SANDAG – Commercial Vehicle Model (CVM)

Final CVM Model Development and Calibration

Project Deliverable: M.9B
Project Documentation: Working Paper 8

HBA Specto Incorporated
Calgary, Alberta

July 2014

Table of Contents

Tables

Figures

1. Introduction

This Working Paper describes the development and calibration of the SANDAG Final Commercial Vehicle Model (CVM), implemented in SANDAG in the spring of 2014.

Establishment work-related person and vehicle movement travel data, collected as part of the SANDAG Work-Related Travel Survey conducted between November 2012 – September 2013 (documented in the SANDAG CVM Report “Work-Related Travel Survey Final Report and Datafiles, produced by HDR Engineering Inc in December 2013), together with 2013 GPS SANDAG area commercial vehicle movement data purchased by SANDAG from ATRI (American Transportation Research Institute), was used to upgrade and refine the existing SANDAG Interim CVM model.

The SANDAG Interim CVM model was implemented in the SANDAG travel model system in the fall of 2012, using a model framework that HBA Specto had successfully developed and applied elsewhere (Calgary, Edmonton, California Statewide Travel Demand Model (CSTDM) and the San Joaquin Valley Interregional Travel Model (SJVITM)).

Working Paper 2 of this project (Model Structure Specification, produced in August 2012) identified possible upgrades to the Interim CVM model that might be possible, given the availability of the SANDAG Work-Related Travel Survey data. The Final CVM explicitly includes the following upgrades identified in Working Paper 2:

- Expansion of industry categories used in the CVM, with the splitting of the original Service industry category into two distinct groups – Government / Office and Service;
- Explicit incorporation of the SANDAG model system time periods into the CVM;
- Inclusion of an additional sub-model to forecast commercial vehicle trip use of toll facilities / managed lanes.

The Final CVM Model was calibrated to match targets derived from the observed establishment commercial vehicle movements in the SANDAG region obtained in the SANDAG Work-related Travel Survey.

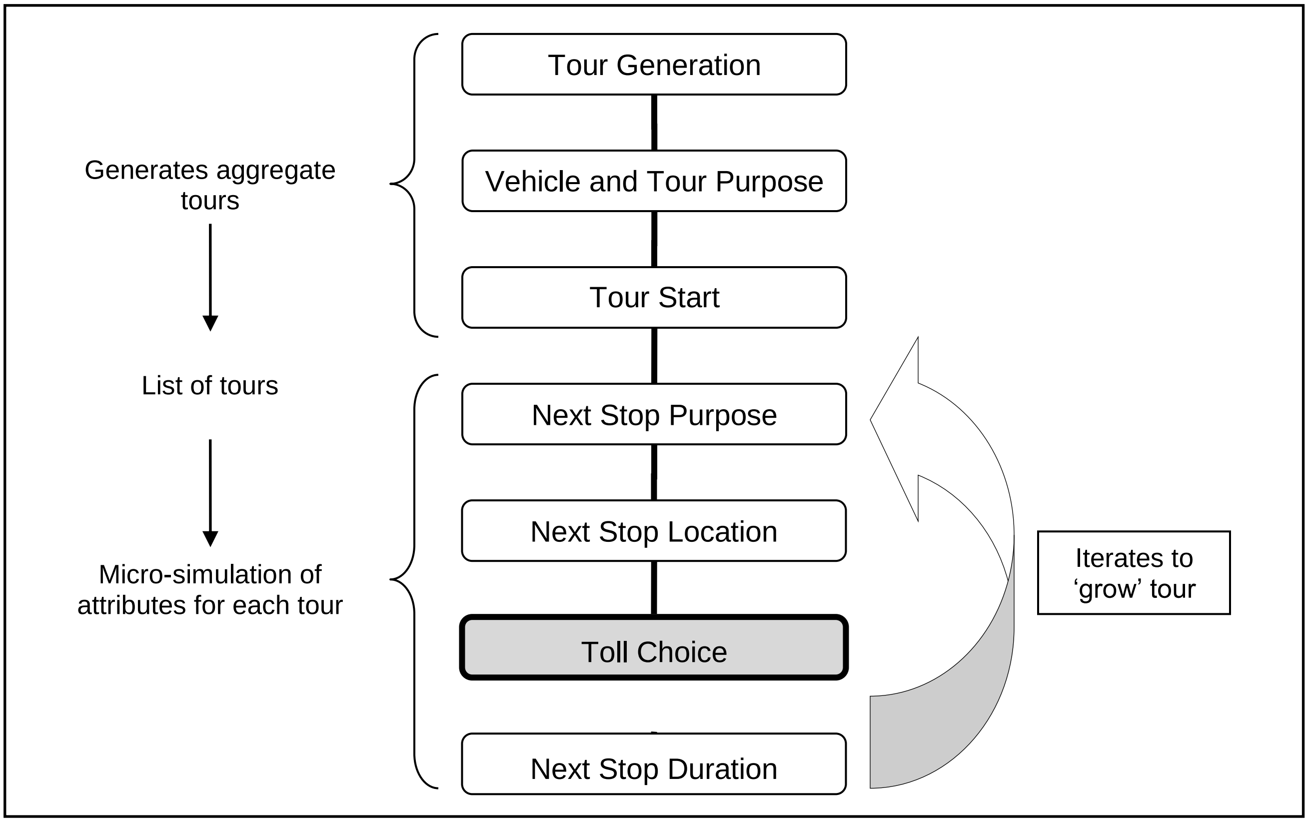
This Working Paper has three main themes:

- Sections 2 through 4 give an overview and detailed description of the specification and form of the SANDAG Final CVM. The model is similar to that of the Interim CVM, with the inclusion of the modifications identified above.
- Section 5 discusses the Final CVM model calibration and validation;
- Section 6 describes the implementation of the Final CVM model in the SANDAG travel model operating environment.

2. Final CVM Model Overview

The tour-based CVM is a group of models that work in series. A basic schematic of the models is shown in Figure 1.

Figure 1: Tour-Based Model Structure



Tour generation quantities by vehicle type, tour purpose, and time of day are generated for each TAZ, using logit and regression equations applied with aggregate TAZ inputs and travel accessibilities, to create a list of tours.

Individual tours generated from each TAZ are then assigned a next stop purpose, next stop location and next stop duration using a micro-simulation process.

In this process, Monte Carlo techniques are used to incrementally 'grow' a tour by having a 'return-to-establishment' alternative within the next stop purpose allocation. If the next stop purpose is not 'return-to-establishment', then the tour extends by one more stop. The location and duration of the next stop are then estimated. For each trip it is also determined whether a toll facility is used as part of the route choice process.

These steps are repeated until the "return to establishment" next stop purpose is chosen.

Seven establishment types are considered, based on aggregations of NAICS categories:

- Industrial (IN) – NAICS 11, 21, 23, 31-33,;
- Wholesale (WH) – NAICS 42;
- Service (SE) – NAICS 61, 62, 71, 72, 81;
- Government / Office (GO) – NAICS 51, 52, 53, 54, 55, 56; 92;
- Retail (RE) – NAICS 44-45;
- Transport and Handling (TH) – NAICS 22, 48-49;

  Fleet Allocator (FA) – (All but Military) (a specific type of establishment that uses a large, coordinated fleet that tends to service an area rather than specific demands – examples include mail and courier, garbage hauling, newspaper delivery, utilities and public works).

Four commercial vehicle types are used, defined in Table 1:

- Light vehicle - FHWA classes 1-3;
- Medium Truck < 8.8 short tons (17,640 pounds) – FHWA classes 5-6;
- Medium Truck > 8.8 short tons (17,640 pounds) – FHWA classes 5-6;
- Heavy Truck – FHWA classes 7-13.

Table 1: CVM Vehicle Classes by FHWA Classification / Caltrans Count Program

FHWA 13 Classes			CVM	Caltrans
#	Vehicle Type	Axle Range		
1	Motorcycle	2	n/a	n/a
2	Passenger Car	2+	Light	n/a
3	Pickups, Vans, SUV	2+	Light	n/a
4	Buses	2+	n/a	n/a
5	2-axle, 6-tire, Single Unit Truck	2	Medium	2-axle
6	3-axle, Single Unit Truck	3	Medium	3-axle
7	4+axle, Single Unit Truck	4+	Heavy	4-axle
8	4 or less axle, Single-Trailer truck	4 or less	Heavy	4-axle
9	5-axle, Single-Trailer truck	5	Heavy	5+axle
10	6+axle, Single-Trailer truck	6+	Heavy	5+axle
11	5 or less axle, Multi-Trailer truck	5 or less	Heavy	5+axle
12	6-axle, Multi-Trailer truck	6	Heavy	5+axle
13	7+axle, Multi-Trailer truck	7+	Heavy	5+axle
14	5-axle 3-axle tractor 2-axle trailer	5	Heavy	5+axle

Note: Class 14 is Caltrans additional Class

Note: in the original CVM model urban area application in Alberta designated truck routes exist – trucks 8 metric tonnes or heavier are required to use these designated routes. The CVM commercial vehicle categorization is explicitly designed to incorporate this weight limit.

The micro-simulation nature of the Final CVM model means that trip start and end times are forecast to the nearest minute. In actual application this continuous time treatment is represented a series of time period groups covering the weekday being modeled. The treatment of time in the Final CVM is consistent with the SANDAG travel model framework:

- The 5 time periods into which the daily tours generated in the Final CVM model are allocated for Tour Start Time, and summarized for integration into the SANDAG travel model vehicle assignment process – Early, AM Peak, Midday, PM Peak, Late.
- The 40 time periods identified in the Final CVM trip list output – these are compatible with the 40 time periods used in the SANDAG person ABM.

Table 2 gives the 5 time periods used in the CVM Tour Start Time model and CVM summary output, for SANDAG traffic assignment and travel skimming.

Table 2: Final CVM Model Time Periods

Time Period	Definition
Early	3AM – 6AM
AM Peak	6AM – 9AM
Midday	9AM – 3:30PM
PM Peak	3:30PM – 7PM
Late	7PM – 3AM

Table 3 gives the 40 fine time periods used to categorize CVM trip list output, starting at 3AM.

Table 3: Final CVM Model Trip List Output Time Periods

Period	Time	Period	Time	Period	Time	Period	Time
1	03.00 – 05.00	**11**	09.30 – 10.00	**21**	14.30 – 15.00	**31**	19.30 – 20.00
2	05:00 – 05:30	**12**	10:00 – 10:30	**22**	15:00 – 15:30	**32**	20:00 – 20:30
3	05:30 – 06:00	**13**	10:30 – 11:00	**23**	15:30 – 16:00	**33**	20:30 – 21:00
4	06:00 – 06:30	**14**	11:00 – 11:30	**24**	16:00 – 16:30	**34**	21:00 – 21:30
5	06:30 – 07:00	**15**	11:30 – 12:00	**25**	16:30 – 17:00	**35**	21:30 – 22:00
6	07:00 – 07:30	**16**	12:00 – 12:30	**26**	17:00 – 17:30	**36**	22:00 – 22:30
7	07:30 – 08:00	**17**	12:30 – 13:00	**27**	17:30 – 18:00	**37**	22:30 – 23:00
8	08:00 – 08:30	**18**	13:00 – 13:30	**28**	18:00 – 18:30	**38**	23:00 – 23:30
9	08:30 – 09:00	**19**	13.30 – 14:00	**29**	18:30 – 19:00	**39**	23:30 – 24:00
10	09:00 – 09:30	**20**	14:00 – 14:30	**30**	19:00 – 19:30	**40**	00:00 – 03:00

Five TAZ level land use types are used in the model:

1. Low Density
2. Residential
3. Commercial
4. Industrial
5. Employment Node

Each TAZ is allocated to one of these land use types, based on whether it satisfies the definition criteria set out in Table 4. These conditions are applied in the order of the land use types given above i.e. a TAZ is first assessed to determine if it is land use type 1 (Low Density); if it does not meet the criteria for this land use type it is assessed to see if it is land use type 2 (Residential), and so on. If a TAZ does not meet the criteria for any of the first 4 land use types it is allocated to land use type 5 (Employment Node).

Table 4: TAZ Land Use Types: Definition Criteria

Land Use Type	Population Density (Persons/Sq.mi)	Employment Density (Jobs / Sq.mi)	Other
Low Density	<250	<250	n/a
Residential	>250	n/a	>2 persons / job
Commercial	n/a	>1,500	1. Retail + Service + Government / Office jobs > 60% TOTAL (excluding work at home) 2. Retail jobs > 25% of Retail + Service + Government / Office jobs
Industrial	n/a	<15,000	< 80% TOTAL jobs are office-based
Employment Node			

Notes:

1. Retail Jobs = Retail Trade + Leisure & Hospitality + Other Service

2. Service plus Government / Office Jobs = FIRE + Information + Personal Business + Education & Health + Government

3. Office jobs = Retail + Service + Work at Home (sedw)

Additional zonal employment characteristics used are:

- percentage of employment in employment categories;
- 0-1 variable whether absolute zonal employment by industry > 500;
- 0-1 variable for Retail Zone (Retail Employment > 50% Total Employment)
- total jobs within 30 minutes travel time.

Travel utilities based on cost are used for travel for movements between zones.

These vary by vehicle type and are always a negative value. The values are determined using the following equation:

Travel Utility ***ij*** = A x Travel Time ***ij*** + B x Travel Distance ***ij*** + C x Travel Toll ***ij***

where A,B and C are shown in Table 5:

Table 5: Travel Utility Coefficients

	Light Vehicles	**Medium Vehicles**	**Heavy Vehicles**
A (Time - minutes)	-0.313	-0.313	-0.302
B (Distance - miles)	-0.138	-0.492	-0.580
C (Toll - $)	-1.000	-1.000	-1.000

These values were originally established using a stated preference study of commercial vehicle route choice by commercial vehicle drivers in Montreal, Canada[1]. The values in Table 5 have been converted to US$ and per mile equivalents. Tolls applying to truck origin-destination travel can be added to the time and distance $ cost equivalents established using the above parameters.

[1] Hunt JD and Abraham JE, 2004, Stated Response Examination of Factors Influencing Commercial Movement Route Choice Behaviour, Proceedings of the 8th International Conference on Applications of Advanced Technologies in Transportation Engineering, Beijing, China, May 2004, pp:72-77.

Travel time, distance and toll can vary between time periods, resulting in separate utilities for each time period. The early and late time periods use the off-peak time period skim assignment results.

Zonal accessibilities are also used throughout the micro-simulation process. Both total employment and population accessibilities are determined using the following function:

$Accessibility_{\boldsymbol{i}}$ = $\Sigma_{\boldsymbol{j}}\ (Opportunity_{\boldsymbol{j}} \times e^{(\lambda \times \text{travel utility } \boldsymbol{ij})})$

where:

$Accessibility_{\boldsymbol{i}}$ = the accessibility for a given zone ***i*** to a particular factor

$Opportunity_{\boldsymbol{j}}$ = the quantity of the factor in zone ***j***

λ = 1.0 for heavy vehicles; 2.0 for medium; 3.0 for light

The above “lambda” values are “asserted values” based on an analysis of accessibility measures results, using various formulations. They reflect the disutility of travelling greater distances. They also produce a hierarchical sensitivity to travel for light, medium and heavy vehicles, with light vehicles being most impacted. Figures 2A to 2D show TAZ level employment and population accessibilities by light and heavy vehicle type for San Diego - darker colours indicate higher accessibility values. Note: These accessibility plots were developed using the 2008 California CSTDM model and zone system.

Figure 2A: Light Vehicle Accessibility to Employment

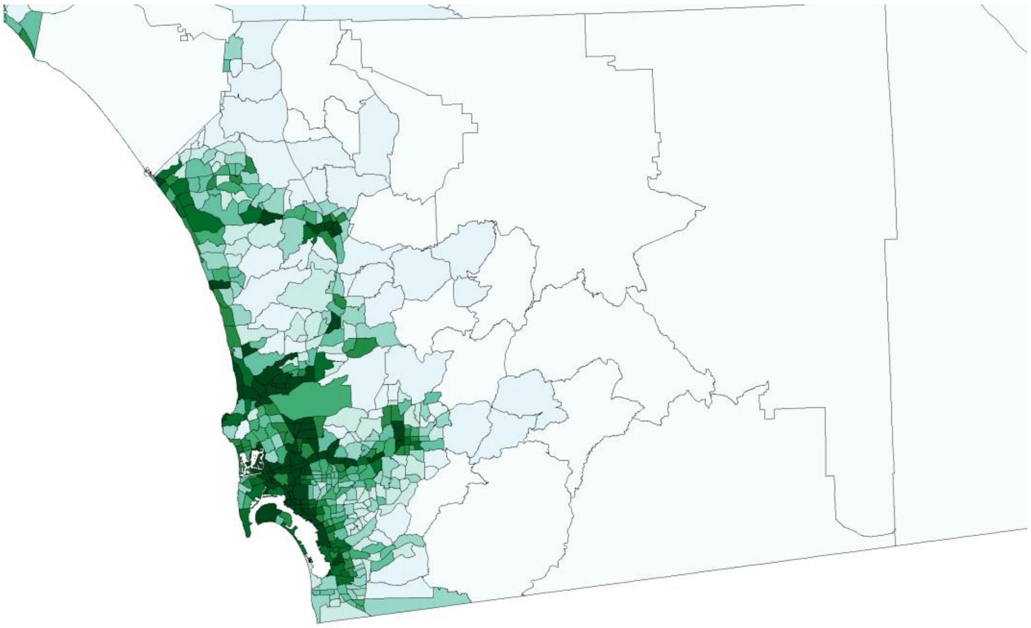


Figure 2B: Heavy Vehicle Accessibility to Employment

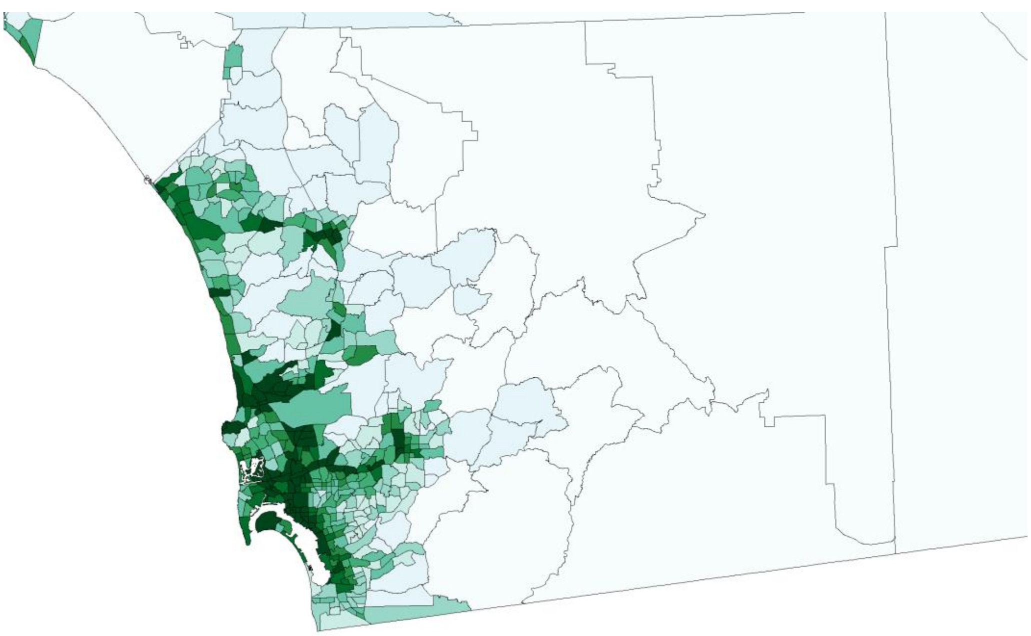


Figure 2C: Light Vehicle Accessibility to Population

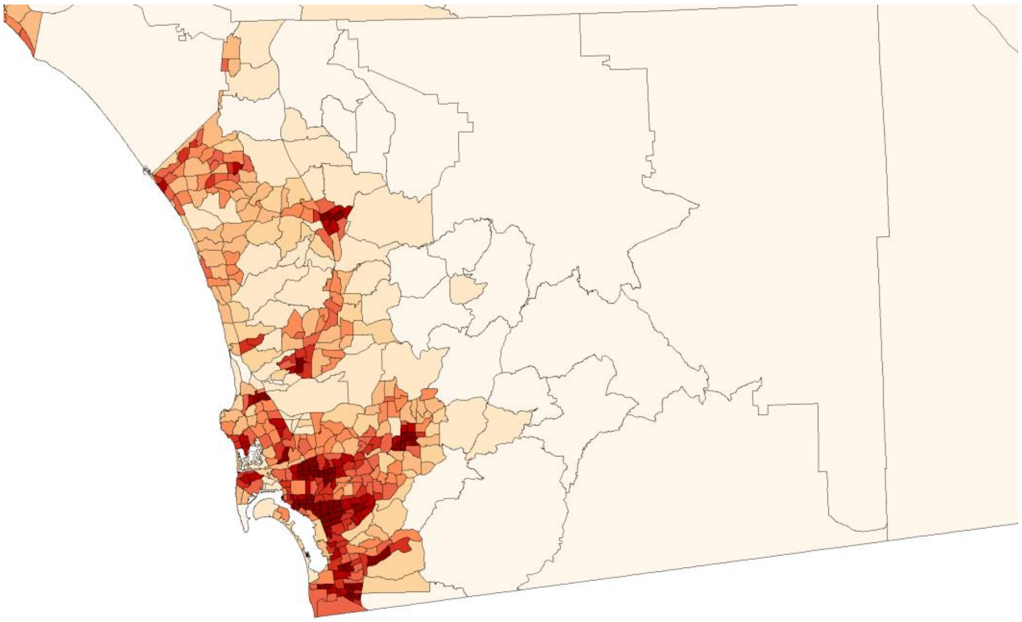
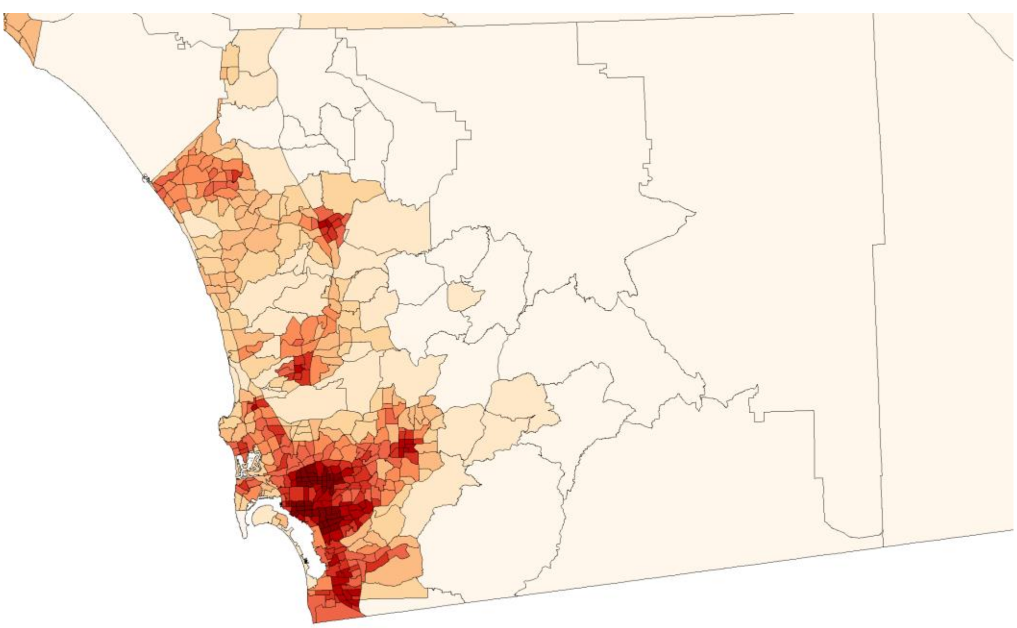


