while still very difficult to calibrate to observed volumes, can also be improved compared to more traditional network loading approaches.

Model Validation

For regional scale models, modifications undertaken to develop a sub area model often require more significant calibration and validation efforts as well as reasonability checks. A sub area model also needs to be calibrated to finer level of detail than strategic regional models to ensure that the model is able to replicate observed detailed travel patterns within the sub area. A screenline calibration process may still be appropriate, although the coverage of the screenlines need to be refined and detailed commensurate with the smaller study area scale than a screenline used to calibrate the regional model. Typically, a sub area model for localized analysis should be calibrated to match observed flows across a screenline comprised of no more than three or four major road links. For corridor studies, the level of calibration should be geared to the corridor level, with no more than one parallel road included on either side of the corridor.

Where a sub area is developed in an area where the original zone system is relatively coarse, it may still be difficult to achieve an adequate level of calibration within the sub area to support forecasting for detailed corridor studies. Practitioners have utilized O-D estimation techniques to adjust a sub area matrix to match observed traffic counts. This approach has been found to be useful, particularly where significant zone splitting is required, and there is concern that intra-zonal trips or other local trip making patterns are being reflected in the original demand matrix. A number of applications have been developed to update a demand



matrix based on traffic counts, including the "DEMADJ" macro developed previously for application within the EMME software environment.

Gateways

Gateways represent external "zones" for the sub area model and represent the origins or destinations of demands flowing into or out of the sub area.

The selection of the sub area model boundary should be based on the location of special interest as well as ensuring that sufficient portions of the adjacent transportation network is included to properly capture the type of response that may expected from the testing of alternatives or scenarios. For example, the preparation of simple forecasts where no changes are assumed to occur in the network may be able to use a very small and focused sub area model as the extent of re-routing would typically be expected to be minimal (except where there is major levels of congestion in the network). Where new infrastructure such as road links, transit lines, or new highways are being tested, a broader sub area will be required to capture the extent of mode choice or assignment changes resulting from the improvement. As noted previously, for applications where new major infrastructure is being tested, it is advisable to test the network wide implications of the improvement in the regional model to determine the extent to which the improvement results in significant changes to assignment results. Ideally, the sub area would include all of these areas, plus an area beyond the area of influence where results are stable.

Gateway locations would then need to be selected based on the extent of the sub area model selected. Careful selection of gateway locations during the sub area model definition stage can reduce the potential for unreasonable sub-area forecasts and improve the local calibration effort. Care must be taken to ensure that gateways are located on actual road / transit network links as opposed to centroid connectors, particularly if a zone includes more than one centroid connector.

It is critical that gateways be located to take advantage of physical boundaries that minimize route choices for users entering the sub area. For example, in a road network, locating the gateway at a location where there are a limited number of alternative routes increases the potential that changes within the sub area road network will have limited change to demand entering through the gateway. An example of this would be a major road corridor within an area bounded by water crossings. Expanding the sub area model to place gateways at the major water crossings may increase the size of the model but reduce the potential for assignment error within the modelling area.

7.3.3 Transferability to Other Analytical Tools

Project forecasts of traffic and/or transit ridership at more detailed levels are often carried out to facilitate additional analysis that is completed "outside the traditional modelling framework". For example, an area transportation study or corridor study may need to assess the performance of study area intersections in order to identify and define system improvements. Similarly, a transit corridor study may need detailed forecasts of boarding and alighting passengers in order to size parking facilities or station passenger platforms. Understanding the ultimate use of the model forecasts/outputs is an important element in providing the analyst with an understanding of the most appropriate subarea analysis procedure to use based on the level of detail and confidence level required in the forecasting results.

The most common use of detailed traffic volume forecasts, generated through a sub area modelling process, is to facilitate detailed traffic engineering assessment of study area intersection performance. Typically, model results are used to input into traffic engineering software, such as Synchro/Sim Traffic, Highway Capacity Software (HCS), Canadian Capacity Guide (CCG) software, or other detailed signal timing and analysis tools. For these applications, forecasts of intersection turning movements are required to be produced as part of the modelling effort.