Figure 2D: Heavy Vehicle Accessibility to Population



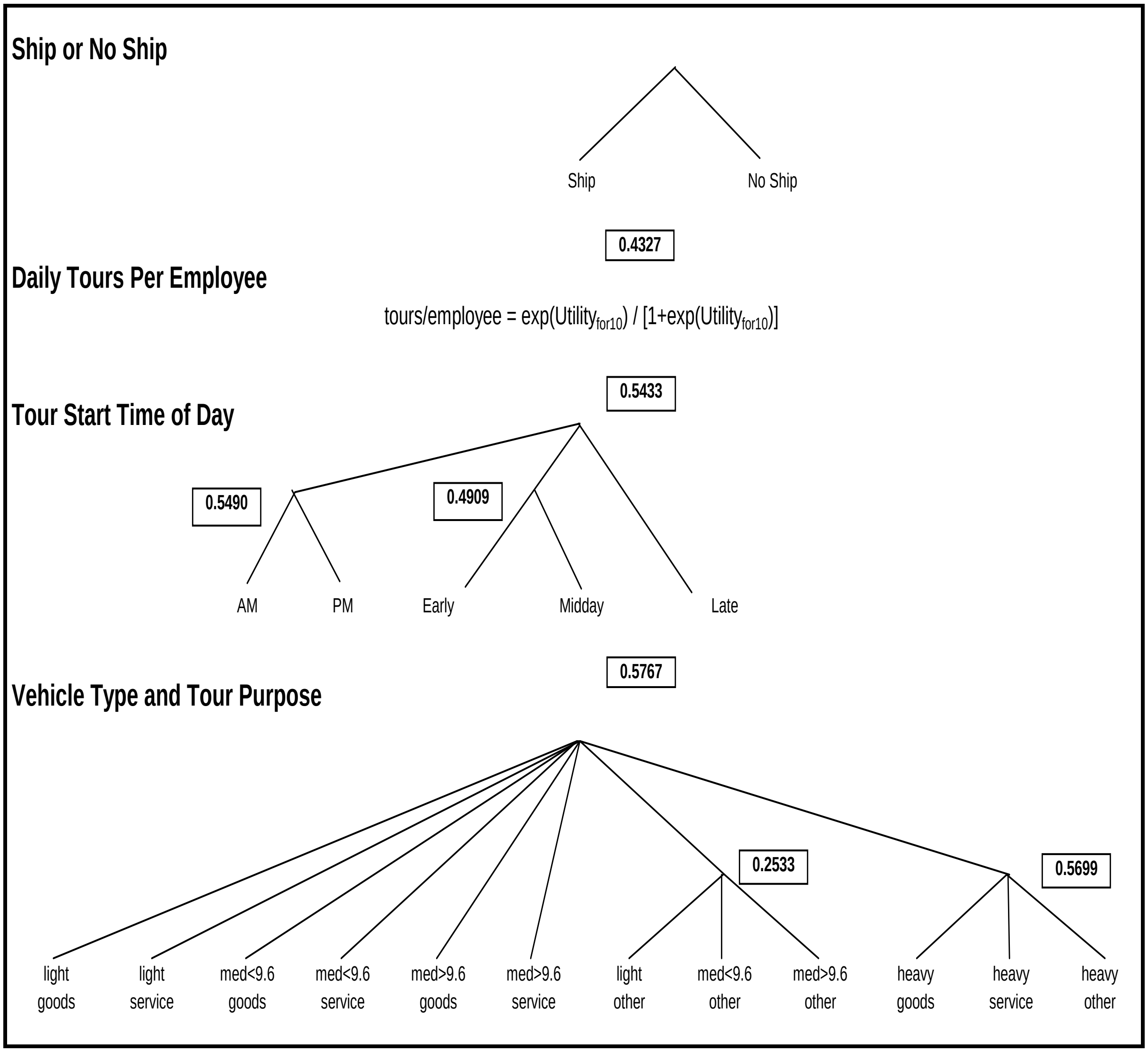
3.0 Final CVM Aggregate TAZ Tour Generation

The number of tours generated for a given zone, vehicle type, purpose and time period is determined using a sequence of nested logit models that start with the relevant total employment in the zone and calculate in order:

- **Ship or No Ship**: estimating out of the total employment in the type of firm for the segment in the zone, the proportion of employment and thus the aggregate employment at ‘shippers’ establishments;
- **Daily Tours Per Employee**: the tours per employee and hence the total number of tours originating in the zone; the range of alternatives goes from 0 to 10 tours per employee (The tours per employee model was estimated using aggregate multiple linear regression with the logarithmic transform of a binary logit expression for the alternatives 0 tours and 10 tours where the utility expression is associated with the 10 tours alternative. The maximum number of tours per employee was larger than 1 and much smaller than 10, which led to the selection of a maximum value of 10 for all segments);
- **Time of Day**: the allocation of the tours originating in the among start times in each of five time periods covering the 24 hours of a typical workday; and
- **Vehicle Type and Tour Purpose**: the allocations of the tours with a given start time period from a zone among vehicle types (among Light, Medium<8.8 tons, Medium>8.8 tons and Heavy) and tour purposes (among Goods, Service and Other).

Figure 3 illustrates the specific nesting structure for the sequence of models for the ‘industry’ firms segment. The nesting structures for the other segments are similar, with slight differences in the structures for the two ‘lowest’ level models concerning the allocations among start times, vehicle types and tour purposes.

Figure 3: Tour Generation Model Structure Example: Industry Tours



As shown in Figure 3, the generation of tours is a multi-step process. The general form of the daily tour generation equation for zone *i* is:

$$\text{Daily Tour Generation}_i \quad = \quad \text{Probability Ship}_i \times \text{Tours/Employee}_i \times \text{Employment}_i$$

3.1 Ship / No Ship Models

The probability of ship/no ship equation for zone *i* is:

Probability of Ship_i = (exp (Utility Ship_i)) / (exp(Utility Ship_i) + exp(Utility No Ship_i))

Utility Ship_i = Σ (Attribute of zone_i x Attribute Coefficient) + Ship Constant

Utility No Ship_i = 0

The utilities for ship by employment category are shown in Table 6.

Table 6: Utility Coefficients for Ship/No Ship by Employment Category

Attribute	Industrial	Wholesale	Retail	Service / Government Office Fleet	Transport & Handling
Ship Constant	1.4892	1.7799	0.0176	-3.6358	1.7632
Ship Constant Fleet				-6.1252	
Commercial Land Use	-0.3602		0.2937		
Industrial Land Use		0.6988		-0.1177	
Employment Land Use	0.5372	1.5434	0.2942	-0.7016	-4.0396
Employment Land Use : Fleet				-4.4767	
Retail Zone	-0.8298	-1.0950	-0.8221	-	-0.8195
% zonal employment INDUSTRIAL	1.0710	-	-	3.0730	-
% zonal employment WHOLESALE	-	-2.507	4.9340	5.1810	-
% zonal employment RETAIL	-	-	-0.9041	-	-
% zonal employment SERVICE	-1.2730	-2.9870	-0.5956	2.3220	-2.2340
% zonal employment TRANSPORT & HANDLING	1.0250	-	-	3.0810	-
Composite Utility – Tour Generation	0.4327	-	-	0.5180	-

Note: Fleet Allocator category is applied to total zonal employment

The composite utility of Tour Generation is calculated by taking the "logsum" of the exponents of the utility of tours / employee AND the utility of making no tours (set at 0).

3.2 Daily Tour Generation Models

The utilities for daily tour generation by employment category are shown in Table 7.

Table 7: Utilities for Daily Tour Generation by Employment Category

Attribute	Industrial	Wholesale	Retail	Service / Government Office Fleet	Transport & Handling
Generation Constant	-3.1870	-3.8423	-3.3526	-2.7782	-3.8125
Generation Constant Fleet				-0.4867	
Residential Land Use		0.4932	0.4932		0.4932
Commercial Land Use				-0.7137	
Industrial Land Use	-0.6467				
Employment Land Use	-0.4693	-0.0407	0.0730	-2.0166	0.7719
Employment LU: Fleet				2.1527	
% zonal employment INDUSTRIAL	-0.9668	-	-	-	-
% zonal employment WHOLESALE	-	0.6118	0.6118	-	0.6118
% zonal employment RETAIL	-	-	-	1.0441	-
% zonal employment SERVICE	0.8487	0.6922	0.6922	-	0.6922
Log (Jobs within 30 minutes)	-0.1116	-0.0752	-0.0752	-0.2441	-0.0752
Composite Utility – Time of Day	0.5433	0.6078	0.3097	0.2308	0.4573

The daily tour generation per employee for zone *i* is calculated as follows:

Utility Tour Generation = ln((tours/employee/10)/((1-(tours/employee/10)))

Utility = ln((R/10) / ((1-(R/10))) where R = tours/employee

exp(Utility) = (R/10) / (1-R/10)

(1-R/10)*exp(Utility) = R/10

R	=	(10-R) * exp(Utility) =10*exp(Utility) - R*exp(Utility)
R + R*exp(Utility)	=	10*exp(Utility)
R(1 + exp(Utility)	=	10 * exp(Utility)
R	=	(10*exp(Utility))/(1+exp(Utility))
Tours/employee	=	(10*exp(Utility))/(1+exp(Utility))

3.3 Tour Time of Day Models

Once the number of daily tours is determined, the tours in each zone are split among each time period by establishment category.

The split among time periods is determined using a logit model formulation as follows:

Tour Generation by Time Period = Daily Tour Generation x Probability U_T

where:

Probability U_T	=	exp (U_T)/ Σ exp(U_T) all time periods
U_T	=	ASC_T + Σ (Attribute of zone *i* x Attribute Coefficient)

where:

U_T	=	utility function for a given time period
ASC_T	=	alternative specific constant for a given time period

The nesting structures for each employment category are given in Figures 4A to 4E. These structures were determined as part of the logit model estimation process for the Edmonton CVM model. They reflect the actual patterns of variation in the observed data for each industry segment. Sub-nests show time periods groups with more variation explained within the grouping - “nesting parameter” values are all between 0 and 1 as required by theory. Estimated time period specific attribute coefficients and resulting calibrated values are shown in Table 8A to Table 8E below.

Figure 4A: Tour Time of Day Nesting Structure: Industry Tours

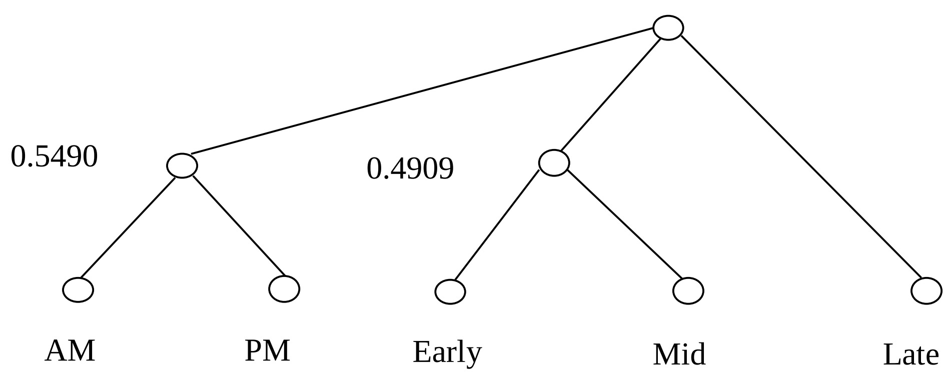


Figure 4B: Tour Time of Day Nesting Structure: Wholesale Tours

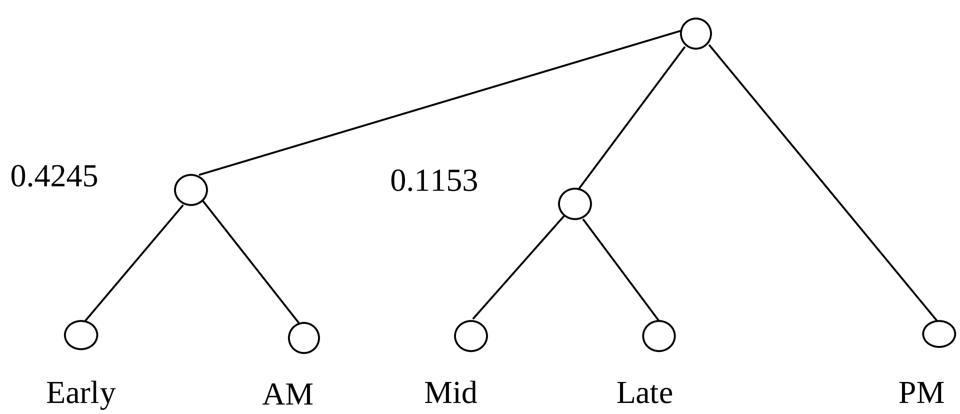


Figure 4C: Tour Time of Day Nesting Structure: Retail / Fleet Tours

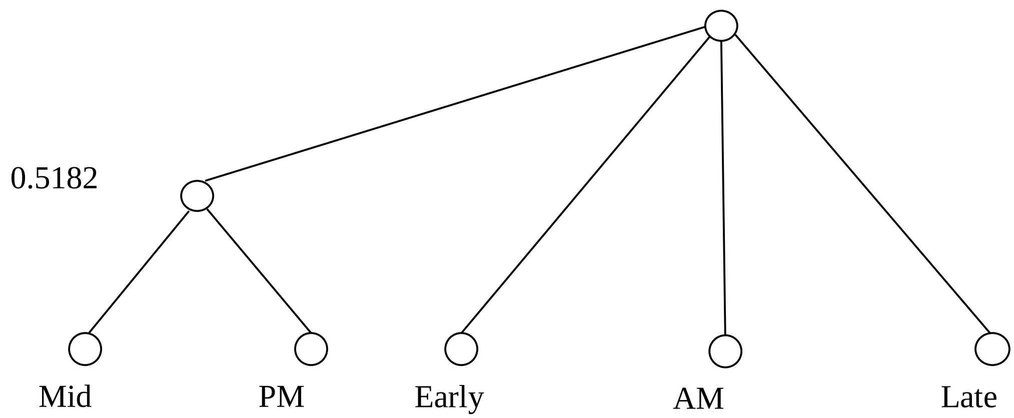


Figure 4D: Tour Time of Day Nesting Structure: Service / Gov Office Tours

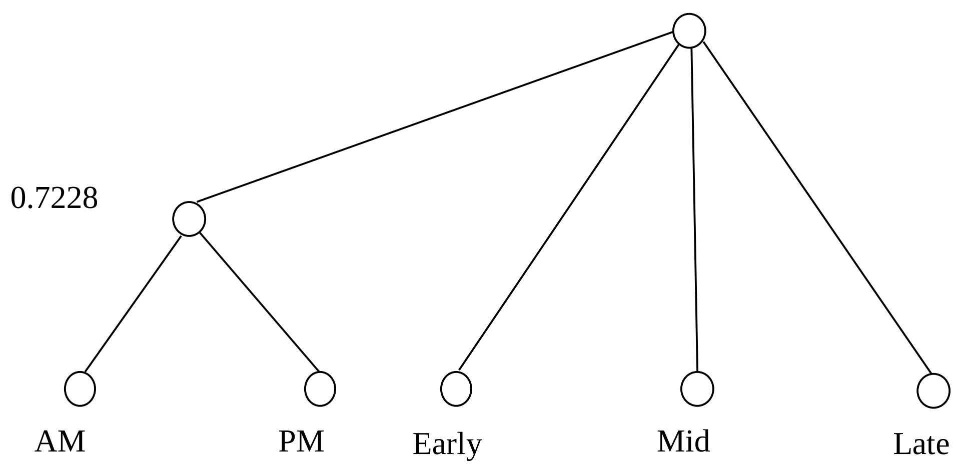


Figure 4E: Tour Time of Day Nesting Structure:Service / Government Office Tours

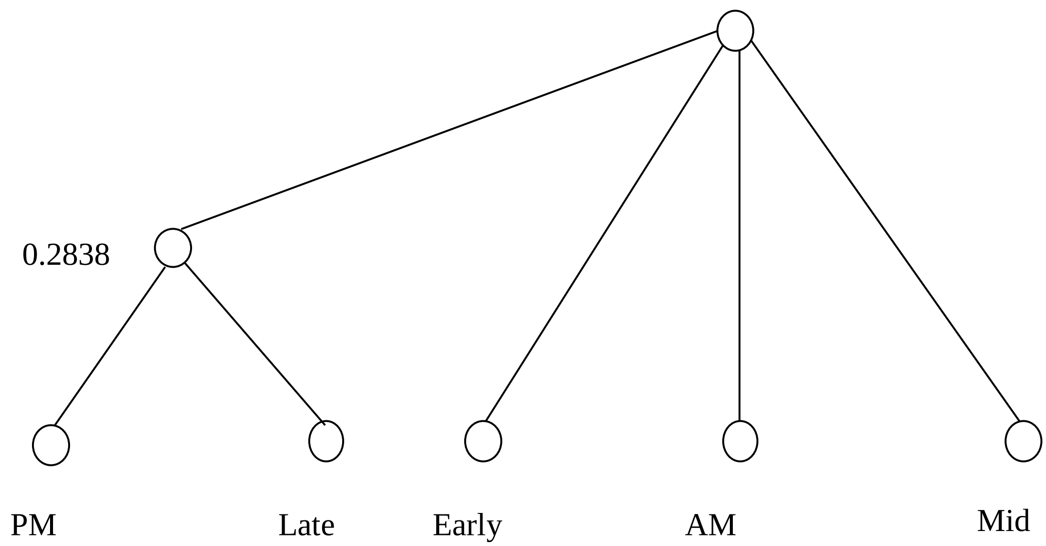


Table 8A: EARLY Time Period Utilities by Employment Category

Attribute	Industrial	Wholesale	Retail / Fleet	Service / Gov Office	Transport & Handling
Residential Land Use	1.1640	-	-	-	-
Industrial Land Use	1.1650	-	0.7020	-0.5162	-0.6363
Employment Land Use	-	-1.2110	-	-0.8024	-
Employment >500 INDUSTRIAL	-0.6308	-	-	-	-
Employment >500 RETAIL	-	-	0.6183	-	-
Employment >500 SERVICE	-	-	-	-0.4914	-
% zonal employment INDUSTRIAL	1.3800	-	-	-	-
% zonal employment RETAIL	-	-	-6.749	-	-
% zonal employment SERVICE	-	-	-	-0.8524	-
% zonal employment T and H	-	-	-	-	3.1450
Composite Utility Tour Purpose/Vehicle Type	-	0.43840	-	-	0.2223
Constant	-0.6942	-1.1804	-1.1627	-1.2273	-1.8727
Constant Government / Office				-0.9749	
Constant Fleet			-2.0043		

Table 8B: AM Time Period Utilities by Employment Category

Attribute	Industrial	Wholesale	Retail / Fleet	Service / Gov Office	Transport & Handling
Residential Land Use	0.8059	-	-	-	-
Industrial Land Use	0.7884	1.3970	0.3770	-	-0.5278
Employment >500 INDUSTRIAL	-0.2712	-	-	-	-
Employment >500 WHOLESALE	-	0.3952	-	-	-
Employment >500 SERVICE	-	-	-	0.2697	-
% zonal employment RETAIL	-	-	-0.3089	-	-
% zonal employment SERVICE	-	-	-	-0.5860	-
% zonal employment T and H	-	-	-	-	-2.2490
Composite Utility Tour Purpose/Vehicle Type	0.5767	-	0.8392	0.2407	0.2223
Constant	0.6813	1.1890	-0.3802	0.9077	2.3329
Constant Government Office				1.7804	
Constant Fleet			-0.7479		

Table 8C: MIDDAY Time Period Utilities by Employment Category

Attribute	Industrial	Wholesale	Retail / Fleet	Service / Gov Office	Transport & Handling
Composite Utility Tour Purpose/Vehicle Type	0.5767	0.4384	0.8392	0.2407	-
Constant	0.5935	2.5163	1.1158	0.8186	0.9776
Constant Fleet			1.5322		

Table 8D: PM Time Period Utilities by Employment Category

Attribute	Industrial	Wholesale	Retail / Fleet	Service / Gov Office	Transport & Handling
Commercial Land Use	-	-	-0.9184	-	-
Industrial Land Use	-0.3953	0.7744	0.9404	-0.5919	-1.6560
Employment Land Use	-	-	-	0.6292	-
% zonal employment WHOLESALE	-	-3.7960	-	-	-
% zonal employment RETAIL	-	-	2.1640	-	-
Retail Zone	-	1.9720	-	-	-
Composite Utility Tour Purpose/Vehicle Type	0.5767	0.4384	0.8392	0.2407	0.2223
Constant	-1.2782	-2.4126	-1.8195	-1.2849	-3.9522
Constant Government Office				-0.5106	
Constant Fleet			-1.5419		

Table 8E: LATE Time Period Utilities by Employment Category

Attribute	Industrial	Wholesale	Retail / Fleet	Service / Gov Office	Transport & Handling
Residential Land Use	0.4634	-	0.9369	-	-
Industrial Land Use	-0.5059	-	-1.1860	-0.3414	-
Employment >500 WHOLESALE	-	-0.7958	-	-	-
% zonal employment INDUSTRIAL	1.1130	-	-	-	-
% zonal employment RETAIL	-	-	1.3810	-	-
Composite Utility Tour Purpose/Vehicle Type	0.5767	0.4384	-	-	0.2223
Constant	-4.5967	-1.0502	-3.3086	-2.5814	-5.7340
Constant Government Office				-1.6508	
Constant Fleet			-2.6482		

3.4 Vehicle Type and Tour Purpose Models

In this step, each tour for an individual zone is assigned both a purpose and a vehicle type. The selection probabilities are determined using nested logit models based on establishment category with utility functions that include zonal-level land use, establishment location and accessibility attributes.

Three choices exist for tour purpose:

- Goods – may make 'goods', 'other' and 'return to establishment' stops.
- Service – may make 'service', 'other' and 'return to establishment' stops.
- Other – may make 'other' and 'return to establishment' stops.

Four commercial vehicle types are used:

- Light vehicle - FHWA classes 1-3;
- Medium Truck < 8.8 short tons (17,640 pounds) – FHWA classes 5-6;
- Medium Truck > 8.8 short tons (17,640 pounds) – FHWA classes 5-6;
- Heavy Truck – FHWA classes 7-13.

The generalized utility function for the combined tour purpose and vehicle choice is:

$$U_{PV} = ASC_{PV} + \theta_{LU,P} + \theta_{LU,V} + \theta_{est,P} + \theta_{est,V} + (\theta_{pop} \times ACC_{pop}) + (\theta_{emp} \times ACC_{emp})$$

where:

U_{PV} = utility function for the combined tour purpose and vehicle choice

ASC_{PV} = alternative specific constant for a given combination of tour purpose and vehicle choice

$\theta_{LU,P}$ = land use attribute coefficient for tour purpose

$\theta_{LU,V}$ = land use attribute coefficient for vehicle choice

$\theta_{est,P}$ = establishment type attribute coefficient for tour purpose

$\theta_{est,V}$ = establishment type attribute coefficient for vehicle choice

θ_{pop} = population accessibility coefficient

θ_{emp} = employment accessibility coefficient

ACC_{pop} = population accessibility

ACC_{emp} = employment accessibility

Nesting structures for the vehicle type / tour purpose models are given in Figures 5A to 5E for each employment type.

Figure 5A: Tour Vehicle Type / Purpose Nesting Structure: Industry Tours

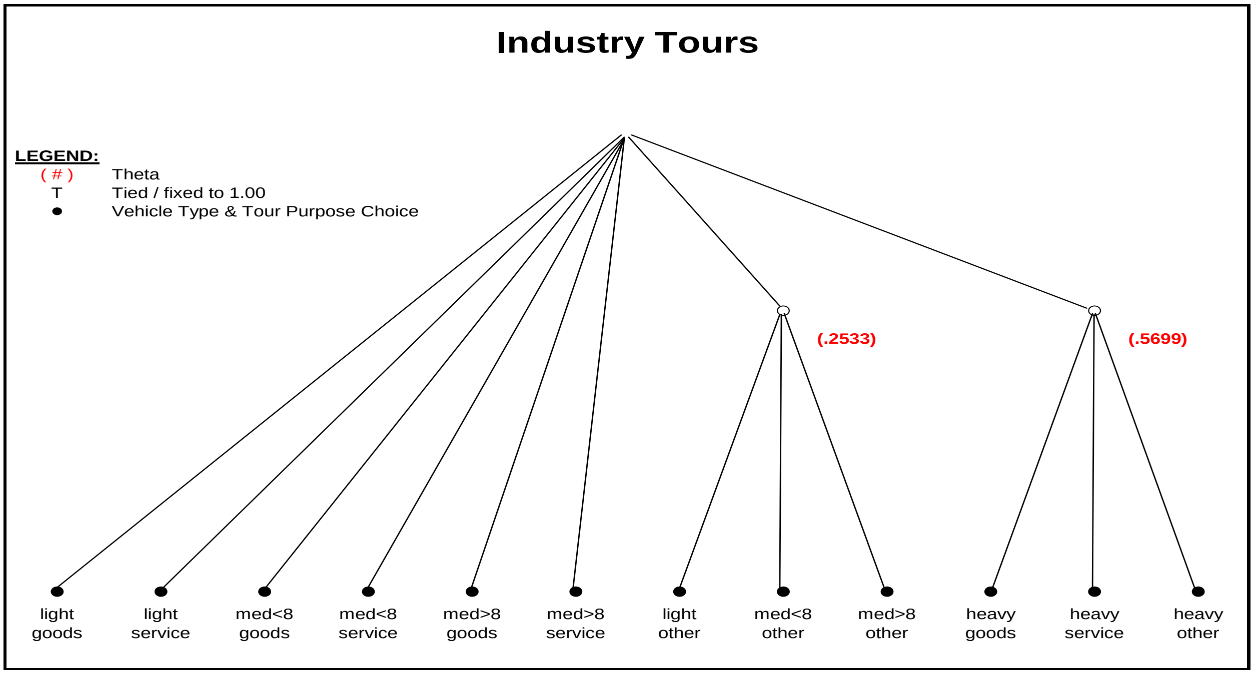


Figure 5B: Tour Vehicle Type / Purpose Nesting Structure: Wholesale Tours

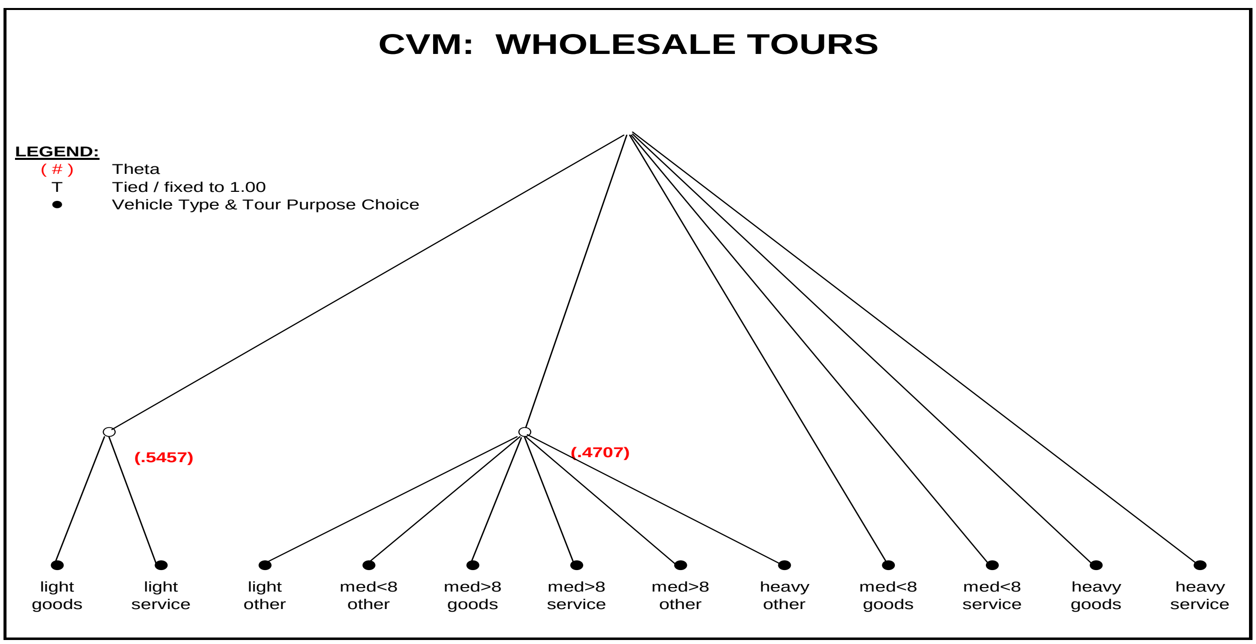


Figure 5C: Tour Vehicle Type / Purpose Nesting Structure: Retail Tours

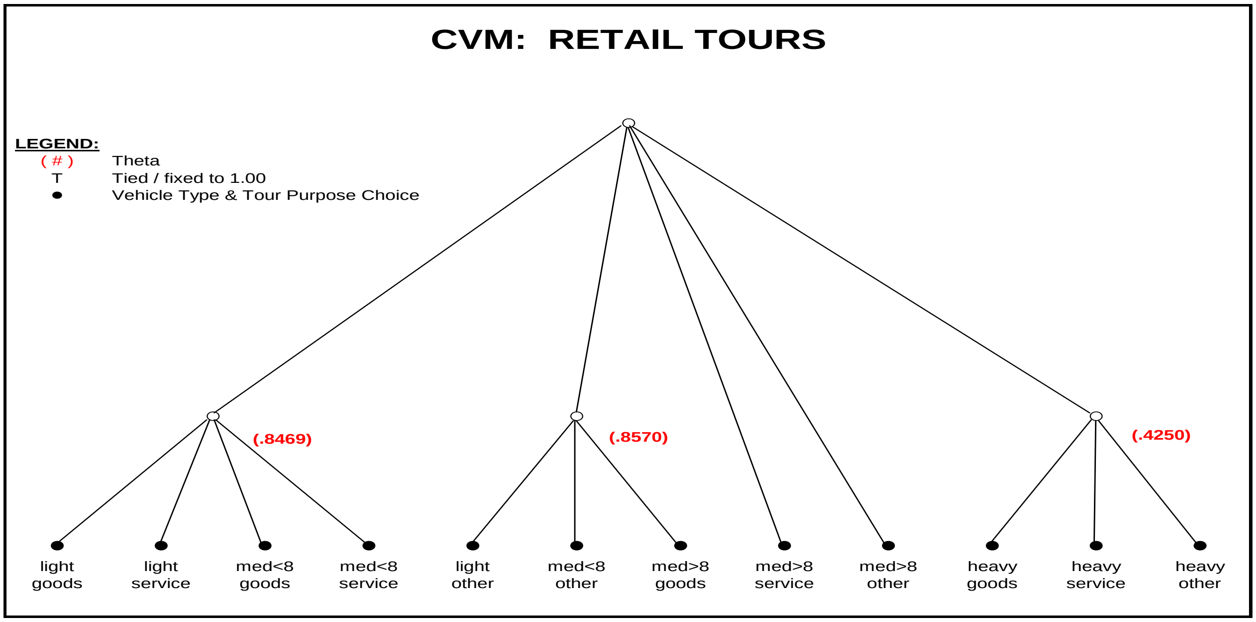


Figure 5D: Tour Vehicle Type / Purpose Nesting Structure: Service / Government Office / Fleet Tours

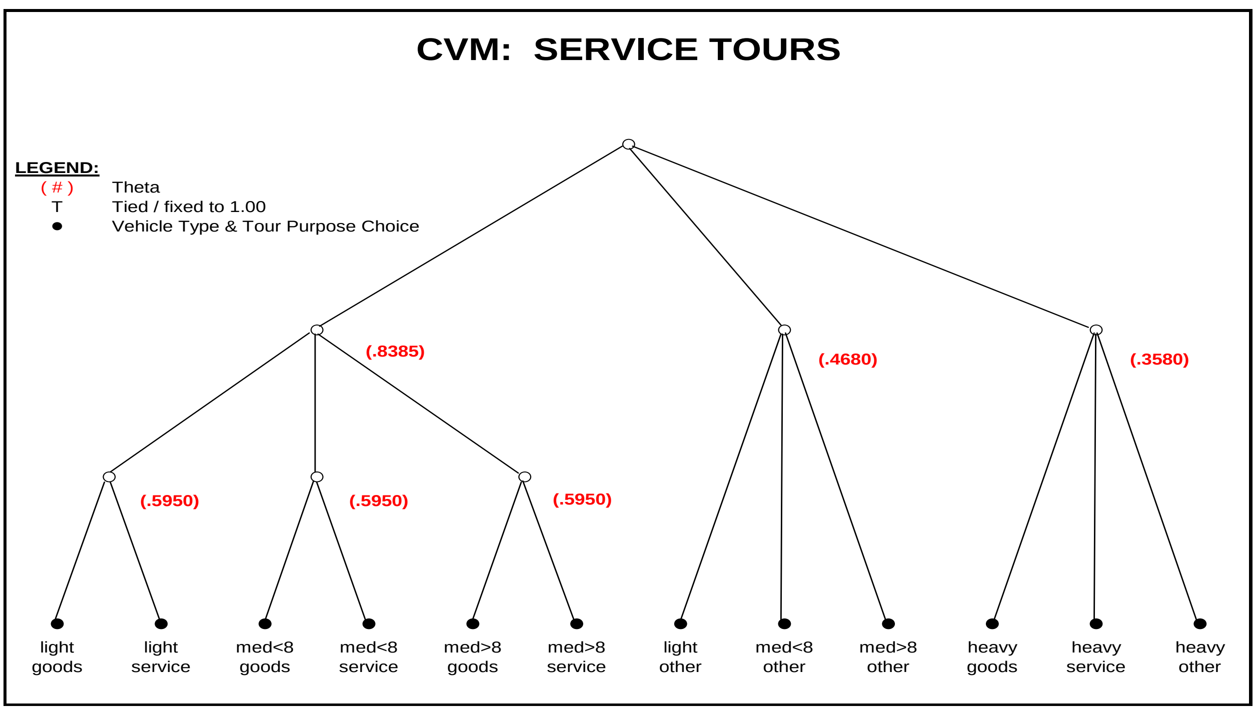
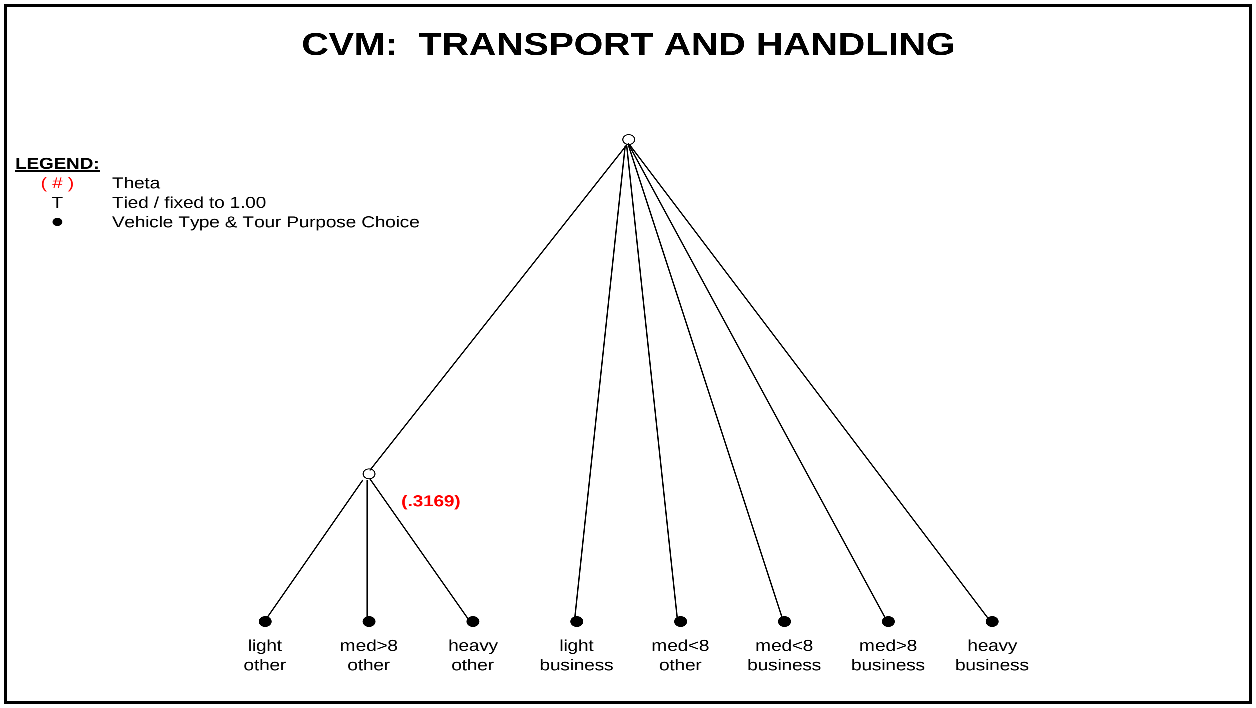


Figure 5E: Tour Vehicle Type / Purpose Nesting Structure: Transport Tours



Tour purpose and vehicle choice model coefficients are shown in Table 9A to 9E.

Table 9A: Utilities for Tour Purpose and Vehicle Choice - INDUSTRY Employment Category

Parameter	Light Goods	Light Service	Light Other	Medium <8.8ton Goods	Medium <8.8ton Service	Medium <8.8ton Other	Medium >8.8ton Goods	Medium >8.8ton Service	Medium >8.8ton Other	Heavy Goods	Heavy Service	Heavy Other
Accessibility to Total Employment ($x10^{-6}$)	6.603	6.603	6.603	6.603	6.603	6.603	6.603	6.603	6.603	6.603	6.603	6.603
Accessibility to Total Population ($x10^{-6}$)	6.603	6.603	6.603	6.603	6.603	6.603	6.603	6.603	6.603	6.603	6.603	6.603
Industrial Land Use (Tour Purpose)	0.5910	-	-	0.5910	-	-	0.5910	-	-	0.5910	-	-
Industrial Land Use (Vehicle Type)	-	-	-	0.8489	0.8489	0.8489	-	-	-	0.7822	0.7822	0.7822
Employment Land Use (Tour Purpose)	-	-1.9100	-4.8680	-	-1.9100	-4.8680	-	-1.9100	-4.8680	-	-1.9100	-4.8680
Employment Land Use (Vehicle Type)	-	-	-	-	-	-	-1.5780	-1.5780	-1.5780	2.5170	2.5170	2.5170
Commercial Land Use (Tour Purpose)	-	0.2850	-	-	0.2850	-	-	0.2850	-	-	0.2850	-
Commercial Land Use (Vehicle Type)	-	-	-	1.3280	1.3280	1.3280	-	-	-	3.8230	3.8230	3.8230
Residential Land Use (Tour Purpose)	-	0.5624	1.0900	-	0.5624	1.0900	-	0.5624	1.0900	-	0.5624	1.0900
Residential Land Use (Vehicle Type)	-	-	-	-1.4430	-1.4430	-1.4430	-0.7010	-0.7010	-0.7010	-1.3120	-1.3120	-1.3120
% Zonal Employment Industrial (Tour Purpose)	1.0120	-	-	1.0120	-	-	1.0120	-	-	1.0120	-	-
% Zonal Employment Industrial (Vehicle Type)	-	-	-	-	-	-	-0.9040	-0.9040	-0.9040	3.8420	3.8420	3.8420
% Zonal Employment Wholesale (Vehicle Type)	-	-	-	-	-	-	-	-	-	-	-	-
Alternative Specific Constant (Tour Purpose)	0.0000	1.2432	-2.1178	0.0000	1.2432	-2.1178	0.0000	1.2432	-2.1178	0.0000	1.2432	-2.1178
Alternative Specific Constant (Vehicle Type)	0.5162	0.5162	0.5162	-3.1199	-3.1199	-3.1199	-1.2308	-1.2308	-1.2308	-2.1986	-2.1986	-2.1986

Table 9B: Utilities for Tour Purpose and Vehicle Choice - WHOLESALE Employment Category

Parameter	Light Goods	Light Service	Light Other	Medium <8.8ton Goods	Medium <8.8ton Service	Medium <8.8ton Other	Medium >8.8ton Goods	Medium >8.8ton Service	Medium >8.8ton Other	Heavy Goods	Heavy Service	Heavy Other
Accessibility to Total Employment $(x10^{-6})$	3.664	3.664	3.664	-	-	-	-	-	-	3.664	3.664	3.664
Accessibility to Total Population $(x10^{-6})$	3.664	3.664	3.664	-	-	-	-	-	-	3.664	3.664	3.664
Industrial Land Use (Tour Purpose)	-	-2.1170	-	-	-2.1170	-	-	-2.1170	-	-2.1170	-	-
Industrial Land Use (Vehicle Type)	-	-	-	-	-	-	-	-	-	-0.7206	-0.7206	-0.7206
Employment Land Use (Tour Purpose)	-	-2.5570	-	-	-2.5570	-	-	-2.5570	-	-	-2.5570	-
Employment Land Use (Vehicle Type)	-	-	-	-	-	-	-	-	-	-1.5730	-1.5730	-1.5730
Commercial Land Use (Tour Purpose)	-	-2.6740	-	-	-2.6740	-	-	-2.6740	-	-	-2.6740	-
Commercial Land Use (Vehicle Type)	-	-	-	-1.0170	-1.0170	-1.0170	-	-	-	-	-	-
Residential Land Use (Tour Purpose)	-	-	-	-	-	-	-	-	-	-	-	-
Residential Land Use (Vehicle Type)	-	-	-	-0.9528	-0.9528	-0.9528	-	-	-	1.0790	1.0790	1.0790
% Zonal Employment Industrial (Tour Purpose)	-	-	-	-	-	-	-	-	-	-	-	-
% Zonal Employment Industrial (Vehicle Type)	-	-	-	-	-	-	-	-	-	-	-1.7930	-1.7930
% Zonal Employment Wholesale (Vehicle Type)	-	-	-	2.9910	2.9910	2.9910	8.5330	8.5330	8.5330	4.4480	4.4480	4.4480
Alternative Specific Constant (Tour Purpose)	0.0000	0.0958	-3.4693	0.0000	0.0958	-3.4693	0.0000	0.0958	-3.4693	0.0000	0.0958	-3.4693
Alternative Specific Constant (Vehicle Type)	1.0748	1.0748	1.0748	-2.2658	-2.2658	-2.2658	-2.1086	-2.1086	-2.1086	-1.3433	-1.3433	-1.3433

Table 9C: Utilities for Tour Purpose and Vehicle Choice - RETAIL Employment Category

Parameter	Light Goods	Light Service	Light Other	Medium <8.8ton Goods	Medium <8.8ton Service	Medium <8.8ton Other	Medium >8.8ton Goods	Medium >8.8ton Service	Medium >8.8ton Other	Heavy Goods	Heavy Service	Heavy Other
Accessibility to Total Employment ($x10^{-6}$)	7.191	7.191	7.191	7.191	7.191	7.191	7.191	7.191	7.191	7.191	7.191	7.191
Accessibility to Total Population ($x10^{-6}$)	7.191	7.191	7.191	7.191	7.191	7.191	7.191	7.191	7.191	7.191	7.191	7.191
Industrial Land Use (Tour Purpose)	-	-	-	-	-	-	-	-	-	-	-	-
Industrial Land Use (Vehicle Type)	-	-	-	0.6027	0.6027	0.6027	-	-	-	-	-	-
Employment Land Use (Tour Purpose)	-	-0.7483	-0.5303	-	-0.7483	-0.5303	-	-0.7483	-0.5303	-	-0.7483	-0.5303
Employment Land Use (Vehicle Type)	-	-	-	-	-	-	0.4739	0.4739	0.4739	-	-	-
Commercial Land Use (Tour Purpose)	-	-0.8507	-	-	-0.8507	-	-	-0.8507	-	-	-0.8507	-
Commercial Land Use (Vehicle Type)	-	-	-	-0.2942	-0.2942	-0.2942	-	-	-	-	-	-
Residential Land Use (Tour Purpose)	-	-0.3099	0.9274	-	-0.3099	0.9274	-	-0.3099	0.9274	-	-0.3099	0.9274
Residential Land Use (Vehicle Type)	-	-	-	-1.2920	-1.2920	-1.2920	-0.4324	00.4324	-0.4324	-	-	-
% Zonal Employment Industrial (Tour Purpose)	0.8801	-	-	0.8801	-	-	0.8801	-	-	0.8801	-	-
% Zonal Employment Industrial (Vehicle Type)	-	-	-	-	-	-	3.0460	3.0460	3.0460	16.830	16.830	-16.830
% Zonal Employment Wholesale (Vehicle Type)	-	-	-	-	-	-	-	-	-	-	-	-
Alternative Specific Constant (Tour Purpose)	0.0000	-0.3072	-3.1011	0.0000	-0.3072	-3.1011	0.0000	-0.3072	-3.1011	0.0000	-0.3072	-3.1011
Alternative Specific Constant (Vehicle Type)	-0.0385	-0.0385	-0.0385	-2.2672	-2.2672	-2.2672	-2.0939	-2.0939	-2.0939	-9.5120	-9.5120	-9.5120