Even where a sub area model has been developed, it is unlikely that the level of calibration will be suitable for use in directly forecasting turning volumes at intersections in the study area. In general, the methods used to prepare forecasts of intersection turning volumes depend largely on the size and complexity of the sub area. Two approaches are discussed below:

- Update Base Matrix – In this approach, a base matrix for the sub area is extracted from the sub area model using a Traversal Matrix approach. Existing base year traffic counts are used to adjust the base sub area matrix to match observed counts using a matrix estimation procedure (application of the DEMADJ macro in EMME). A review of the traffic count data is generally carried out prior to its application to the modelling framework to ensure it is representative of a common base year (corrected for seasonality factors and different count years). The future turning movements are obtained by applying growth factors to the estimated base sub area trip matrix, representing the forecasted growth in origins and destinations from the model and carrying out network assignment of the resulting future forecast trip matrix. This approach is often helpful when local trips (intrazonal trips) are not adequately represented in the model assignment results, but are reflected in link / turning movement counts. The adjusted base trip matrix takes these additional trips into account before applying the forecast growth in trips from the model. As would be expected, as the number of traffic count locations included in updating the trip base matrix the reliability of the forecasts increases proportionally.
- Link Based Growth – In this approach, base year intersection turning movement counts are factored to the future year based on the overall mid-block demand on the approach links for the future year. The intersection turning movements are converted to a matrix format and factoring is done using a fratar or furness method. Care should be taken to ensure that the link volumes forecast for the future year are reasonable compared to existing volumes before undertaking this step. Where the level of calibration is not suitable to use the future year forecasted link volumes directly, a growth factor based on the future year link volume divided by the simulated base year link volume could be used to estimate the final future link volume.

Micro simulation has emerged more recently as a technique applied to sub area modelling to provide a more detailed assessment of conditions within a localized area and the term implies simulates the flow of traffic on network elements at increased levels of fidelity. “Micro simulation” involves the development of a detailed model to simulate the movement of individual persons or vehicles through a transportation network based on very detailed inputs describing transportation network characteristics, person / driver behaviour and characteristics, and traffic control strategies (i.e. signals / signal timing, ITS, etc). “Micro simulation” is often used to describe a family of detailed simulation approaches, which vary considerably in their level of detail. The range of simulation approaches, include:

- Micro simulation – each vehicle is simulated individually as it moves through the network and vehicle movements are controlled by driver behaviour models, detailed car following logic, gap acceptance rules, and interactions with traffic control measures. This approach is the most sophisticated and complex simulation approach and provides the greatest range of analysis options, but requires significant input data and time to properly develop and calibrate the network;

- Mesoscopic level – vehicles are collected into traffic cells and streams and their movements are based upon predefined capacities and speed-density functions. Individual vehicle movements are tracked, but vehicle movements are determined based on aggregated speed-density functions rather than car-following and lane-changing logic. This approach is moderately complex while still offering a significant enhancement over traditional static models. The data requirements are more detailed than static models but is less intensive for network development and calibration than a micro simulation model; or
- Macroscopic level - vehicle movements are based upon volume delay functions that depend upon the functional class of the road system, similar to a travel demand model. The operation of traffic signals is not modelled explicitly in although signal timing plans are converted to movement based equivalent capacities. This is least complex approach but does not offer much more analysis capability than a static model. The data requirements are similar to that of a static demand forecasting model and therefore are less intensive for network development and calibration.

Many of these advanced traffic simulation models are either integrated with travel demand forecasting software or are capable of importing networks and travel demand matrices for use in developing sub area micro simulation models.

7.3.4 Steps Forward in Filling the Gaps

While it would be impractical to design a regional model that is suitably detailed and calibrated to undertake detailed sub area analysis forecasts in all areas of the City, there are steps that can be considered in future model enhancement process to move the model in this direction. Some of the key considerations may include:

- Zone system – The TRANS model zone system is quite detailed in many of the urban downtown areas today, and tends to become progressively more coarse as it moves out to the suburban areas based on the level of detailed planning of proposed development areas. Increasing the number of zones in some of the suburban areas may significantly improve the ability to utilize the model in the future to undertake or support sub area analysis in these areas in the future. Given that these suburban areas represent areas where new growth will be directed, the ability to undertake sub area analysis would significantly improve the ability to undertake the necessary secondary plan studies to assess growth related transportation needs. Historically the decision on the most appropriate number of zones to use in a regional model has in part been based on computer processing requirements. Recent advances to transportation planning software and computer hardware has made it much more practical to run large scale models with an increased number of zones, than in the past.