Table 9D: Utilities for Tour Purpose and Vehicle Choice – SERVICE / GOV OFFICE / FLEET Employment Category

Parameter	Light Goods	Light Service	Light Other	Medium <8.8ton Goods	Medium <8.8ton Service	Medium <8.8ton Other	Medium >8.8ton Goods	Medium >8.8ton Service	Medium >8.8ton Other	Heavy Goods	Heavy Service	Heavy Other
Accessibility to Total Employment (x10^{-6})	40.99	40.99	40.99	40.99	40.99	40.99	40.99	40.99	40.99	40.99	40.99	40.99
Accessibility to Total Population (x10^{-6})	40.99	40.99	40.99	40.99	40.99	40.99	40.99	40.99	40.99	40.99	40.99	40.99
Industrial Land Use (Tour Purpose)	1.8730	-	-	1.8730	-	-	1.8730	-	-	1.8730	-	-
Industrial Land Use (Vehicle Type)	-	-	-	0.9352	0.9352	0.9352	-	-	-	-4.9180	-4.9180	-4.9180
Employment Land Use (Tour Purpose)	-	-0.4268	-	-	-0.4268	-	-	-0.4268	-	-	-0.4268	-
Employment Land Use (Vehicle Type)	-	-	-	-	-	-	-2.5360	-2.5360	-2.5360	-7.7330	7.7330	-7.7330
Commercial Land Use (Tour Purpose)	-	-	-	-	-	-	-	-	-	-	-	-
Commercial Land Use (Vehicle Type)	-	-	-	-1.1200	-1.1200	-1.1200	-	-	-	-7.0770	-7.0770	-7.0770
Residential Land Use (Tour Purpose)	-	-	-	-	-	-	-	-	-	-	-	-
Residential Land Use (Vehicle Type)	-	-	-	-2.6570	-2.6570	-2.6570	-3.2710	-3.2710	-3.2710	-6.8420	-6.8420	-6.8420
% Zonal Employment Industrial (Tour Purpose)	0.5355	-	-	0.5355	-	-	0.5355	-	-	0.5355	-	-
% Zonal Employment Industrial (Vehicle Type)	-	-	-	-	-	-	-	-	-	-	-	-
% Zonal Employment Wholesale (Vehicle Type)	-	-	-	-	-	-	-	-	-	-	-	-
Alternative Specific Constant (Tour Purpose) - SERVICE / GOV OFFICE	0.0000	2.6633	-1.7230	0.0000	2.6633	-1.7230	0.0000	2.6633	-1.7230	0.0000	2.6633	-1.7230
Alternative Specific Constant (Tour Purpose) - FLEET	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Alternative Specific Constant (Vehicle Type) - SERVICE	0.1862	0.1862	0.1862	-5.6145	-5.6145	-5.6145	-2.8786	-2.8786	-2.8786	0.5650	0.5650	0.5650
Alternative Specific Constant (Vehicle Type) - GOVERNMENT OFFICE	0.2470	0.2470	0.2470	-5.6640	-5.6640	-5.6640	-2.9209	-2.9209	-2.9209	0.5227	0.5227	0.5227
Alternative Specific Constant (Vehicle Type) - FLEET	1.1330	1.1330	1.1330	-3.1092	-3.1092	-3.1092	2.6181	2.6181	2.6181	5.4009	5.4009	5.4009

Table 9E: Utilities for Tour Purpose and Vehicle Choice – TRANSPORT AND HANDLING Employment Category

Parameter	Light Business	Light Other	Medium <8.8ton Business	Medium <8.8ton Other	Medium >8.8ton Business	Medium >8.8ton Other	Heavy Business	Heavy Other
Accessibility to Total Employment ($x10^{-6}$)	12.55	12.55	12.55	12.55	12.55	12.55	12.55	12.55
Accessibility to Total Population ($x10^{-6}$)	12.55	12.55	12.55	12.55	12.55	12.55	12.55	12.55
Industrial Land Use (Tour Purpose)	-	-	-	-	-	-	-	-
Industrial Land Use (Vehicle Type)	-	-	0.4906	0.4906	-	-	0.7601	0.7601
Employment Land Use (Tour Purpose)	-	-	-	-	-	-	-	-
Employment Land Use (Vehicle Type)	-	-	-	-	-	-	1.1150	1.1150
Commercial Land Use (Tour Purpose)	-	-	-	-	-	-	-	-
Commercial Land Use (Vehicle Type)	-	-	-	-	-	-	-	-
Residential Land Use (Tour Purpose)	-	-	-	-	-	-	-	-
Residential Land Use (Vehicle Type)	-	-	-	-	-1.6300	-1.6300	-	-
% Zonal Employment Industrial (Tour Purpose)	-	-	-	-	-	-	-	-
% Zonal Employment Industrial (Vehicle Type)	-	-	-	-	-1.1370	-1.1370	0.7476	0.7476
% Zonal Employment Wholesale (Vehicle Type)	-	-	-	-	-	-	-	-
Alternative Specific Constant (Tour Purpose)	0.0000	-7.7135	0.0000	-7.7135	0.0000	-7.7135	0.0000	-7.7135
Alternative Specific Constant (Vehicle Type)	1.7040	1.7040	-1.0920	-1.0920	1.1787	1.1787	0.9013	0.9013

4. Final CVM Tour Micro-simulation

The list of tours per zone is fed into the micro-simulation process, where each tour is assigned a tour start time, next stop purpose, next stop location and next stop duration. The micro-simulation process is executed using JAVA applications. The commercial vehicle model uses a 24-hour, continuous concept of time. Tours can cross from any time period to another, but are capped at 24 hours length.

4.1 Tour Start Time Models

For every tour, start times are established. Tour start times are determined using a Monte Carlo process, with sampling distributions based on a cumulative percentage distribution function, calculated by time period.

Curve-fitting techniques were applied to the observed SANDAG Work-Place Survey start time distributions of tours, to obtain functions matching the observed data. The general equation forms used for the tour start time are:

- Cubic: $y = a+bx+cx^2+dx^3$

Table 10 gives the tour start time functions used in the SANDAG Final CVM.

Table 10: Tour Start Time Functions by Time Period

Start time	Function Type	a	b	c	d
Early (12 AM – 7AM)	Cubic	0	5.3044	-4.8308	2.4882
AM (7AM – 9AM)	Cubic	0	3.8414	-1.7678	0.7838
MIDDAY (9AM – 4PM)	Cubic	0	3.5990	0.5329	2.1232
PM (4PM – 6PM)	Cubic	0	2.0439	-0.3593	1.5213
Late (6PM – 12AM)	Cubic	0	12.3530	-21.2590	16.3760

The observed start times for the early time period (12AM – 7AM) were heavily weighted towards the end of the time period, with few tours starting between 12AM and 6AM. For this observed distribution an “exponential” function gave the best fit. For other time periods the observed distributions were more evenly spread out and “cubic” functions gave the best fit.

4.2 Next Stop Purpose Models

Once the tour start time has been assigned to a given tour, the micro-simulation begins the iterative process of ‘growing’ the tour by assigning sets of *next stop purpose*, *next stop location* and *next stop duration* until the *next stop purpose* returns to establishment.

The purpose for each subsequent stop is assigned from the following alternatives:

- Goods – pick up goods, drop off goods, or combination of both
- Service – perform service, pick up supplies needed to perform service
- Return to Establishment – return to the business establishment operating the vehicle
- Other – operations not included in the above; may include such things as fuel stops, banking, vehicle repairs, meals, etc.

The term ‘business stop’ is used to refer to stops made by Transport and Handling vehicles because they provide the service of moving goods.

The next stop purpose model assigns a purpose to the next stop made. This purpose determines whether the vehicle is returning to the establishment, performing a stop for a business purpose or a non-business purpose. With a tour purpose already decided, the range of next stop purposes is limited; service tours permit service and other stops; goods tours permit goods and other stops; transportation handling tours permit business and other stops, and other tours permit only other stops.

In addition, after the first trip has been determined (i.e. for the second and every stop thereafter), the option to return to the establishment is provided, which determines tour length.

The Monte Carlo process is used to assign the next stop purpose with the selection probabilities determined using single-level logit models for 14 different segments based on combinations of industry category, vehicle type and tour purpose, consistent with differences in the influences on next stop choice behaviour, as follows:

- **S-SGO-L**: service tours by Services and Government / Office establishments using light vehicles;
- **S-SGO-MH**: service tours by Services and Government / Office establishments using medium or heavy vehicles;
- **G-SGO-LMH**: goods tours by Services and Government / Office establishments using any vehicle type;
- **S-R-LMH**: service tours by Retail establishments using any vehicle type;
- **G-R-LMH**: goods tours by Retail establishments using any vehicle type;
- **S-I-L**: service tours by Industrial establishments using light vehicles;
- **S-I-MH**: service tours by Industrial establishments using medium or heavy vehicles;
- **G-I-LMH**: goods tours by Industrial establishments using any vehicle type;
- **S-W-LMH**: service tours by Wholesale establishments using any vehicle type;
- **G-W-L**: goods tours by Wholesale establishments using light vehicles;
- **G-W-MH**: goods tours by Wholesale establishments using medium or heavy vehicles;
- **S-T-LMH**: service tours by Transport establishments using any vehicle type;
- **G-T-LMH**: goods tours by Transport establishments using any vehicle type; and
- **O-X-LMH**: other tours by any establishments using any vehicle type.

For next stop purpose for Fleet Allocator tours the Transport establishment models were used.

The generalized form of the utility functions used is:

$$U_{business} = ASC_{business} + \theta_{business\ previous} \times \ln(\text{number of previous business stops})$$

$$\begin{aligned} U_{other} = {} & \theta_{other\ previous} \times \ln(\text{number of previous other stops}) \\ & + \theta_{other\ total\ time} \times \text{elapsed total time} \\ & + \theta_{other\ emp\ acc} \times \text{accessibility to employment} \end{aligned}$$

and

$$\begin{aligned} U_{return} = {} & ASC_{return} + \theta_{total\ previous} \times \ln(\text{number of previous stops}) \\ & + \theta_{total\ time} \times \text{elapsed total time} + \theta_{travel\ time} \times \text{elapsed travel time} \\ & + \theta_{return\ gen\ utility} \times \text{travel utility for return to establishment} \end{aligned}$$

where:

- $ASC_{business}$ and ASC_{return} are the alternative specific constants for the business stop purpose (actually goods or service stop purpose, depending on the segment) and the return to establishment stop purpose, respectively;
- ‘number of previous business stops’ is the number stops for business purposes made previously in the tour;
- ‘number of previous other stops’ is the number of stops for other purposes made previously in the tour;
- ‘number of previous stops’ is the number of stops for any purposes made previously in the tour;

- 'elapsed total time' is the total time that has been spent on the tour up to that point, including all times spent at stops and in travel between stops up to that point (minutes);
- 'elapsed travel time' is the total time that has been spent travelling on the tour up to that point, including all times spent in travel between stops but not including all times spent at stops up to that point (minutes);
- 'travel utility for return to establishment' is the travel utility associated with making the trip from the current location zone to the zone where the tour began for the vehicle type being used; and
- 'accessibility to employment' is the accessibility for the current location to all categories of employment in all zones for the vehicle type being used.

The estimation results for the above generalized utility function for each segment are shown in Tables 11A through 11D, with each table covering a different subset of the full set of 13 segments.

Table 11A: Next Stop Purpose Utility Functions for Selected Segments

Parameter	S-SGO-L	S-SGO-MH	G-SGO-LMH	S-R-LMH	G-R-LMH
$ASC_{business}$	2.352	2.936	2.284	2.707	3.725
$\theta_{business\ previous}$	0.4774	0.3514	1.133	0.6021	0.1141
$\theta_{other\ previous}$	1.053	0.2715	1.336	0.9202	1.557
$\theta_{other\ total\ time}$	0.1048	0.1046	0.2716	0.1532	-0.1128
$\theta_{other\ emp\ acc}$	0	0	0	0	0
$\theta_{total\ previous}$	-0.7774	-1.045	-0.5174	-0.1112	-1.519
$\theta_{total\ time}$	0.3402	0.2539	0.3909	0.1837	0.2083
$\theta_{travel\ time}$ ($\times 10^{-3}$)	2.587	5.969	6.431	-0.8995	8.930
$\theta_{return\ gen\ utility}$	0.06057	0.03981	0.0006944	0.05538	-0.03348
ASC_{return} Light S/GO	3.1894/2.5764	n/a	3.3363/2.8843	2.742	4.0802
ASC_{return} Medium S/GO	n/a	2.8633/2.3503	4.1763/3.7243	2.742	4.0802
ASC_{return} Heavy S/GO	n/a	4.1103/3.5973	5.4233/4.9713	2.742	4.0802

Table 11B: Next Stop Purpose Utility Functions for Selected Segments

Parameter	S-I-L	S-I-MH	G-I-LMH	S-W-LMH	G-W-L
$ASC_{business}$	2.525	2.599	2.890	2.302	3.448
$\theta_{business\ previous}$	1.075	0.06148	0.3996	0.9692	0.4821
$\theta_{other\ previous}$	1.121	1.202	0.9585	1.159	1.412
$\theta_{other\ total\ time}$	0.2234	0.1187	0.1103	0.1509	-0.1719
$\theta_{other\ emp\ acc}$	0	0	0	0	0
$\theta_{total\ previous}$	-0.9242	-1.133	-1.127	-0.3461	-0.4929
$\theta_{total\ time}$	0.3525	0.3025	0.2748	0.3419	0.2715
$\theta_{travel\ time}$ $(\times 10^{-3})$	3.123	9.960	4.555	2.754	4.501
$\theta_{return\ gen\ utility}$	0.03253	0.1075	0.03335	0.09744	0.01402
ASC_{return} Light	3.5383	n/a	3.4725	2.2306	2.5370
ASC_{return} Medium	n/a	1.6197	2.8365	1.6296	n/a
ASC_{return} Heavy	n/a	3.1397	4.3575	3.2316	n/a

Table 11C: Stop Purpose Utility Functions for Selected Segments

Parameter	G-W-MH	S-T-LMH Transport	G-T-LMH Transport	B-T-LMH Fleet	O-X-LMH Service/GO
$ASC_{business}$	2.984	2.901	2.901	2.901	-
$\theta_{business\ previous}$	0.3894	1.395	1.395	1.395	-
$\theta_{other\ previous}$	1.316	2.174	2.174	2.174	0
$\theta_{other\ total\ time}$	0.006591	0.2447	0.2447	0.2447	0
$\theta_{other\ emp\ acc}$	0	0	0	0	7.015×10^{-7}
$\theta_{total\ previous}$	-0.4665	0.06366	0.06366	0.06366	-3.380
$\theta_{total\ time}$	0.1746	0.2964	0.2964	0.2964	0.7893
$\theta_{travel\ time}$ $(\times 10^{-3})$	10.28	1.819	1.819	1.819	0
$\theta_{return\ gen\ utility}$	0.02118	0.07048	0.07048	0.07048	0.2696
ASC_{return} Light	n/a	2.7640	3.1247	2.1326	2.9647
ASC_{return} Medium	1.5920	2.4220	2.7787	2.1326	3.8037
ASC_{return} Heavy	3.2010	3.7290	4.0907	2.1326	5.0517

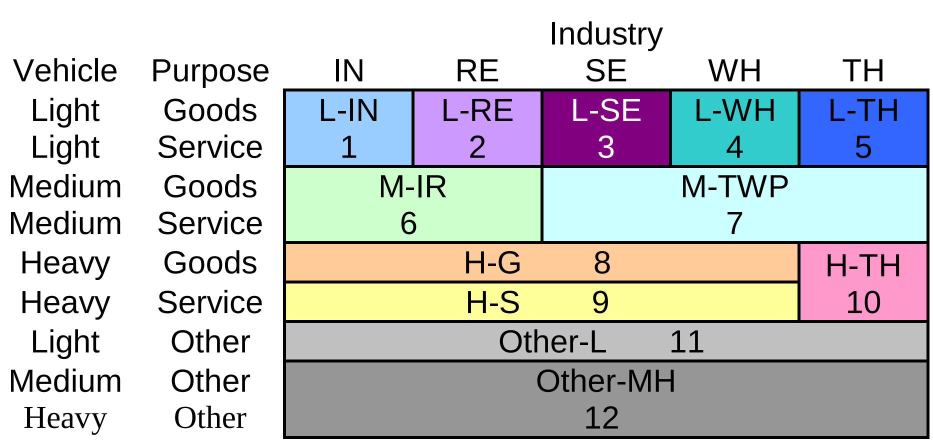
Table 11D: Stop Purpose Utility Functions for Selected Segments

Parameter	O-X-LMH Retail	O-X-LMH Industry	O-X-LMH Wholesale	O-X-LMH Transport	O-X-LMH Fleet
$ASC_{business}$	-	-	-	-	-
$\theta_{business\ previous}$	-	-	-	-	-
$\theta_{other\ previous}$	0	0	0	0	9
$\theta_{other\ total\ time}$	0	0	0	0	0
$\theta_{other\ emp\ acc}$	7.015×10^{-7}	7.015×10^{-7}	7.015×10^{-7}	7.015×10^{-7}	7.015×10^{-7}
$\theta_{total\ previous}$	-3.380	-3.380	-3.380	-3.380	-3.380
$\theta_{total\ time}$	0.7893	0.7893	0.7893	0.7893	0.7893
$\theta_{travel\ time}$ $(\times10^{-3})$	0	0	0	0	0
$\theta_{return\ gen\ utility}$	0.2696	0.2696	0.2696	0.2696	0.2696
ASC_{return} Light	3.1097	2.9967	2.8017	2.9557	2.0137
ASC_{return} Medium	3.1097	2.3607	2.2017	2.6137	2.0137
ASC_{return} Heavy	3.1097	3.8817	3.8037	3.9207	2.0137

4.3 Next Stop Location Models

A logit choice model is used to determine which of the zones is next to be visited by the commercial vehicle. All of these zones are available for the vehicle's choice, although some of the zones are more attractive than others. The next stop location model uses 12 segments as defined below in Figure 6:

Figure 6: Next Stop Location segments



1 – L-IN – Light vehicles, industrial firms, goods and service trips

2 – L-RE – Light vehicles, retail firms, goods and service trips

3 – L-SE – Light vehicles, service firms, goods and service trips (also used for Fleet Allocator Tours)

4 – L-WH – Light vehicles, wholesale firms, goods and service trips

5 – L-TH – Light vehicles, transportation handling firms, goods and service trips

6 – M-IR – Medium vehicles, industrial and retail firms, goods and service trips

7 – M-TWP – Medium vehicles, transportation handling, wholesale and service firms, goods and service trips

8 – H-G – Heavy vehicles, all industries except transportation handling, goods trips

9 – H-S – Heavy vehicles, all industries except transportation handling, service trips

10 – H-TH – Heavy vehicles, transportation handling, goods and service (business) trips

11 – Other-L – Light vehicles, all industries, other trips

12 – Other-MH – Medium and heavy vehicles, all industries, other trips

These segments are divided based on trip purpose for this model, rather than tour purpose. (As an example, a light-retail-goods tour can generate an “other’ stop, and this other stop would use the light-other stop location model.)

The generalized utility function for each zone j as the next stop location is as follows:

$U_{\text{zone } j}$ = $\theta_{Acc\_E} \times$ accessibility to employment for zone j

+ $\theta_{Acc\_P} \times$ accessibility to population for zone j

+ $\theta_{Income} \times$ average household income in zone j

+ $\theta_{ODCostAdd} \times$ travel utility for trip from current zone to zone j) if not first Trip

+ $\theta_{DECostAdd} \times$ travel utility for trip from zone j to zone containing establishment, if not first trip

+ $\theta_{EmpDens} \times$ employment density in zone j (jobs/mi^2)

+ $\theta_{PopDens} \times$ population density in zone j (people/ mi^2)

+ $\theta_{ODCost} \times$ logsum (travel utility for trip from current zone to zone j)

- applied on all trips, logsum from Trip Toll / No Toll Choice sub-model

+ $\theta_{size\ term} \times$ ln (total employment in zone j

+ $\theta_{PopTot} \times$ total population in zone j

+ $\theta_{EmpIn} \times$ industrial employment in zone j

+ $\theta_{EmpWh} \times$ wholesale employment in zone j

+ $\theta_{EmpRe} \times$ retail employment in zone j

+ $\theta_{EmpSe} \times$ service employment in zone j

+ $\theta_{EmpTh} \times$ transportation employment in zone j

+ $\theta_{LULoEmp} \times$ total employment in zone j $\times$ binary flag zone j low density land use

+ $\theta_{LUResEmp} \times$ total employment in zone j $\times$ binary flag zone j residential land use

+ $\theta_{LURCEmp} \times$ total employment in zone j $\times$ binary flag zone j commercial land use

+ $\theta_{LUInEmp} \times$ total employment in zone j $\times$ binary flag zone j industrial land use

+ $\theta_{LUEmpEmp} \times$ total employment in zone j $\times$ binary flag zone j employment node

+ $\theta_{Area} \times$ total area of zone j (mi^2)

where:

‘average household income for zone j’ is set to the region-wide average household income, weighted across all households for zones j where there are no households;

‘accessibility to population for zone j’ is the accessibility for zone j to all categories of population in all zones for vehicle type being used;

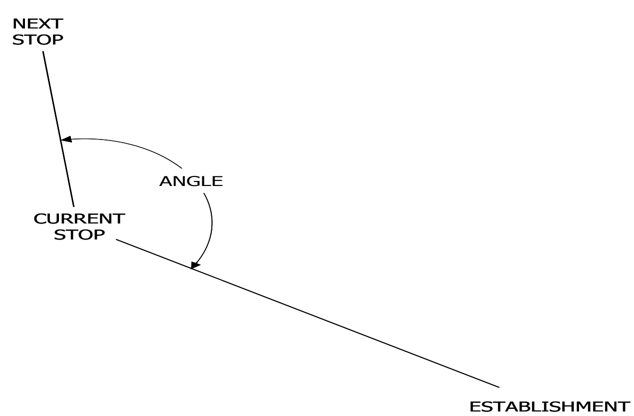
’accessibility to employment for zone j’ is the accessibility for zone j to all categories of employment in all zones for vehicle type being used;

‘enclosed angle for zone j’ is the angle (in degrees) enclosed by (a) the straight line from the current zone to the zone containing the establishment and (b) the straight line from the current zone to zone j.

The enclosed angle measures the angle formed by the intersection of the lines connecting the establishment to the current location and from the current location to the possible destination alternative.

An example of this angle is shown in Figure 7. A value of 0° indicates that zone j is in the same direction as the zone containing the establishment and a value of 180° indicates that zone j is in the opposite direction from the zone containing the establishment. An enclosed angle of 0° would imply heading back directly towards the establishment; an enclosed angle of 180° would imply that the vehicle is heading directly away from the establishment; values range between these two extremes.

Figure 7: Enclosed Angle



Between zones, the off-peak generalized cost is used. There are three measures of generalized cost; OD, OD Additional and DE Additional. OD represents the log sum of the toll / no toll choice travel costs for any trip from the origin to the destination under consideration, and . OD Additional represents the travel cost for trips from the origin to the destination, but is only applied to trips other than the initial departure from establishment. DE Additional represents the ‘return to establishment’ travel cost (from the considered destination back to the establishment), for all trips other than the initial departure.

This permits a variable cost structure on tours; the original trip cost is usually lower than the cost for travel to additional stops, and the return to establishment cost is unnecessary for the first trip, when it correlates nearly 100% with the travel cost from the establishment to the destination under consideration. Utilities for next stop location are shown in Tables 12A-12D.

Table 12A: Next Stop Location Utility Functions for selected segments

Parameter	L-IN	L-RE	L-SE/GO/FL	L-WH
θ_{Acc_E} ($\times 10^{-5}$)	3.257	-3.91	-7.301	-3.511
θ_{Acc_P}($\times 10^{-5}$)	-5.174	-2.085	-2.100	-1.840
θ_{Income}($\times 10^{-6}$)	3.413	0	8.606	3.474
θ_{EncAng}($\times 10^{-2}$)	-0.511	0	-0.463	0.175
$\theta_{ODCostAdd}$	0.3475	0.5512	0.9831	0.7845
$\theta_{ODCostAdd}$ FLEET	n/a	n/a	1.0665	n/a
$\theta_{DECostAdd}$	0	0.4273	0	0.2387
$\theta_{EmpDens}$($\times 10^{-6}$)	0	0	-4.626	-7.967
$\theta_{PopDens}$($\times 10^{-6}$)	42.241	0	36.794	0
θ_{ODCost}	1.8562	1.8912	n/a	1.1513
θ_{ODCost} SERVICE	n/a	n/a	1.9767	n/a
θ_{ODCost} GOVOFF	n/a	n/a	1.6307	n/a
θ_{ODCost} FLEET	n/a	n/a	1.3164	n/a
$\theta_{SizeTerm}$	0.745	0.625	0.809	0.766
θ_{PopTot}	0.886	0.800	3.290	0.338
θ_{EmpIn}	3.539	-86	1.869	-86
θ_{EmpWh}	31.817	14.101	56.079	15.221
θ_{EmpRe}	4.516	1.508	33.567	15.546
θ_{EmpSe}	-86	-86	-86	-86
θ_{EmpTh}	-86	10.621	-86	-86
$\theta_{LULoEmp}$	-86	-86	-86	-86
$\theta_{LUResEmp}$	-86	-86	7.938	-86
$\theta_{LURCEmp}$	-86	2.027	-86	-86
$\theta_{LUInEmp}$	-86	10.513	5.657	6.855
$\theta_{LUEmpEmp}$	-86	-86	3.285	-86
θ_{Area}	7.955	76.017	490.612	24.254

Table 12B: Next Stop Location Utility Functions for selected segments

Parameter	L-TH	M-IR	M-SEGOWTFL	H-G
θ_{Acc_E} ($\times 10^{-5}$)	0	-84.498	-56.887	0
θ_{Acc_P}($\times 10^{-5}$)	0	-1.451	-1.663	-3.136
θ_{Income}($\times 10^{-6}$)	0	-3.741	5.316	-16.263
θ_{EncAng}($\times 10^{-2}$)	-0.157	-0.326	-0.429	-0.677
$\theta_{ODCostAdd}$	0.5117	0.3238	0.3084	0.0764
$\theta_{ODCostAdd}$ FLEET	n/a	n/a	0.6163	0.1638
$\theta_{DECostAdd}$	0	0	0	0.1092
$\theta_{DECostAdd}$ FLEET	n/a	n/a	0	0.2344
$\theta_{EmpDens}$($\times 10^{-6}$)	-11.094	0	-30.275	15.089
$\theta_{PopDens}$($\times 10^{-6}$)	76.847	76.328	0	0
θ_{ODCost} INDUSTRY	n/a	1.0982	n/a	1.059
θ_{ODCost} RETAIL	n/a	1.2712	n/a	0.560
θ_{ODCost} SERVICE	n/a	n/a	1.0182	0.692
θ_{ODCost} GOVOFF	n/a	n/a	0.8422	0.580
θ_{ODCost} WHOLESALE	n/a	n/a	0.6012	0.369
θ_{ODCost} T&H	1.5800	n/a	0.9602	n/a
θ_{ODCost} FLEET	n/a	n/a	0.6652	0.8489
$\theta_{SizeTerm}$	1	0.704	0.867	0.587
θ_{PopTot}	0.085	0.832	-86	-86
θ_{EmpIn}	-86	6.161	21.084	0.967
θ_{EmpWh}	3.679	36.288	49.905	-86
θ_{EmpRe}	0.438	-86	16.579	-86
θ_{EmpSe}	-86	-86	-86	-86
θ_{EmpTh}	-86	8.154	-86	-86
$\theta_{LULoEmp}$	-86	-86	-86	-86
$\theta_{LUResEmp}$	-86	-86	5.786	-86
$\theta_{LURCEmp}$	0.222	1.491	2.641	1.491
$\theta_{LUInEmp}$	1.946	1.910	6.579	1.622
$\theta_{LUEmpEmp}$	-86	-86	-86	-86
θ_{Area}	-86	177.739	205.764	80.760

Table 12C: Next Stop Location Utility Functions for selected segments

Parameter	H-S	H-TH	L-OT (All except TH)	L-OT (TH)
θ_{Acc_E} ($\times 10^{-5}$)	0	15.419	-10.65	-10.65
θ_{Acc_P}($\times 10^{-5}$)	-2.717	-2.092	-2.008	-2.008
θ_{Income}($\times 10^{-6}$)	0	-14.221	0	0
θ_{EncAng}($\times 10^{-2}$)	-0.583	-0.567	-0.420	-0.420
$\theta_{ODCostAdd}$	0.1872	0.0380	-0.1143	-0.0758
$\theta_{ODCostAdd}$ FLEET	0.4015	n/a	-0.1129	n/a
$\theta_{DECostAdd}$	0	0	0.4579	0.3036
$\theta_{DECostAdd}$ FLEET	0	n/a	0.4925	n/a
$\theta_{EmpDens}$($\times 10^{-6}$)	-28.146	-132.287	-26.624	-26.624
$\theta_{PopDens}$($\times 10^{-6}$)	99.926	-2113.891	0	0
θ_{ODCost} INDUSTRY	1.0502	n/a	2.423	n/a
θ_{ODCost} RETAIL	0.5512	n/a	2.190	n/a
θ_{ODCost} SERVICE	0.6832	n/a	2.594	n/a
θ_{ODCost} GOVOFF	0.5712	n/a	2.248	n/a
θ_{ODCost} WHOLESALE	0.3602	n/a	1.656	n/a
θ_{ODCost} T&H	n/a	0.7276	n/a	2.3226
θ_{ODCost} FLEET	0.8300	n/a	1.8747	n/a
$\theta_{SizeTerm}$	0.618	0.700	1	1
θ_{PopTot}	0.050	0.477	0.672	0.672
θ_{EmpIn}	5.190	3.733	1.830	1.830
θ_{EmpWh}	-86	19.561	19.289	19.289
θ_{EmpRe}	6.107	-86	32.820	32.820
θ_{EmpSe}	-86	-86	-86	-86
θ_{EmpTh}	-86	-86	-86	-86
$\theta_{LULoEmp}$	-86	-86	-86	-86
$\theta_{LUResEmp}$	-86	7.305	2.258	2.258
$\theta_{LURCEmp}$	-86	-86	-86	-86
$\theta_{LUInEmp}$	-86	0.879	-86	-86
$\theta_{LUEmpEmp}$	-86	-86	-86	-86
θ_{Area}	502.696	51.476	221.496	221.496

Table 12D: Next Stop Location Utility Functions for selected segments

Parameter	MH-OT (IN)	MH-OT (RE)	MH-OT (SE/ GO)	MH-OT (WH)	MH-OT (TH)	MH-OT (FLEET)
θ_{Acc_E} ($\times 10^{-5}$)	0	0	0	0	0	0
θ_{Acc_P}($\times 10^{-5}$)	-5.158	-5.158	-5.158	-5.158	-5.158	-5.158
θ_{Income}($\times 10^{-6}$)	-16.299	-16.299	-16.299	-16.299	-16.299	-16.299
θ_{EncAng}($\times 10^{-2}$)	-0.628	-0.628	-0.628	-0.628	-0.628	-0.628
$\theta_{ODCostAdd}$ MEDIUM	0	0	0	0	0	0
$\theta_{ODCostAdd}$ HEAVY	0	0	0	0	0	0
$\theta_{ODCostAdd}$ FLEET	0	0	0	0	0	0
$\theta_{DECostAdd}$ MEDIUM	0.0280	0.0280	0.0280	0.0280	0.0280	0.0542
$\theta_{DECostAdd}$ HEAVY	0.0323	0.0323	0.0323	0.0323	0.0153	0.0693
$\theta_{EmpDens}$($\times 10^{-6}$)	-22.932	-22.932	-22.932	-22.932	-22.932	-22.932
$\theta_{PopDens}$($\times 10^{-6}$)	-310.561	-310.561	-310.561	-310.561	-310.561	-310.561
θ_{ODCost} MEDIUM	1.2075	1.3805	1.1485	0.7315	1.0905	0.9087
θ_{ODCost} MEDIUMGO	n/a	n/a	0.9725	n/a	n/a	n/a
θ_{ODCost} HEAVY	0.7516	0.6786	0.7836	0.4606	0.8104	1.0455
θ_{ODCost} HEAVYGO	n/a	n/a	0.6716	n/a	n/a	n/a
$\theta_{SizeTerm}$	0.652	0.652	0.652	0.652	0.652	0.652
θ_{PopTot}	-86	-86	-86	-86	-86	-86
θ_{EmpIn}	-86	-86	-86	-86	-86	-86
θ_{EmpWh}	100.994	100.994	100.994	100.994	100.994	100.994
θ_{EmpRe}	-86	-86	-86	-86	-86	-86
θ_{EmpSe}	-86	-86	-86	-86	-86	-86
θ_{EmpTh}	-86	-86	-86	-86	-86	-86
$\theta_{LULoEmp}$	-86	-86	-86	-86	-86	-86
$\theta_{LUResEmp}$	8.202	8.202	8.202	8.202	8.202	8.202
$\theta_{LURCEmp}$	11.427	11.427	11.427	11.427	11.427	11.427
$\theta_{LUInEmp}$	7.291	7.291	7.291	7.291	7.291	7.291
$\theta_{LUEmpEmp}$	-86	-86	-86	-86	-86	-86
θ_{Area}	216.729	216.729	216.729	216.729	216.729	216.729

4.4 Trip Toll / No Toll Choice Models

These models forecast for each trip on each tour (where the trip vehicle type, time period, origin and destination are known from previous sub-model forecasts) chooses a toll facility as part of its route choice.

For each commercial vehicle type, for each time period, two sets of travel skims are estimated using TRANSCAD:

- For the No-Toll scenario, all commercial vehicle toll facilities ARE NOT made available as part of the network used for assignment and skimming. The resulting times and costs are by definition those for the best O-D routes NOT using a toll facility;
- For the Toll scenario, all commercial vehicle toll facilities ARE made available as part of the network used for assignment and skimming, with a zero cost for the toll applied for the assignment path selection process. For some O-D pairs the resultant quickest route O-D route uses toll facilities, and the time, distance, and toll cost are all skimmed. In these cases the skim process also gives the distance travelled on a toll route. All O-D pairs where this toll route distance is non-zero are by definition those where using a toll facility is advantageous. For all other O-D pairs, where the toll route distance is 0, the assignment process does not find any route where using a toll facility provides a time benefit, even with the toll cost at 0, and the resultant skim times and costs are similar to those obtained for the No Toll scenario.

The Toll / No Toll Choice sub-model is a simple binomial logit model for each trip between zones i-j, where:

The probability of using a Toll facility for a trip i-j is:

$$\text{Probability of Toll}_{ij} = (\exp(\text{Utility Toll}_{ij})) / (\exp(\text{Utility Toll}_{ij}) + \exp(\text{Utility No Toll}_{ij}))$$

Utility functions were explicitly estimated for the SANDAG region using data on commercial vehicle trip toll facility usage from the SANDAG Work-Place survey, plus the processed SANDAG ATRI commercial vehicle data, of the form:

Utility (Toll) = p1 * (toll skim travel utility between zone I and j)
(for particular trip time period / vehicle type)
+ p2 * (Proportion of total trip distance made on toll facility)

Utility (No Toll) = p1 * (no toll skim travel utility between zone I and j)
(for particular trip time period / vehicle type)

The travel utilities are calculated using the travel utility coefficients for each vehicle type given in Table 5 above, and repeated below for clarity:

Table 5: Travel Utility Coefficients

	Light Vehicles	Medium Vehicles	Heavy Vehicles
A (Time - minutes)	-0.313	-0.313	-0.302
B (Distance - miles)	-0.138	-0.492	-0.580
C (Toll - $)	-1.000	-1.000	-1.000

Owing to observed data limitations a single Toll / No Toll trip choice function was estimated for all industry and vehicle types, with calibration by vehicle type. Table 13 summarizes Toll / No Toll Choice Utility parameter values:

Table 13: Travel Utility Coefficients for Toll / No Toll Choice Model

	Light Vehicles	Medium Vehicles	Heavy Vehicles
P1 (travel utility)	0.2572	0.2572	0.2572
P2 (proportion of toll O-D route distance using toll facility	-1.2099	-3.6876	-3.6876

Monte Carlo techniques are used with these models to assign an explicit 0 or 1 value to the choice of each trip using a toll facility.

Note: Once The Toll / No Toll trip choice model has been applied to every trip in every commercial vehicle tour, the results are summarized to give O-D matrices of commercial vehicle trips using Toll facilities / not using Toll facilities, by time period and vehicle class. The forecast commercial vehicle toll trips have explicitly considered the cost of the toll as part of their choice decision, and thus need to be assigned to the road network using a process where toll facilities are available, and the path selection is not influenced by the toll cost.

4.5 Stop Duration Models

The duration of stops is of interest to the commercial vehicle model for two main reasons. Firstly, by delaying vehicles at stops, their trips are spread throughout the day and cross time periods realistically. Secondly, the total elapsed time for a vehicle since leaving its' establishment is important for the return-to-establishment decision in the next stop purpose model.

The exponential function, with the following form was used for all stop duration model segments:

$$T = \mathbf{c}e^{(\mathbf{a}x+\mathbf{b})} + \mathbf{d}$$

Where:

- T is the time duration of the stop (in hours)
- a, b, c, and d are calibrated constants for the exponential function
- x is a flat random input between 0 and 1.

17 separate stop duration models were estimated using SANDAG Work-Place Survey data. The stop duration segments are:

- **S-S-LIMH**: service tours by Services establishments using any vehicle type;
- **G-S-LIMH**: goods tours by Services establishments using any vehicle type;
- **S-GO-L**: service tours by Government / Office establishments using light vehicles;
- **S-GO-IMH**: service tours by Government / Office establishments using medium or heavy vehicles;
- **G-GO-L**: goods tours by Government / Office establishments using light vehicles;
- **G-GO-IMH**: goods tours by Government / Office establishments using medium or heavy vehicles;
- **SG-R-LIMH**: service or goods tours by Retail establishments using any vehicle type;
- **S-I-L**: service tours by Industrial establishments using light vehicles;
- **S-I-IMH**: service tours by Industrial establishments using medium or heavy vehicles;
- **G-I-L:** goods tours by Industrial establishments using light vehicles;
- **G-I-IMH**: goods tours by Industrial establishments using medium or heavy vehicles;
- **S-W-LIMH**: service tours by Wholesale establishments using any vehicle type;
- **G-W-L**: goods tours by Wholesale establishments using light vehicles;
- **G-W-IMH**: goods tours by Wholesale establishments using medium or heavy vehicles;
- **B-T-LI:** business tours by Transport establishments using light vehicles;
- **B-T-MH**: business tours by Transport establishments using medium or heavy vehicles; and
- **O-X-LIMH**: other tours by any establishments using any vehicle type.

For next stop duration for Fleet Allocator tours the Retail establishment models were used.

The model coefficients for each segment are given in Table 14.

Table 14: Stop Duration Models

Stop Segment	Function Type	a	b	c	D
S-S-LIMH	Exponential	0	5.1134	0	0.0267
S-S-LIMH	Exponential	0	4.3592	0	0.0314
S-GO-L	Exponential	0	4.5095	0	0.0633
S-GO-IMH	Exponential	0	5.1964	0	0.0378
G-GO-L	Exponential	0	4.4626	0	0.0321
G-GO-IMH	Exponential	0	5.1706	0	0.0230
SG-R-LIMH	Exponential	0	4.0413	0	0.0265
S-I-L	Exponential	0	4.6374	0	0.0587
S-I-IMH	Exponential	0	5.4562	0	0.0268
G-I-L	Exponential	0	4.2586	0	0.0474
G-I-IMH	Exponential	0	2.4600	0	0.1881
S-W-LIMH	Exponential	0	3.6834	0	0.0431
G-W-L	Exponential	0	3.6834	0	0.0431
G-W-IMH	Exponential	0	2.5843	0	0.1082
B-T-L	Exponential	0	4.6284	0	0.0235
B-T-IMH	Exponential	0	4.4156	0	0.1012
O-X-LIMH	Exponential	0	3.8561	0	0.0416

The parameters for each stop duration sub-model were determined by applying “curve-fitting” procedures to the observed duration distributions from the SANDAG Work-Place Survey observed data.

To implement these models, a random number is generated and used to determine the stop length in hours from the appropriate curve. The overall model process flow then returns to the next stop purpose model, and the next stop on the tour is generated.

5. Final CVM Model Calibration and Validation

The SANDAG Final CVM model was run with current SANDAG travel model Base year (2012) inputs. Overall calibration targets were developed at a series of meetings held in late February 2014 between SANDAG and HBA Specto staff. The targets were based, where possible, on the observed results obtained from the SANDAG Work-Place Survey, for each industry segment.

For certain model segments insufficient data was collected in the Work-Place Survey to give confidence in the results. In these cases a comparison was made with the results obtained from the Interim CVM model run (which are based on a model calibrated initially to survey data for the Edmonton and Calgary urban regions in Alberta, Canada, and adjusted for San Diego conditions), and targets set through a combination of averaging the Work-Place Survey & Interim Model results; & in a few cases using the Interim Model result directly. Table 15 gives the overall calibration targets used.

The Final CVM was calibrated in detail for the following categories:

- Daily tour generation per employee
- Tour start time
- Tour vehicle type
- Trip toll / no toll choice
- Trips per tour
- Trip length

The calibrated model was then validated to observed truck classified count data obtained from WIM locations, plus SANDAG occupancy count data for peak periods at various sites on the road network. Validation results are also given below

Table 15: Final CVM: Overall Calibration Targets

Interim Model results	**Totals**					**Rates**			
Industry	Employees	Tours	Trips	VMT	Med/Hvy VMT	Tours/emp	Trips/tour	Avg trip len	% Light
Industrial	171,100	28,713	130,922	1,029,686	674,751	0.168	4.56	7.86	34%
Wholesale	47,800	7,888	37,665	313,964	227,990	0.165	4.77	8.34	27%
Retail	149,518	14,756	78,718	462,781	207,299	0.099	5.33	5.88	55%
Service/Gov/Office	930,420	33,208	130,288	1,127,605	377,706	0.036	3.92	8.65	67%
Government/Office	400,000	14,283	56,038	484,991	162,454	0.036	3.92	8.65	67%
Service	530,420	18,925	74,250	642,614	215,252	0.036	3.92	8.65	67%
Transport	26,814	4,213	32,721	271,080	247,303	0.157	7.77	8.28	9%
Fleet Allocator	1,325,652	38,497	286,733	1,972,729	1,794,826	0.029	7.45	6.88	9%
Total	**1,325,652**	**127,275**	**697,047**	**5,177,846**	**3,529,875**	**0.096**	**5.48**	**7.43**	**43%**
Survey results	**Totals**					**Rates**			
Industry	Employees	Tours	Trips	VMT	Med/Hvy VMT	Tours/emp	Trips/tour	Avg trip len	% Light
Industrial	150,606	10,224	36,298	311,648	50,827	0.068	3.55	8.59	84%
Wholesale	58,271	2,365	13,233	136,029	31,276	0.041	5.60	10.28	77%
Retail	144,499	1,782	5,144	45,872	9,168	0.012	2.89	8.92	80%
Service/Gov/Office	737,094	23,854	80,864	618,338	45,240	0.032	3.39	7.65	93%
Government/Office	297,397	18,489	64,302	507,000	44,982	0.062	3.48	7.88	91%
Service	439,697	5,365	16,561	111,338	-	0.012	3.09	6.72	100%
Transport	28,891	6,305	26,415	142,189	40,039	0.218	4.19	5.38	72%
Fleet Allocator	1,119,361	24,118	230,198	1,878,632	1,045,796	0.022	9.54	8.16	44%
Total	**1,119,361**	**68,647**	**392,151**	**3,132,707**	**1,222,088**	**0.061**	**5.71**	**7.99**	**81%**
Calibration Targets Feb 28	**Totals**					**Rates**			
Industry	Employees	Tours	Trips	VMT	Med/Hvy VMT	Tours/emp	Trips/tour	Avg trip len	% Light
Industrial	171,100	20,164	71,590	614,664	251,517	0.118	3.55	8.59	59%
Wholesale	47,800	4,914	27,497	282,670	135,129	0.103	5.60	10.28	52%
Retail	149,518	14,756	78,718	462,781	149,892	0.099	5.33	5.88	68%
Service/Gov/Office									
Government/Office	400,000	24,867	86,487	681,916	144,459	0.062	3.48	7.88	79%
Service	530,420	19,095	58,948	396,291	66,371	0.036	3.09	6.72	83%
Transport	26,814	5,014	18,502	133,773	88,443	0.187	3.69	7.23	34%
Fleet Allocator	1,325,652	28,563	272,622	2,224,851	1,631,370	0.022	9.54	8.16	27%
Total	**1,325,652**	**117,373**	**614,365**	**4,796,947**	**2,467,182**	**0.089**	**5.23**	**7.81**	**50%**
					Survey	Average	Model	Survey adj.	