  As part of the TRANS model update, the zone system was refined to increase the number of zones from the previous 344 zone system to the new 600 zone system. This zone system was used to incorporate the results from the recent 2005 Household survey into the model development process. This additional refinement should improve the ability to undertake sub area analysis within the new model. It is recommended that a rigorous methodology for zone splitting be developed for use in the suburban growth areas where the zone structure is still relatively large, to ensure that future sub area modelling in these areas is applied on a consistent basis.
- Network Detail – Similar to the concept of an increased level of detail in the zone system, the level of detail used for network coding in the TRANS model significantly improves the ability to utilize the model for more localized analysis. Increasing the number of zone connectors, implementing reasonable capacity constraints on the zone connectors, and examining how the connectors load traffic into the network can go a long way to improving the accuracy of forecasts at a detailed level. Including more collector roads within the model road network, and using these to distribute traffic to /

from the centroid connectors, may allow for improved network loading that is closer to established traffic patterns. The additional detail may also provide improved estimates of intra-zonal travel time and walk times, which is critical in terms of modern transit mode split forecasting. It is therefore important that the road/transit networks within the model be continually updated in this respect, particularly for new growth areas. The completion of Secondary Planning Studies and related planning studies are often carried out in sufficient detail to provide increased level of detail for the future underlying road/transit network structure and consequently serve as an important source to adjust and revise the road/transit network detail as well as the zone connectors in these growth areas.

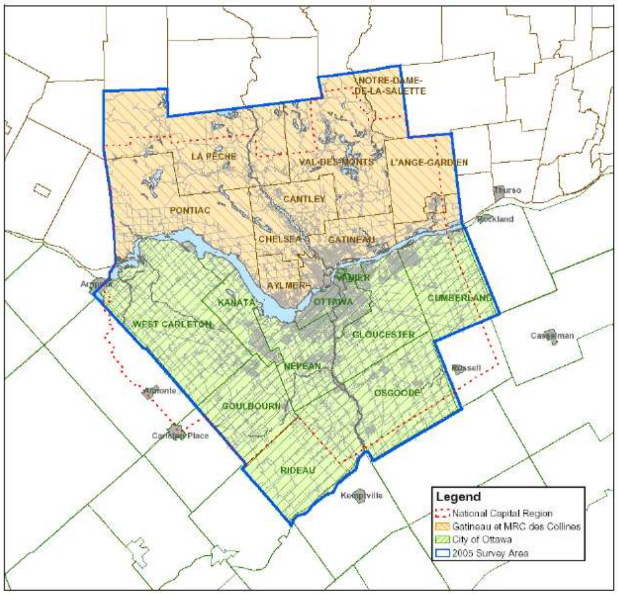
7.4 Ongoing Data Refinement and Updates

The TRANS Model Redevelopment Study carried out and documented within this report relied on a number of recent data collection activities across the National Capital Region (study area as defined by the City of Ottawa, Ville de Gatineau and the Municipalité régionale de comté des Collines de l'Outaouais). Many of these data collection efforts were focussed on identifying the trip characteristics, travel behaviours and trip patterns of the resident population of the study area. While these study area datasets proved considerably valuable in the redevelopment of the TRANS model to forecast local travel patterns based on resident travel needs there are a number of other travel components that impact on the overall daily travel within the study area. The redeveloped TRANS model while not specifically forecasting travel associated with commercial or externally based travel does include specific features to adequately consider the impacts of these two important travel components. These two specific travel components which influence the overall travel demands observed on area transportation systems and the need to update base year estimates of travel are discussed in the following sections.