5.1 Daily Commercial Vehicle Tours / Employee Calibration

The SANDAG Final CVM was calibrated to match the overall target generation rates, by industry category. Additional calibration parameters were also applied to to reflect the varying generation rates by TAZ land use type. Similar additional calibration parameters had been used in the Interim CVM model, and were derived from observed data from the Alberta CVM model surveys.

Generation rates for an industry can vary significantly by land use type, depending upon the actual occupations ("white collar" / "blue collar") of the workers. These factors explicitly incorporate this variation.

During validation, it was observed that the initial calibrated model forecasts of light commercial vehicles under-represented observed light commercial vehicle flows. The CVM generation targets were therefore adjusted to reflect an increase in light commercial vehicle forecasts of 20%, and the model recalibrated.

Figure 8 shows the comparison between target and model generation rates, illustrating a very good fit between target and model data.

Figure 8 Tour Generation Calibration Results

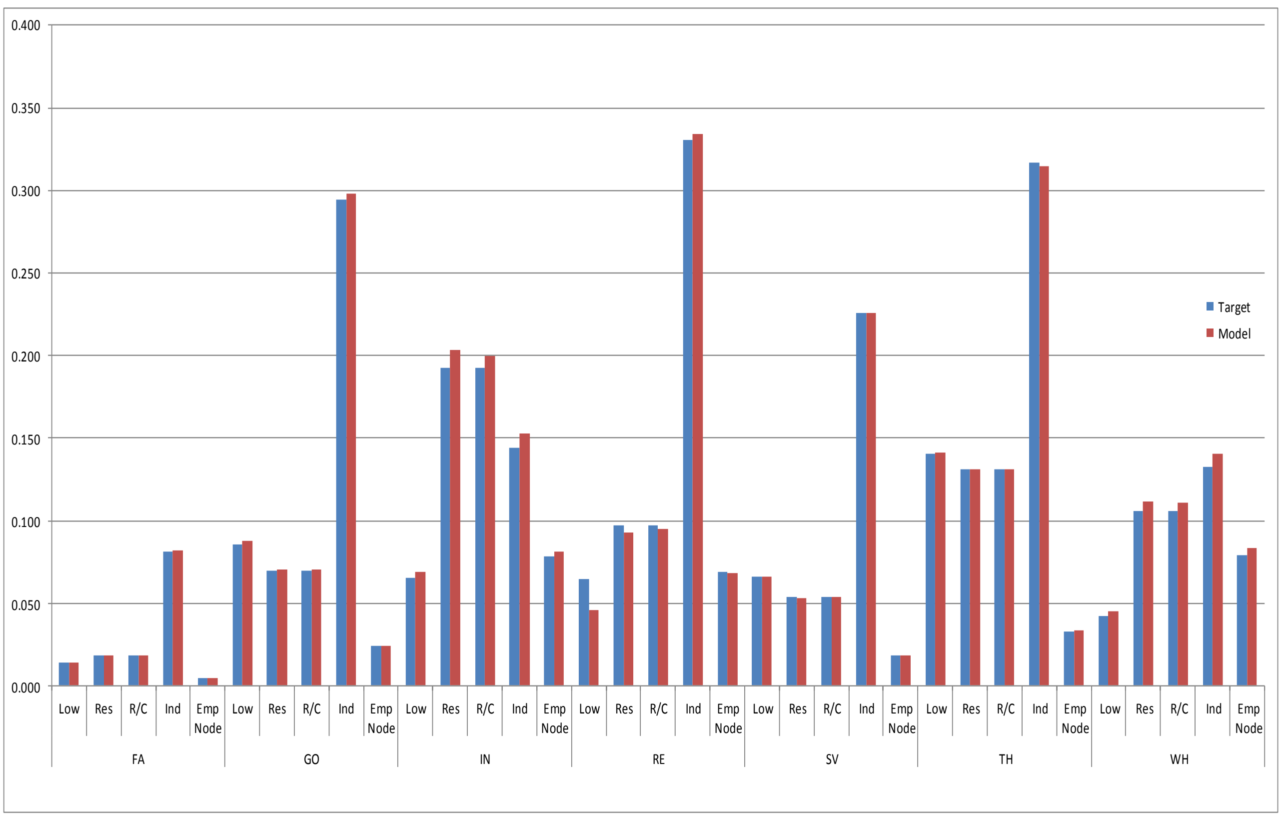


Table 16 gives final Tour Generation calibration scaling factors applied.

Table 16: Tour Generation Calibration Scaling Factors

Industry	TAZ Land Use Type	Calibration Scaling Factor
Service	Low Density	4.1374
Service	Residential	2.2546
Service	Commercial	2.6429
Service	Industrial	3.2391
Service	Employment Node	4.2139
Government Office	Low Density	11.8418
Government Office	Residential	4.5588
Government Office	Commercial	4.1018
Government Office	Industrial	5.1797
Government Office	Employment Node	14.1177
Retail	Low Density	0.6764
Retail	Residential	1.2354
Retail	Commercial	1.7748
Retail	Industrial	1.2966
Retail	Employment Node	0.1446
Industrial	Low Density	0.6712
Industrial	Residential	0.7201
Industrial	Commercial	0.7671
Industrial	Industrial	0.7934
Industrial	Employment Node	0.2481
Wholesale	Low Density	1.2189
Wholesale	Residential	0.5536
Wholesale	Commercial	0.5035
Wholesale	Industrial	0.4371
Wholesale	Employment Node	0.2212
Transport / Handling	Low Density	0.7609
Transport / Handling	Residential	0.4813
Transport / Handling	Commercial	0.4271
Transport / Handling	Industrial	1.1211
Transport / Handling	Employment Node	0.5308
Fleet	Low Density	0.4931
Fleet	Residential	1.8562
Fleet	Commercial	2.3996
Fleet	Industrial	1.7171
Fleet	Employment Node	2.4541

5.2 Tour Start Time Calibration

Tour start time target shares were derived from the observed data from the SANDAG Work-Place Survey, with some smoothing to give reasonable targets for the Early and Late Time periods. The time period definitions used are consistent with those used in the SANDAG travel modelling system. Fleet Allocator targets were taken from the Service sector shares.

During validation, it was observed that the initial calibrated model results under-represented commercial travel made in the Early and AM time periods. Revised tour start time calibration targets were prepared to match observed commercial vehicle time distributions more closely. Table 17 gives the final target time period shares by industry type.

Table 17: Target Tour Start Time Shares

	Targets				
Industry	Time periods				
Revised Targets	OE (3AM - 6AM)	AM (6AM - 9AM)	MD (9AM - 3.30PM)	PM (3.30PM - 7PM)	OL (7PM - 3AM)
Fleet Allocator	2.0%	33.4%	57.8%	5.8%	1.1%
Government/Office	2.0%	54.4%	37.2%	4.9%	1.6%
Industry	8.0%	58.6%	28.8%	3.7%	0.8%
Retail	2.0%	32.8%	57.9%	5.6%	1.8%
Service	2.0%	33.4%	57.8%	5.8%	1.1%
Transport	8.0%	62.4%	26.6%	1.7%	1.3%
Wholesale	4.0%	62.9%	29.4%	2.9%	0.8%

Figures 9a and 9b give tour start time calibration results, illustrating a good fit between target and model data.

Figure 9a Tour Start Time Calibration Results (Industry, Government Office, Transport)

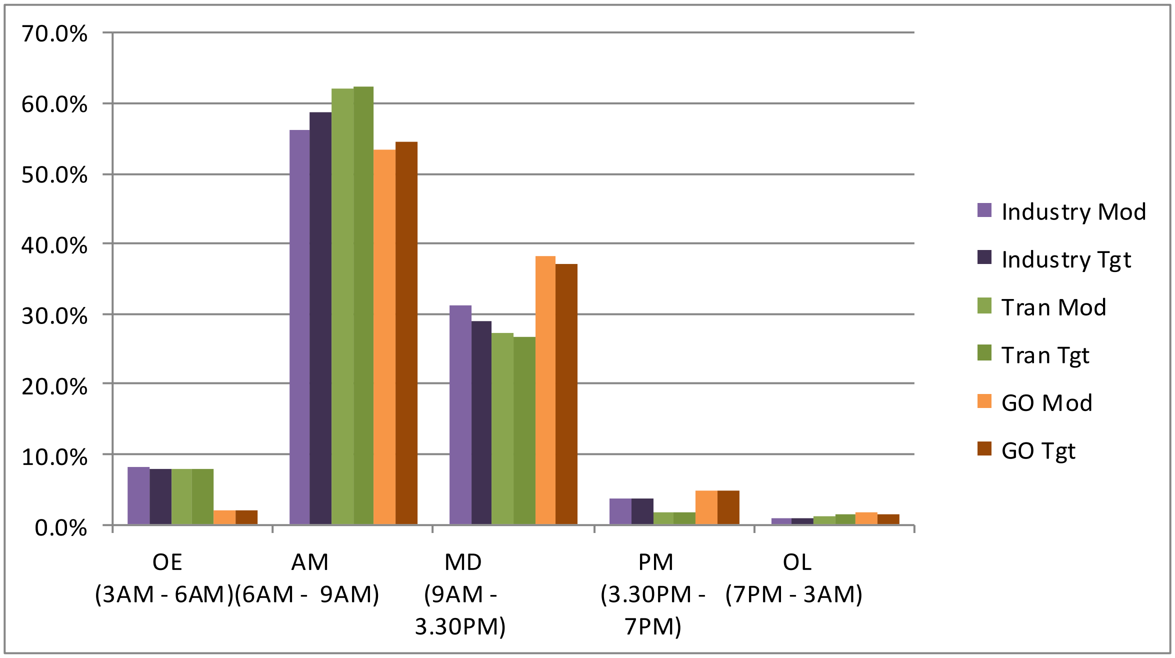
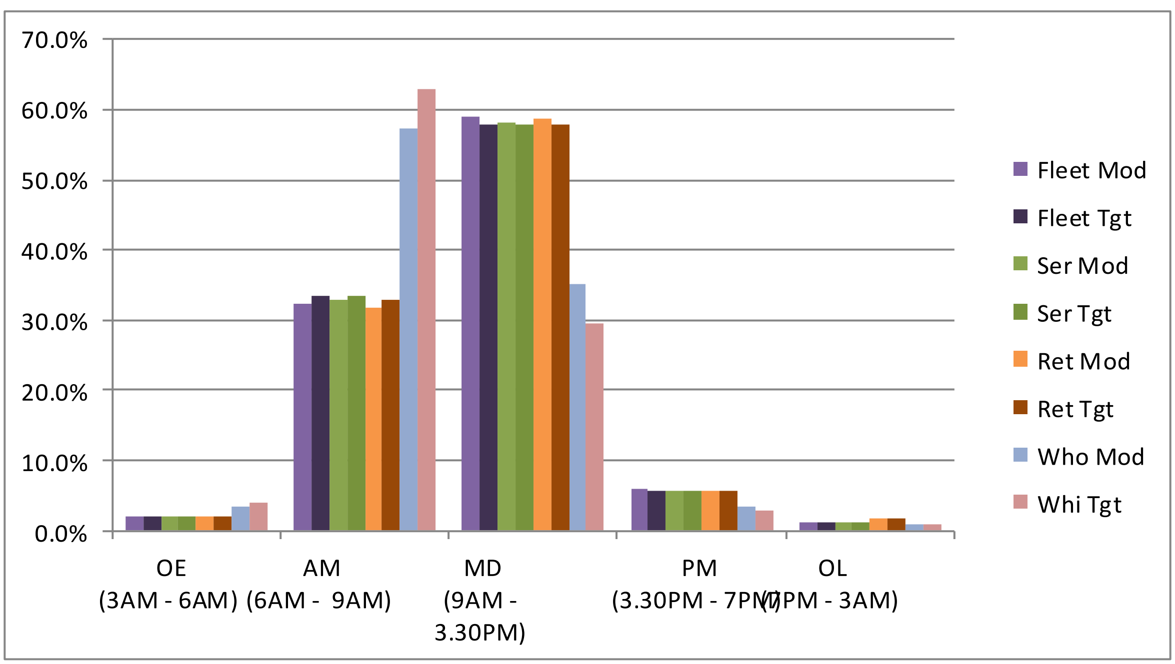


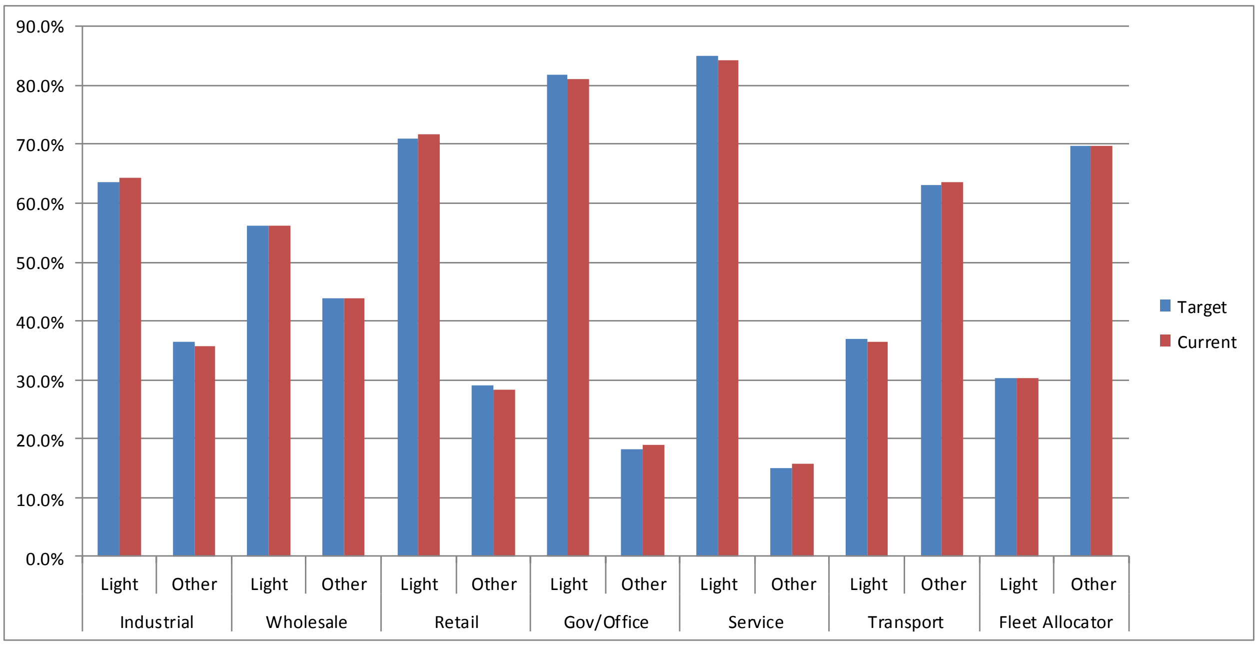
Figure 9b Tour Start Time Calibration Results (Fleet, Service, Retail, Wholesale)



5.3 Vehicle Type Calibration

The targets identified in Table 9 were used in the vehicle type calibration. Figure 10 gives calibration results by industry type, showing an excellent model fit to these targets.

Figure 10 Vehicle Type Calibration Results



5.4 Trip Toll / No Toll Calibration

The Trip Toll / No Toll Choice model was calibrated and validated so that the overall SANDAG model (CVM plus External) produced reasonable truck loadings on the SR-125 toll. Limited observed data was available, with daily truck data for one WIM site, plus AM / Midday light duty commercial vehicle & truck data for two occupancy count locations. In addition, the observed data did not explicitly differentiate between internal and external vehicle movements , so the Final CVM toll vehicle targets were based on SANDAG information that for this facility around 25% of daily trucks were external. Table 18 gives daily truck SR-125 calibration results using WIM data. Table 19 gives the results for the occupancy count locations.

Table 18: SR-125 Toll Facility Truck Flow Calibration/Validation: WIM Data

Time Period	2-Way Trucks Observed	2-Way Trucks SANDAG Model	Model to Observed %
Early	7	7	100%
AM	47	88	187%
Midday	140	212	151%
PM	52	80	154%
Late	26	32	123%
Daily	272	419	154%

Table 19: SR-125 Toll Facility Truck Flow Calibration/Validation: Occupancy Data

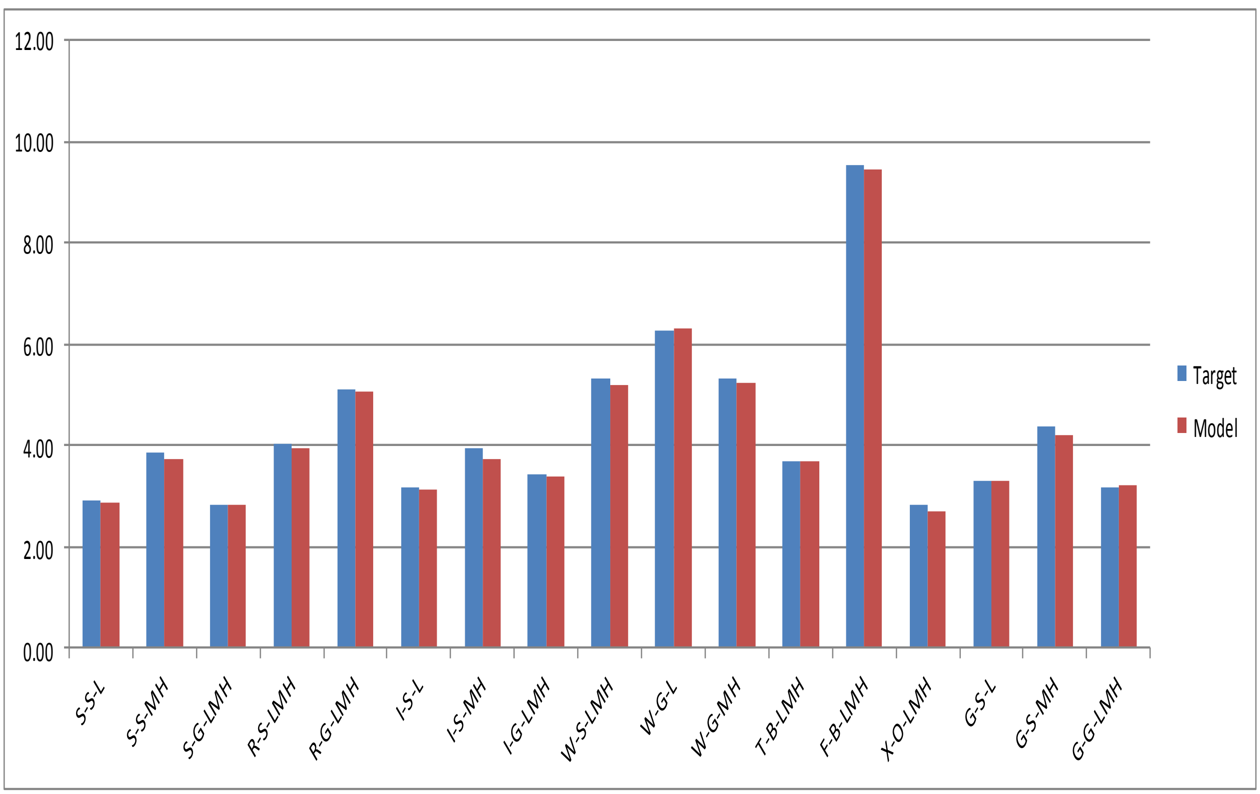
Location	Time Period	Vehicle Type	Observed	SANDAG Model	Model to Observed %
San Miguel Road (NBD)	AM	Light Duty	142	87	61%
Near SR-905 (2-way)	AM/Midday	Light Duty	303	150	50%
San Miguel Road (NBD)	AM	Truck	67	66	99%
Near SR-905 (2-way)	AM/Midday	Truck	300	265	88%

The results show a reasonably good match between modelled and observed commercial vehicle toll flows on SR-125, given the limited observed data and the uncertainty around the real number of externally-generated vehicles in the observed data.

5.5 Trips / Tour Calibration

The Next Stop Purpose model constants for the next stop being a “return home” stop were adjusted to produce model trips / tour by model segment that matched model segment target values, derived from the overall industry targets in Table 14. Tables 11A-11D in section 4.2 above contain the final model constants used. Figure 11 gives trips / tour calibration results by model segment, again showing an excellent model fit to targets.

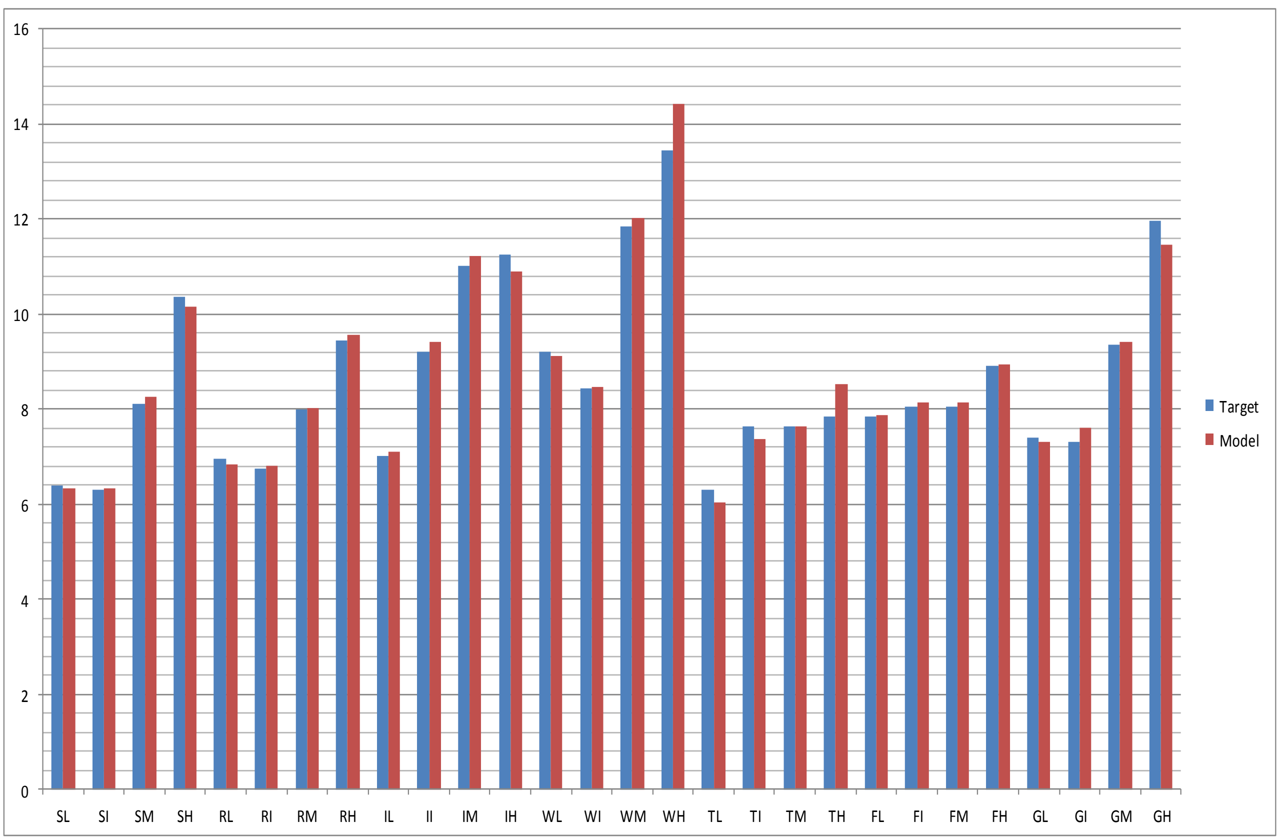
Figure 11 Trips per Tour Calibration Results



5.6 Trip Length Calibration

The Next Stop Location model parameters for travel disutility to the next stop were adjusted, to produce model trip lengths by model segment that matched overall target values from Table 14. Tables 12A-12D in section 4.3 above contain the final model parameters used Figure 12 gives calibration results, showing a good model / target match.

Figure 12 Trip Length Calibration Results

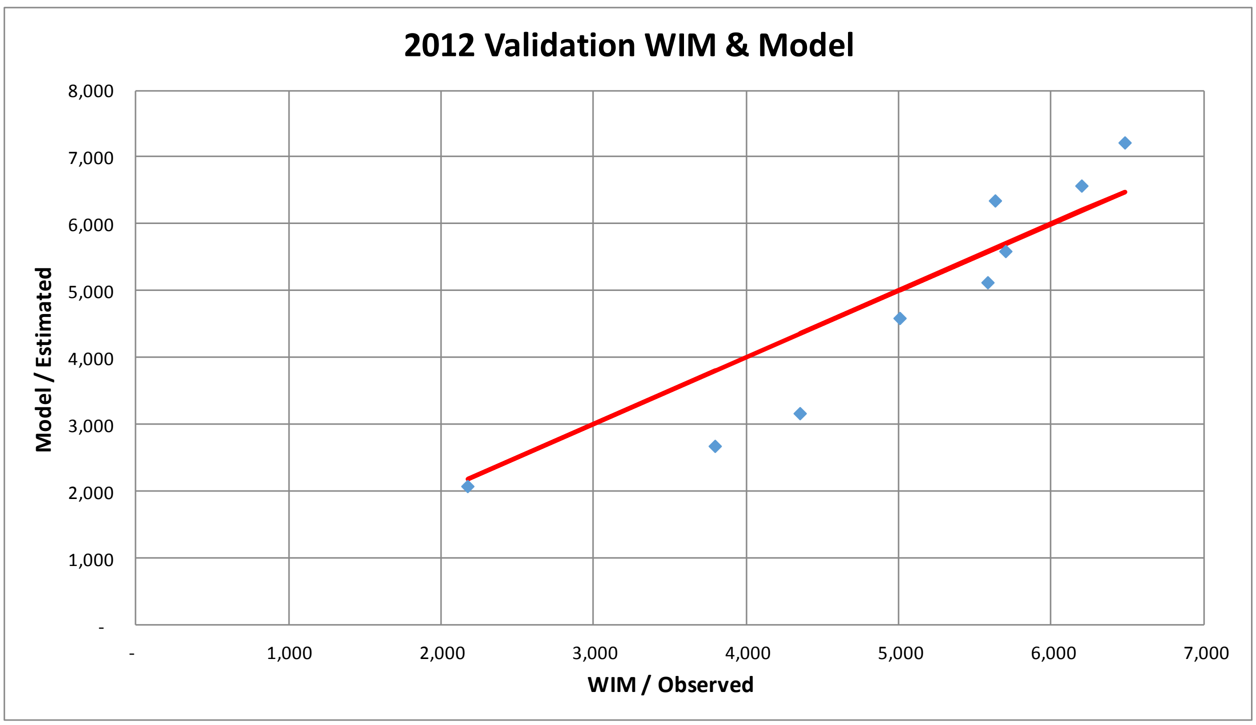


5.7 Final CVM Validation

The Final CVM run output from the 2012 Base Year run were compared to observed commercial vehicle count data at WIM and occupation count locations, Figures 13a through 13c show validation results.

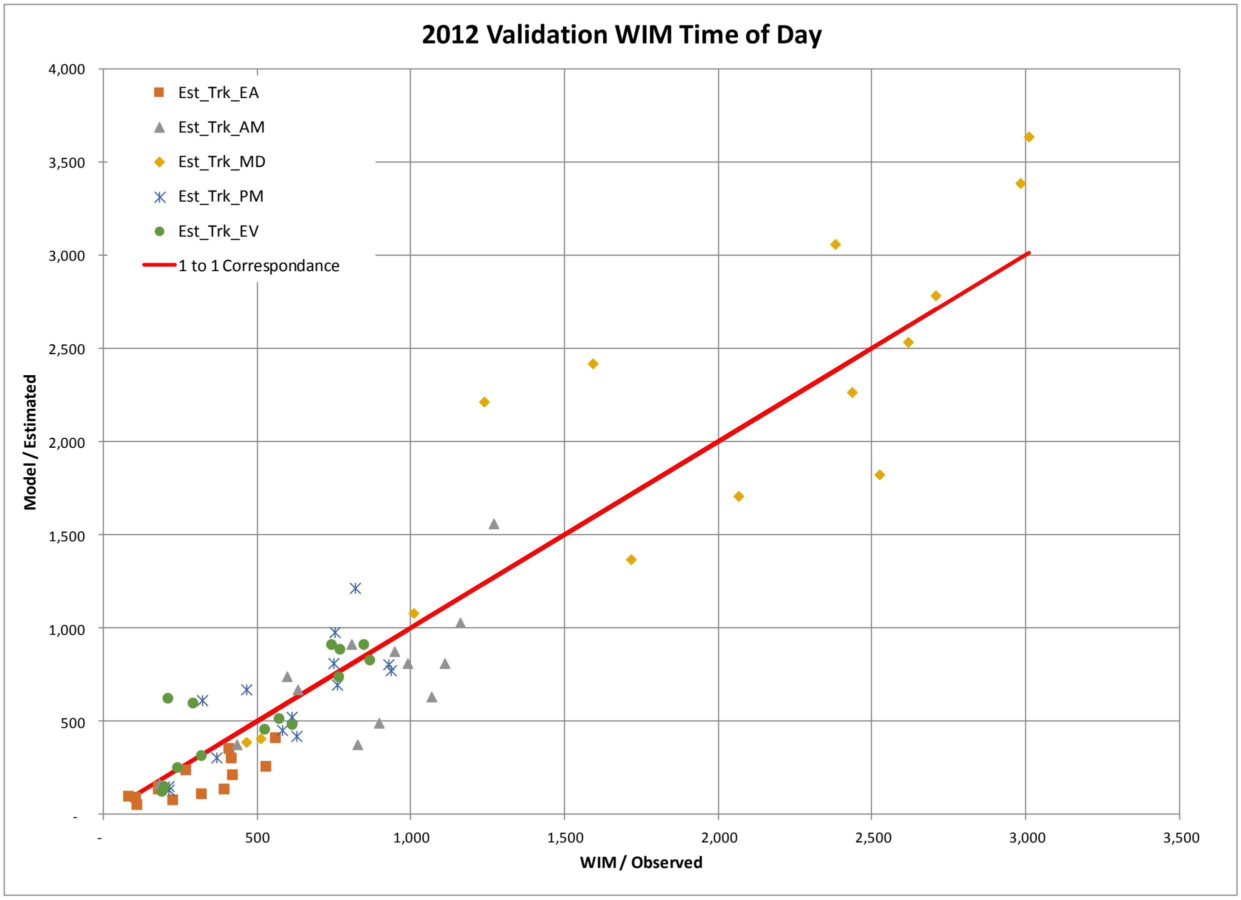
It should be noted that the SANDAG model output data results in Figure 13a-13c include both CVM and External Model truck forecasts, so are not a 100% indication of the Final CVM model performance on its own. However, as External Model flows are thought to make up only around 25% of truck flows in the SANDAG region, the results are indicative of the CVM accuracy.

Figure 13a Comparison of Final CVM Output with WIM Data: Daily Truck Volumes



The above daily volume comparison between model and observed results shows a reasonable fit.

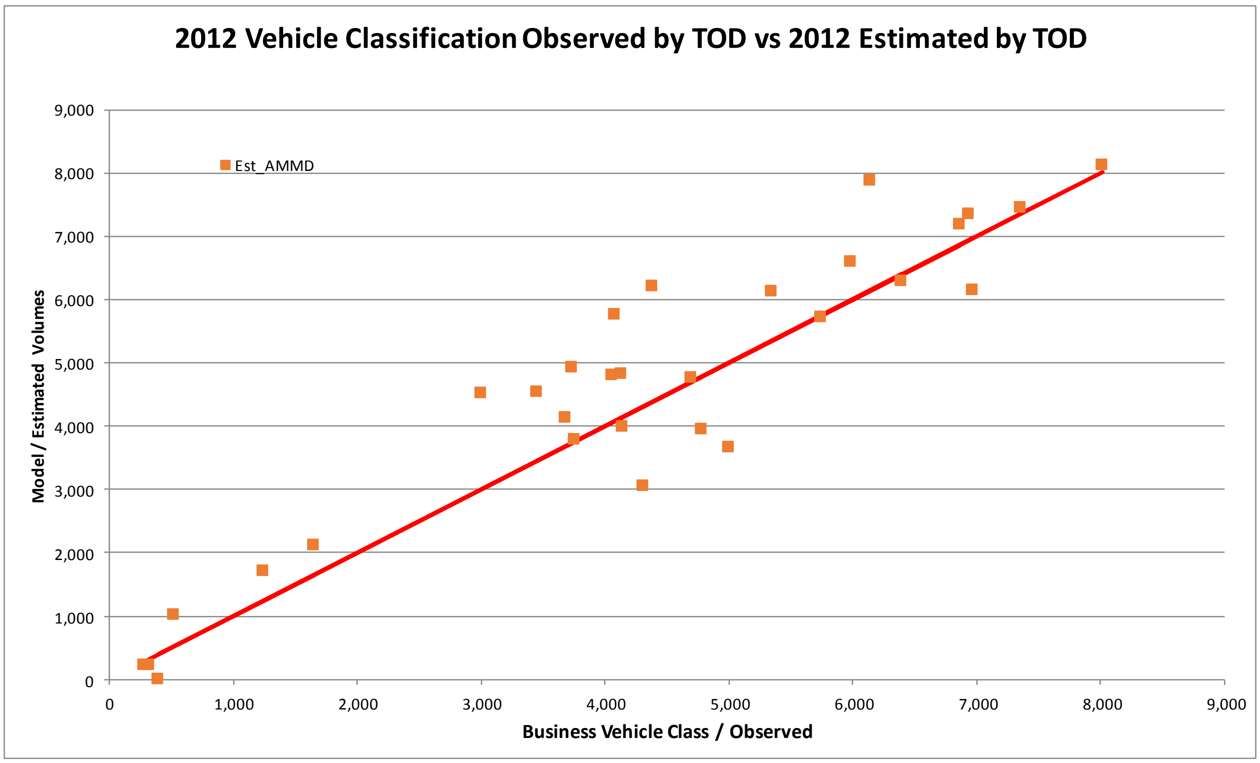
Figure 13b Comparison of Final CVM Output with WIM Data: by Time Period



The model results show a reasonable fit with observed data for the later time periods in the day (Midday, PM and Late).

The overall model results still show significant under-representation of Early AM commercial truck flows, and some under-representation of AM peak flows, even after significant adjustments to Final CVM tour start time distributions to reflect observed distributions in these Early and AM time periods. The observed flows do not give an indication of the breakdown between internal-internal truck movements & external truck movements, so it is not clear whether this time period validation issue is caused by a problem with the Final CVM, or the SANDAG External Truck Model, or both models. Without additional understanding of the observed data further adjustments of the Final CVM time period distribution, away from the patterns observed in the Survey data, was not considered appropriate.

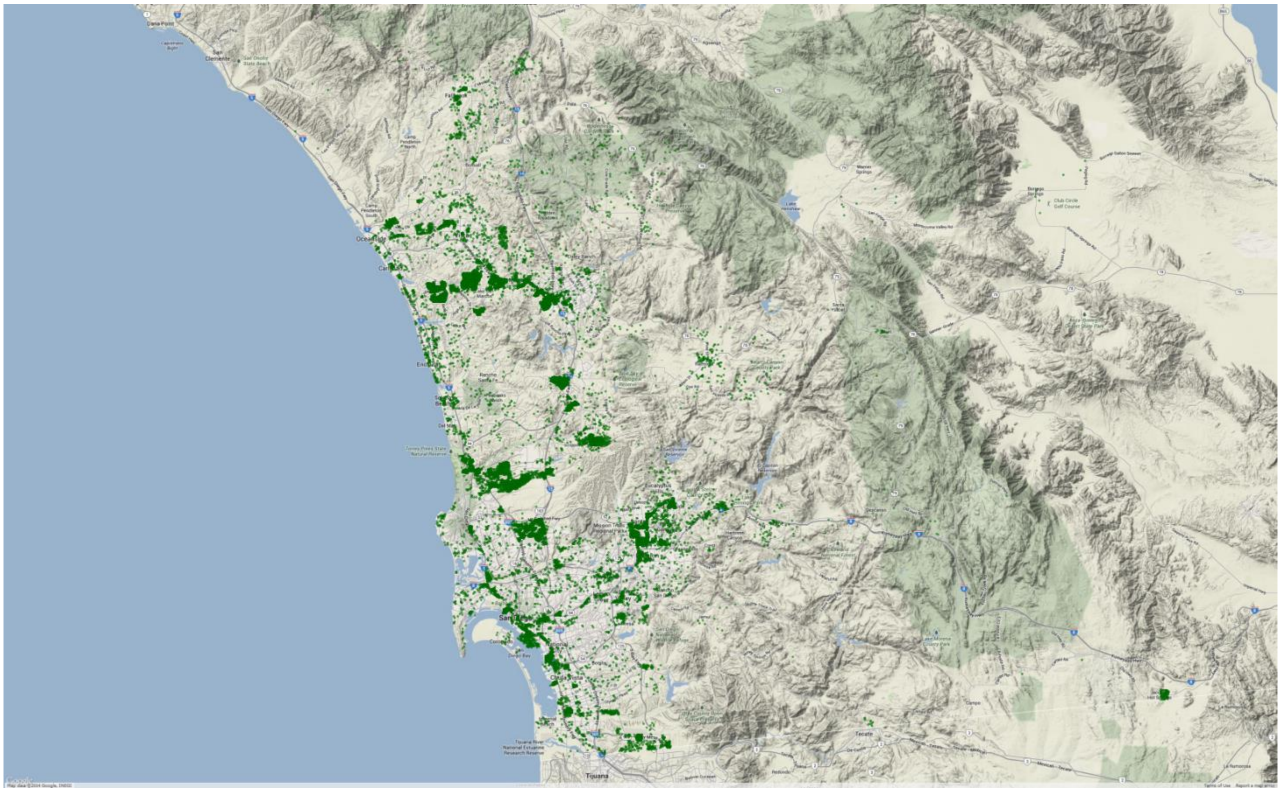
Figure 13c Comparison of Final CVM Output with Occupancy Counts: Business Vehicles (AM & Mid-Day)



The results in Figure 13c show a good fit between SANDAG truck model output data and observed data, for light business vehicles, for the AM / Midday time period covered by the observed occupancy count data.

Figure 14 illustrates model trip generation output results by model zone, for the Industry sector. Similar output plots were produced by the other model industry groups. Visual inspection of these plots confirmed that the model output was reasonable and consistent with expectations.

Figure 14 Daily Tour Generation Output by Zone: Industry Sector



Based on the above results, the Final CVM model is considered to be validated to observed volumes.

Future validation of the Final CVM could be enhanced if additional observed data on commercial vehicle flows was explicitly available for:

- A breakdown of commercial vehicle flows by broad origin-destination, particularly whether flows are internal-internal (and captured by the Final CVM model), or external (and captured by the External Truck Model);
- Toll facility usage for light duty commercial vehicles, for all toll facilities.

5.8 Final CVM Sensitivity Testing

Two separate sensitivity tests of the Final CVM were performed:

- Travel times were increased by 10%;
- Toll costs were increased by 50%.

Results from the two tests are given in Tables 20 and 21.

Table 20: Final CVM Sensitivity Test Results: 10% Increase in Travel Times

Tour Generation								
Tours	**FA**	**GO**	**IN**	**RE**	**SV**	**TH**	**WH**	**Total**
Base	27727	24616	22107	14489	18392	6203	5001	118535
Travel Time	27504	24273	21916	14297	18089	6193	4997	117269
TT vs Base	-0.8%	-1.4%	-0.9%	-1.3%	-1.6%	-0.2%	-0.1%	-1.1%
Number of trips								
Trips	**FA**	**GO**	**IN**	**RE**	**SV**	**TH**	**WH**	**Total**
Base	264,213	83,159	74,148	67,930	55,150	22,306	28,603	595,509
Travel Time	261,293	82,679	73,807	66,702	55,120	21,722	28,418	589,741
TT vs Base	-1.1%	-0.6%	-0.5%	-1.8%	-0.1%	-2.6%	-0.6%	-1.0%
Trips per tour								
Trips	**FA**	**GO**	**IN**	**RE**	**SV**	**TH**	**WH**	**Total**
Base	9.53	3.38	3.35	4.69	3.00	3.60	5.72	5.02
Travel Time	9.50	3.41	3.37	4.67	3.05	3.51	5.69	5.03
TT vs Base	-0.3%	0.8%	0.4%	-0.5%	1.6%	-2.5%	-0.6%	0.1%
VMT								
Miles	**FA**	**GO**	**IN**	**RE**	**SV**	**TH**	**WH**	**Total**
Base	2,157,293	655,863	632,624	490,554	376,227	154,077	293,176	4,759,814
Travel Time	2,150,429	653,756	635,179	476,288	379,065	156,491	293,652	4,744,860
TT vs Base	-0.3%	-0.3%	0.4%	-2.9%	0.8%	1.6%	0.2%	-0.3%
Vehicle choice								
Tours	**L**	**I**	**M**	**H**	**Total**			
Base	69,436	4,713	24,886	19,500	118,535			
Travel Time	62,561	5,349	27,649	21,710	117,269			
TT vs Base	-9.9%	13.5%	11.1%	11.3%	-1.1%			

Overall, the results show a reasonable decrease in the number of tours, trips and VMT arising from a 10% increase in travel time, with some variation by segment. In some situations the forecast number of trips per tour increases, as well as average trip length.

The use of vehicles shift from light vehicles to the heavier truck categories. The results are consistent with those seen in other applications of the CVM (in California and Alberta).

As travel times (congestion) rise, the time it takes to deliver a good or service increases. Eventually, the establishment can't handle the usual shipping volume with the same number of vehicles, so they must adjust tour patterns, and deploy more and / or different vehicles to handle the same business volume. The CVM results can thus be counter to what might be expected from personal travel, but businesses have different operating principles and requirements than people do.

Note: this sensitivity test was performed using a single run of the CVM for the Base & Travel Time Increase scenarios, and comparing the run results. Part of the variation found in the results arises because of the micro-simulation "noise" that occurs as a direct result of the disaggregate CVM micro-simulation application.

Table 21: Final CVM Sensitivity Test Results: 50% Increase in Toll Charges

	Daily Demand				Daily VMT				Elasticity	
Category	Base	Toll +50%	Change	% Change	Base	Toll +50%	Change	% Change	Demand	VMT
Light Commercial Vehicles : Toll	6,303	6,216	(88)	-1.4%	103,717	102,159	(1,559)	-1.5%	-0.028	-0.030
Medium Commercial Vehicles : Toll	325	299	(26)	-8.0%	6,093	5,484	(609)	-10.0%	-0.160	-0.200
Heavy Commercial Vehicles : Toll	185	172	(13)	-7.2%	3,597	3,297	(300)	-8.3%	-0.145	-0.167
ALL Commercial Vehicles : Toll	6,813	6,686	(127)	-1.9%	113,407	110,939	(2,468)	-2.2%	-0.037	-0.044
Light Commercial Vehicles : No Toll	339,408	339,129	(278)	-0.1%	2,423,395	2,422,029	(1,366)	-0.1%		
Medium Commercial Vehicles : No Toll	204,376	204,851	475	0.2%	1,736,177	1,733,813	(2,363)	-0.1%		
Heavy Commercial Vehicles : No Toll	95,316	96,173	857	0.9%	927,745	930,479	2,735	0.3%		
ALL Commercial Vehicles : No Toll	639,100	640,154	1,054	0.2%	5,087,316	5,086,321	(994)	0.0%		

In practice this test effectively applied to only around 1% of vehicle movements, those using toll facilities in the Base case. Overall the results show a reasonable decrease in the number of commercial vehicle trips and VMT associated with the toll increase, with demand and VMT elasticities ranging from -3% to -16% based on vehicle type. Non-toll vehicle trip demand increases slightly, with VMT showing very little change.

Note: This scenario sensitivity test was performed by running the CVM 10 times for both the Base & the Toll Increase scenario, and averaging the results in each case. This process helps to reduce the amount of micro-simulation noise in the results.

5.9 Vehicle Type / EMFAC Input

SANDAG uses the California Air Resources Board EMFAC program for regional air quality analysis, with the latest version produced in 2011. EMFAC 2011 uses 50 different vehicle classes by vehicle type and fuel technology. Trucks are classified by 7 weight classes:

- Light-Duty Truck (0-3,750 lbs);
- Light-Duty Truck (3,750-5,750 lbs);
- Medium-Duty Truck (5,750-8,500 lbs);
- Light-Heavy Duty Truck (8,500-10,000 lbs),
- Light-Heavy Duty Truck (10,000-14,000 lbs),
- Medium-Heavy Duty (14000-33,000 lbs),and
- Heavy-Heavy Duty (33,000+ lbs).

The output from the CVM needs to be converted, to be consistent with the EMFAC categories, in a post-processor step. Table 22 gives the relationship between EMFAC 2011 and the Final CVM commercial vehicle categories (the 2007 EMFAC categories are also included in the Table, as this older version was used by SANDAG in previous model applications.