7.4.1 External Based Travel

The redeveloped TRANS model is based on forecasting travel demand based on demographic projections within a predefined study area (see Exhibit 7.1 Study Area: TRANS Model). The areas located outside the collective boundaries of the City of Ottawa, Ville de Gatineau and the Municipalité régionale de comté des Collines de l'Outaouais (i.e. Carleton Place, Russell, Rockland and Thurso) while being classified as located

Exhibit 7.2 Study Area TRANS Model



within the Ottawa-Gatineau commuter shed are not explicitly included in the forecasting of travel behaviour within the modelling framework. However, the TRANS model does include opportunities to "account" for travel demands associated with the regions outside the study area through the establishment of a number of external traffic zones. These external traffic zones represent areas located outside the "resident" study area of the model and consequently travel demands impacting on the study area are typically developed based on comprehensive roadside travel surveys. These surveys are typically updated to reflect growth in travel from the commuter shed as well as identifying key trip destinations within the study area (Ottawa-Gatineau). These surveys are then aggregated and used to produce a trip table for the base year.

The most recent comprehensive O-D external survey was carried out in 1993. The trip table, prepared based on reported travel patterns and trip characteristics in 1993, has in the intervening years been updated based on traffic volume counts carried out at major gateways leading into Ottawa-Gatineau. While this approach ensures the scale of the travel entering the Ottawa-Gatineau region is up to date, little is gained in terms of understanding the trip patterns, destinations within Ottawa-Gatineau. Consequently, periodic updates of externally based travel is fundamental in understanding the dependency of the outlying commuter shed on specific regions of the combined cities of Ottawa and Gatineau. Surveys of this nature identify the relationships and trip characteristics of travel between outlying communities and Ottawa-Gatineau and serve as a basis to identify future year travel demands and impacts on area roadways and public transit systems.

In addition to the traditional surveys which tend to extract a representative sample of the observed roadside traffic on key roadways which serve as gateways into Ottawa-Gatineau, the Census of Canada also collects relevant information regarding specific home/work locations. The Place of Work, Place of Residence (POW/POR) data also provides detailed information with respect to the scale of commuting between outlying communities and Ottawa-Gatineau.

Updated information on the scale of growth in externally based travel (non residents but within the commuter shed of the regions) while an important segment of travel on area roadways and transportation infrastructure has been estimated based on previous surveys to represent less than ten percent of peak hour regional trips. However, as new data and updated travel demands from areas outside of Ottawa-Gatineau are collected they can be fully integrated with the existing TRANS model as described in the appropriate sections of the Users Guide.

7.4.2 Commercial Vehicle Activity

As described previously the TRANS Model was developed to explicitly model travel behaviour of the population of Ottawa-Gatineau based on the reported travel characteristics in the 2005 TRANS Travel Survey. It is noted that commercial travel is not typically reported in these resident based surveys (OD surveys are administered to a sample of households where specific travel associated with the household is obtained). Commercial travel includes travel by both heavy trucks as well as light trucks and other vehicle types which are engaged in commercial activity. The TRANS Goods Movement Survey undertaken in the early 1990's was designed to capture a significant portion of this travel component. This survey, as well as more recent provincial studies, are designed to focus on identifying specific "hot spots" for commercial travel including heavy truck origins and destinations. Identifying specific locations where significant volumes of commercial vehicles exist are helpful in development modelling approaches and land use relationships to assist in future forecasting growth in this important travel component.

In many cases, peak period traffic counts on area roadways are also particularly helpful in identifying the volume and percentage of overall travel which can be classified as being part of the commercial vehicle travel component. The 1999 and 2006 National Roadside Surveys (NRS), a truck origin-destination survey covering inter-provincial truck movements are typically used as well as traffic counts at intersections and screenline classification counts to assist in quantifying commercial travel. The TRANS Model as redeveloped includes the impacts of commercial vehicle activity on area roads based on a predefined trip table which is an estimate of the peak hour commercial travel. Existing estimates of commercial travel (trip matrices) are assigned to the base road network and validated against the observed ground counts.

While a number of techniques within EMME/3 are available to update and validate base year data, similar to the externally based trip tables used by the model it is important to undertake specific surveys periodically to ensure the commercial vehicle matrix reflects the existing travel patterns (as well as emerging activity centres for commercial vehicle activity) and can therefore be used to forecast future year commercial vehicle travel.

Technical Appendices (Bound Separately)