Table 22 EMFAC2011, EMFAC2007 And Final CVM Vehicle Categories

EMFAC 2011:Vehicle	EMFAC 2011:Type	EMFAC2007	CVM Category
LDA – DSL	Passenger Car	LDA – DSL	Light
LDA – GAS	Passenger Car	LDA – GAS	Light
LDT1 - DSL	Light-Duty Truck (0-3,750 lbs)	LDT1 - DSL	Light
LDT1 – GAS	Light-Duty Truck (0-3,750 lbs)	LDT1 - GAS	Light
LDT2 – DSL	Light-Duty Truck (3,750-5,750 lbs)	LDT2 - DSL	Light
LDT2 – GAS	Light-Duty Truck (3,750-5,750 lbs)	LDT2 - GAS	Light
LHD1 – DSL	Light-Heavy-Duty Truck (8,501-10,000 lbs)	LHDT1 - DSL	Light
LHD1 – GAS	Light-Heavy-Duty Truck (8,501-10,000 lbs)	LHDT1 - GAS	Light
LHD2 – DSL	Light-Heavy-Duty Truck (10,001-14,000 lbs)	LHDT2 - DSL	Intermediate Medium
LHD2 – GAS	Light-Heavy-Duty Truck (10,001-14,000 lbs)	LHDT2 - GAS	Intermediate Medium
MCY – GAS	Motorcycles	MCY - GAS	
MDV – DSL	Medium-Duty Truck (5,751-8,5000 lbs)	MDV - DSL	Light
MDV – GAS	Medium-Duty Truck (5,751-8,5000 lbs)	MDV - GAS	Light
MH – DSL	Motor Home	MH - DSL	
MH – GAS	Motor Home	MH - GAS	
Motor Coach - DSL	OBUS – DSL	OBUS - DSL	
OBUS - GAS	Other Bus	OBUS - GAS	
PTO – DSL	Power Take Off	HHDT - DSL	
SBUS - DSL	School Bus	SBUS - DSL	
SBUS - GAS	School Bus	SBUS - GAS	
T6 Ag - DSL	Medium-Heavy Duty Truck	MHDT - DSL	Medium
T6 CAIRP heavy - DSL	Medium-Heavy Duty Truck	MHDT - DSL	Medium
T6 CAIRP small - DSL	Medium-Heavy Duty Truck	MHDT - DSL	Medium
T6 instate construction heavy - DSL	Medium-Heavy Duty Truck	MHDT - DSL	Medium
T6 instate construction small - DSL	Medium-Heavy Duty Truck	MHDT - DSL	Medium
T6 instate heavy - DSL	Medium-Heavy Duty Truck	MHDT - DSL	Medium
T6 instate small - DSL	Medium-Heavy Duty Truck	MHDT - DSL	Medium
T6 OOS heavy - DSL	Medium-Heavy Duty Truck	MHDT - DSL	Medium
T6 OOS small - DSL	Medium-Heavy Duty Truck	MHDT - DSL	Medium
T6 Public - DSL	Medium-Heavy Duty Truck	MHDT - DSL	Medium
T6 utility - DSL	Medium-Heavy Duty Truck	MHDT - DSL	Medium
T6TS - GAS	Medium-Heavy Duty Truck	MHDT - GAS	Medium

T7 Ag - DSL	Heavy-Heavy Duty Truck	HHDT - DSL	Heavy
T7 CAIRP - DSL	Heavy-Heavy Duty Truck	HHDT - DSL	Heavy
T7 CAIRP construction – DSL	Heavy-Heavy Duty Truck	HHDT - DSL	Heavy
T7 NNOOS - DSL	Heavy-Heavy Duty Truck	HHDT - DSL	Heavy
T7 NOOS - DSL	Heavy-Heavy Duty Truck	HHDT - DSL	Heavy
T7 other port - DSL	Heavy-Heavy Duty Truck	HHDT - DSL	Heavy
T7 POAK - DSL	Heavy-Heavy Duty Truck	HHDT - DSL	Heavy
T7 POLA - DSL	Heavy-Heavy Duty Truck	HHDT - DSL	Heavy
T7 Public - DSL	Heavy-Heavy Duty Truck	HHDT - DSL	Heavy
T7 Single - DSL	Heavy-Heavy Duty Truck	HHDT - DSL	Heavy
T7 single construction – DSL	Heavy-Heavy Duty Truck	HHDT - DSL	Heavy
T7 SWCV - DSL	Heavy-Heavy Duty Truck	HHDT - DSL	Heavy
T7 tractor - DSL	Heavy-Heavy Duty Truck	HHDT - DSL	Heavy
T7 tractor construction - DSL	Heavy-Heavy Duty Truck	HHDT - DSL	Heavy
T7 utility - DSL	Heavy-Heavy Duty Truck	HHDT - DSL	Heavy
T7IS - GAS	Heavy-Heavy Duty Truck	HHDT - GAS	Heavy
UBUS - DSL	Urban Bus	UBUS - DSL	
UBUS - GAS	Urban Bus	UBUS - GAS	

Note: the CVM truck categories are based on vehicle configuration, as given in Table 1, and are consistent with the FHWA classification system. They do not directly fit into the EMFAC weight-based categorisation system. Insufficient data was collected on medium / heavy truck movements in the SANDAG Work-Place Survey to facilitate a change in the CVM vehicle definitions.

6. Final CVM Implementation in SANDAG

This section describes how the Final CVM is implemented in SANDAG.

- Section 6.1 gives an overview of the implementation;
- Section 6.2 identifies hardware and software requirements;
- Section 6.3 describes SANDAG directory structures and CVM model operation;
- Section 6.4 describes required input files;
- Section 6.5 describes output files and output processing.

6.1 Overview of Final CVM Implementation

The CVM is implemented in the SANDAG ABM travel model system, which uses the TRANSCAD software interface.

The CVM model itself contains two specially-written computer programs:

1. A program written in python script to calculate the TAZ-level tour generation component of the model;
2. A program written in java script to implement the tour micro-simulation component of the model.

The first (python) program reads in the following input data:

- A TAZ demographic data input file;
- TAZ to TAZ Skim files from Transcad giving midday travel “disutility cost” data by vehicle type, and midday auto travel time, in csv format
- A run settings input file.

This program calculates, and outputs for use by the second (java) program:

- The number of daily tours generated in each TAZ for each industry by tour purpose, vehicle type and time of day;
- TAZ accessibility measures.

The second (java) program reads in the following input data:

- The number of daily tours generated in each TAZ for each industry by tour purpose, vehicle type and time of day (first model output);
- TAZ accessibility measures (first model output);
- Model specification files for each industry type / time of day, giving details of parameters and travel skim and demographic data input sources;
- A TAZ demographic data input file (the same file as used in the first (python) program);
- TAZ to TAZ Skim files from Transcad giving time, distance and cost data by time period by commercial vehicle type. This file is in a different format than that used in the first program, but contains the same data;
- A run properties file.

This program then micro-simulates each tour, and produces a trip list for every trip on every tour giving TAZ origin and destination, vehicle type, and fine level time period of travel.

In the last stage of the CVM implementation Transcad model scripts read in the CVM trip list and convert the data to trip tables by model vehicle type and time period, for vehicle trip assignment.

6.2 Final CVM Hardware and Software Requirements

The Final CVM can run on a standard “desktop” computer or server. The minimum “memory” requirements are:

- The current python application uses around 150Mb of RAM, on a single core.
- The java program uses around 2Gb of RAM.

The java program can take advantage of multiple threads (the number of threads to be used is specified in the input properties file). Each of the 30 Industry Type / Time period tour list files calculated in the Tour Generation stage is allocated to an available thread (these are accessed in the order specified in the properties file, allowing some optimization of run time).

Each CVM run with the same inputs will produce different fine detail results, because of the randomness inherent in the micro-simulation modelling process of individual tours. It is recommended that the CVM is run “multiple times” with the same inputs, and the results averaged. This approach increases CVM run time, but reduces variability between run results. The standard SANDAG application has been set up to apply a “10 times” factor.

Model run times are dependent upon the computer specifications, but are generally on the order of 15-30 minutes.

The following software is required to run the CVM:

- Python (version 2.6, 64bit): http://www.python.org/download/releases/2.6.6/
    - Numpy (version 1.4.1): http://numpy.scipy.org/
- Java 6 (Update 18, 64bit): http://www.java.com/en/download/manual.jsp

6.3 SANDAG Directory Structure and Final CVM Model Operation

The CVM model operation is integrated within the overall SANDAG ABM model structure, implemented in Transcad.

The ABM program operation is controlled by a master file “***sandag_abm-master.rsc”,*** which contains instructions to run scripts to create network skims, run the different demand models, create trip table output, perform network assignments, and produce summary results..

This master file and associated Transcad scripts have been modified to;

- Run the CVM python and java sub-programs;
- Create the required disutility (weighted combinations of time, distance and cost) input matrices (see below) in Transcad, for use in the CVM java sub-program;
- Output the required disutility and time skims in csv format, for use in the CM python sub-model;
- Process the CVM model trip list into Transcad trip tables by vehicle type and time period.

6.3.1 File Directory Structure

The CVM model is set up on the SANDAG file system in the directory T:\Transnet2\devel\CVM\sr13\2012_calib2. This root directory contains the Python code (sdcvm.py and settings.py) as well as a batch file running the model, and is the location for the Java event log output.

The model sub-directories are:

- Code – contains the Java code
- Inputs – contains all input files as described below, except settings.py

- Outputs – contains the "trip list" outputs of the model, providing detailed descriptions of the travel made by each commercial vehicle. Note that the trip matrices as output are written to a Transcad matrix file in a directory specified in cvm.properties

6.3.2 Running the Final CVM

The CVM operates in two steps.

1. The first step runs a python program sdcvm.py to produce an intermediate output file CVMToursAccess.csv, containing:
   a. Aggregate TAZ-level numbers of tours by industry and time period, to be micro-simulated;
   b. TAZ population and employment accessibility measures used in the micro-simulation.
   c. zonal employment density and population density values which are capped at 100,000 jobs / sq.mile for employment density, and 50,000 persons / sq.mile for population density. These caps are required because the next stop location models use density as an explanatory variable for trip zone destination choice. In the SANDAG model there are a small number of very small zones by area in the Downtown, which have very high densities, some in excess of 250,000 persons / sq.mile, much larger than the densities occurring in the initial Alberta model estimation data-sets.
2. The second step runs the java micro-simulation program for each tour, and produces a series of trip list output files identifying trips by vehicle type and SANDAG model time period, in the format Trip_*Ind*_*Time*.csv where Ind is a two letter industry code and Time is a two letter tour start time code. It also produces a series of trip matrices in Transcad format.

6.4 Final CVM Input Files

Five input file(s) are required:

1. A zonal properties file;
2. Travel skims files;
3. A CVM python program run settings file;
4. A CVM java program run properties file;
5. Model specification files.

The first two sets of files are used by both the python and java CVM sub-models. The third input file is used by the python program (which generates an intermediate output file also used by the java program). The last two sets of files are used by the java program.

6.4.1 Zonal Properties Input File

Table 23 gives the required fields in the zonal properties file, for each TAZ to be modelled. The zonal properties file name is specified in the cvm properties input file – generally named “Zonal Properties CVM.csv”.

Table 23: CVM Zonal Input Requirements

Field Name	Description
TAZ	Transportation Analysis Zone
Pop	Population
Income	Average Annual Household Income
Area_SqMi	TAZ area in square miles
x-meters	Projected X coordinate of TAZ centroid (California Albers NAD 83)
y-meters	Projected Y coordinate of TAZ centroid (California Albers NAD 83)
EmpDens	Employee density
PopDens	Population density
TotEmp	Total employment
Military	Military employment
CVM_IN	Industrial employment
CVM_RE	Retail employment
CVM_SV	Service Employment
CVM_TH	Transportation and Utilities Employment
CVM_WH	Wholesale Employment
CVM_LU_Type	Land use type
SqrtArea	Square root of the area
CVM_LU_Low	Low density land use flag
CVM_LU_Res	Residential land use flag
CVM_LU_Ret	Retail/commercial land use flag
CVM_LU_Ind	Industrial land use flag
CVM_LU_Emp	Other land use flag
Emp_LU_Lo	Total employment if CVM_LU_Low = 1
Emp_LU_Re	Total employment if CVM_LU_Res = 1
Emp_LU_RC	Total employment if CVM_LU_Ret = 1
Emp_LU_In	Total employment if CVM_LU_In = 1
Emp_LU_EN	Total employment if CVM_LU_Emp = 1

6.4.2 Travel Skims Input Files

Table 24 summarizes the 72 travel skim matrices used as input to the CVM from separate multi-class assignments run for each three model time periods (AM peak, PM peak, Midday – the Midday skims are also used to represent travel conditions in the Early and Late time periods).

Table 24: Travel Skim Matrices Input to the CVM

Vehicle Type	Toll Status	Time Periods	Skim Variable
Light, Intermediate, Medium, Heavy	No Toll	AM, Midday, PM	Time
Light, Intermediate, Medium, Heavy	No Toll	AM, Midday, PM	Distance
Light, Intermediate, Medium, Heavy	Toll	AM, Midday, PM	Time
Light, Intermediate, Medium, Heavy	Toll	AM, Midday, PM	Distance
Light, Intermediate, Medium, Heavy	Toll	AM, Midday, PM	Distance on Toll
Light, Intermediate, Medium, Heavy	Toll	AM, Midday, PM	Toll Cost

In the current version of the SANDAG CVM program the skim input locations are hard-coded in a special java sub-program. This is required because the Toll / No Toll trip choice sub-model is an additional model feature not present in other applications of the CVM, and this sub-model requires additional travel skim input data not used in the regular CVM application.

The java code CommercialTripMode.java specifies the use of Transcad skims in the San Diego CVM program. The file is in the CVM's .jar file in the directory com/hbaspecto/activityTravel/cvm. If changes need to be made to the use of skims, this file can be extracted from the .jar file (using unzip) and recompiled (using eclipse or the java compiler javac), to replace its associated compiled file CommercialTripMode.class. A new .jar file can be created including that includes the modified .class file, or the classpath of the model run command can be modified to refer to the new .class file in a separate location outside of the .jar file.[2]

The code below, from this file, shows the skim matrices that are used as input to the CVM from separate multi-class assignments run for each of the four model time periods.

In the code, the part before addCoefficient describes the type of skim that is being specified, with options of:

- For the route choice avoiding tolls:
  - noTollDistance, distance of the best no-toll option,
  - noTollTime, time of the best no-toll option,
- For the route choice where there is no disutility of the toll itself, thus involving toll facilities when using one or more toll facilities saves travel time over not using any toll facilities:
  - tollDistance, distance on toll facilities (zero if toll options provide no benefit)
  - totalDistance, total distance
  - tollTime, total time
  - tollCost, cost of toll facilities used, in cents, 0 if tolls provide no benefit.

After the word addCoefficient, the parameters are:

- Vehicle type, “M”, “I”, “L”, or “H”

[2] Refer to the documentation from Oracle.com on java compilation for detailed instructions, or any experienced Java programmer can easily make the changes inside of the Eclipse program to generate a replacement .jar file.

- "default" for default travel time skim, or "" for a time-of-day specific skim
- Starting time of time-of-day specific skim, or "" for default time-of-day skim
- The cube specific name of the skim. The part before the ":" is the file name, the part after the ":" is the skim name
- The ending time of time-of-day specific skims, or 0 for default time-of-day skims.

```
switch (myType) {
case "M:T":
case "M:NT":
  noTollDistance.addCoefficient("M", "default", "", "implhdn_MD:Length (Skim)", 0);
  noTollDistance.addCoefficient("M", "", "6", "implhdn_AM:Length (Skim)", 9);
  noTollDistance.addCoefficient("M", "", "15.5", "implhdn_PM:Length (Skim)", 19);
  noTollTime.addCoefficient("M", "default", "", "implhdn_MD:*STM_MD (Skim)", 0);
  noTollTime.addCoefficient("M", "", "6", "implhdn_AM:*STM_AM (Skim)", 9);
  noTollTime.addCoefficient("M", "", "15.5", "implhdn_PM:*STM_PM (Skim)", 19);
  tollDistance.addCoefficient("M", "default", "", "implhdt_MD:tolldst_MD - Length", 0);
  tollDistance.addCoefficient("M", "", "6", "implhdt_AM:tolldst_AM - Length", 9);
  tollDistance.addCoefficient("M", "", "15.5", "implhdt_PM:tolldst_PM - Length", 19);
  totalDistance.addCoefficient("M", "default", "", "implhdt_MD:Length (Skim)", 0);
  totalDistance.addCoefficient("M", "", "6", "implhdt_AM:Length (Skim)", 9);
  totalDistance.addCoefficient("M", "", "15.5", "implhdt_PM:Length (Skim)", 19);
  tollTime.addCoefficient("M", "default", "", "implhdt_MD:*STM_MD (Skim)", 0);
  tollTime.addCoefficient("M", "", "6", "implhdt_AM:*STM_AM (Skim)", 9);
  tollTime.addCoefficient("M", "", "15.5", "implhdt_PM:*STM_PM (Skim)", 19);
  tollCost.addCoefficient("M", "default", "", "implhdt_MD:ITOLL2_MD (Skim)", 0);
  tollCost.addCoefficient("M", "", "6", "implhdt_AM:ITOLL2_AM (Skim)", 9);
  tollCost.addCoefficient("M", "", "15.5", "implhdt_PM:ITOLL2_PM (Skim)", 19);
  break;
case "H:T":
case "H:NT":
  noTollDistance.addCoefficient("H", "default", "", "imphhdn_MD:Length (Skim)", 0);
  noTollDistance.addCoefficient("H", "", "6", "imphhdn_AM:Length (Skim)", 9);
  noTollDistance.addCoefficient("H", "", "15.5", "imphhdn_PM:Length (Skim)", 19);
  noTollTime.addCoefficient("H", "default", "", "imphhdn_MD:*STM_MD (Skim)", 0);
  noTollTime.addCoefficient("H", "", "6", "imphhdn_AM:*STM_AM (Skim)", 9);
  noTollTime.addCoefficient("H", "", "15.5", "imphhdn_PM:*STM_PM (Skim)", 19);
  tollDistance.addCoefficient("H", "default", "", "imphhdt_MD:tolldst_MD - Length", 0);
  tollDistance.addCoefficient("H", "", "6", "imphhdt_AM:tolldst_AM - Length", 9);
  tollDistance.addCoefficient("H", "", "15.5", "imphhdt_PM:tolldst_PM - Length", 19);
  totalDistance.addCoefficient("H", "default", "", "imphhdt_MD:Length (Skim)", 0);
  totalDistance.addCoefficient("H", "", "6", "imphhdt_AM:Length (Skim)", 9);
  totalDistance.addCoefficient("H", "", "15.5", "imphhdt_PM:Length (Skim)", 19);
  tollTime.addCoefficient("H", "default", "", "imphhdt_MD:*STM_MD (Skim)", 0);
```

```
      tollTime.addCoefficient("H", "", "6", "imphhdt_AM:*STM_AM (Skim)", 9);
      tollTime.addCoefficient("H", "", "15.5", "imphhdt_PM:*STM_PM (Skim)", 19);
      tollCost.addCoefficient("H", "default", "", "imphhdt_MD:ITOLL2_MD (Skim)", 0);
      tollCost.addCoefficient("H", "", "6", "imphhdt_AM:ITOLL2_AM (Skim)", 9);
      tollCost.addCoefficient("H", "", "15.5", "imphhdt_PM:ITOLL2_PM (Skim)", 19);
      break;
    case "I:T":
    case "I:NT":
      noTollDistance.addCoefficient("I", "default", "", "impmhdn_MD:Length (Skim)", 0);
      noTollDistance.addCoefficient("I", "", "6", "impmhdn_AM:Length (Skim)", 9);
      noTollDistance.addCoefficient("I", "", "15.5", "impmhdn_PM:Length (Skim)", 19);
      noTollTime.addCoefficient("I", "default", "", "impmhdn_MD:*STM_MD (Skim)", 0);
      noTollTime.addCoefficient("I", "", "6", "impmhdn_AM:*STM_AM (Skim)", 9);
      noTollTime.addCoefficient("I", "", "15.5", "impmhdn_PM:*STM_PM (Skim)", 19);
      tollDistance.addCoefficient("I", "default", "", "impmhdt_MD:tolldst_MD - Length", 0);
      tollDistance.addCoefficient("I", "", "6", "impmhdt_AM:tolldst_AM - Length", 9);
      tollDistance.addCoefficient("I", "", "15.5", "impmhdt_PM:tolldst_PM - Length", 19);
      totalDistance.addCoefficient("I", "default", "", "impmhdt_MD:Length (Skim)", 0);
      totalDistance.addCoefficient("I", "", "6", "impmhdt_AM:Length (Skim)", 9);
      totalDistance.addCoefficient("I", "", "15.5", "impmhdt_PM:Length (Skim)", 19);
      tollTime.addCoefficient("I", "default", "", "impmhdt_MD:*STM_MD (Skim)", 0);
      tollTime.addCoefficient("I", "", "6", "impmhdt_AM:*STM_AM (Skim)", 9);
      tollTime.addCoefficient("I", "", "15.5", "impmhdt_PM:*STM_PM (Skim)", 19);
      tollCost.addCoefficient("I", "default", "", "impmhdt_MD:ITOLL2_MD (Skim)", 0);
      tollCost.addCoefficient("I", "", "6", "impmhdt_AM:ITOLL2_AM (Skim)", 9);
      tollCost.addCoefficient("I", "", "15.5", "impmhdt_PM:ITOLL2_PM (Skim)", 19);
      break;
    case "L:T":
    case "L:NT":
      noTollDistance.addCoefficient("L", "default", "", "impldn_MD:Length (Skim)", 0);
      noTollDistance.addCoefficient("L", "", "6", "impldn_AM:Length (Skim)", 9);
      noTollDistance.addCoefficient("L", "", "15.5", "impldn_PM:Length (Skim)", 19);
      noTollTime.addCoefficient("L", "default", "", "impldn_MD:*STM_MD (Skim)", 0);
      noTollTime.addCoefficient("L", "", "6", "impldn_AM:*STM_AM (Skim)", 9);
      noTollTime.addCoefficient("L", "", "15.5", "impldn_PM:*STM_PM (Skim)", 19);
      tollDistance.addCoefficient("L", "default", "", "impldt_MD:ldtdst_MD - Length", 0);
      tollDistance.addCoefficient("L", "", "6", "impldt_AM:ldtdst_AM - Length", 9);
      tollDistance.addCoefficient("L", "", "15.5", "impldt_PM:ldtdst_PM - Length", 19);
      totalDistance.addCoefficient("L", "default", "", "impldt_MD:Length (Skim)", 0);
      totalDistance.addCoefficient("L", "", "6", "impldt_AM:Length (Skim)", 9);
      totalDistance.addCoefficient("L", "", "15.5", "impldt_PM:Length (Skim)", 19);
      tollTime.addCoefficient("L", "default", "", "impldt_MD:*STM_MD (Skim)", 0);
      tollTime.addCoefficient("L", "", "6", "impldt_AM:*STM_AM (Skim)", 9);
      tollTime.addCoefficient("L", "", "15.5", "impldt_PM:*STM_PM (Skim)", 19);
      tollCost.addCoefficient("L", "default", "", "impldt_MD:ITOLL2_MD (Skim)", 0);
      tollCost.addCoefficient("L", "", "6", "impldt_AM:ITOLL2_AM (Skim)", 9);
```

```
 tollCost.addCoefficient("L", "", "15.5", "impldt_PM:ITOLL2_PM (Skim)", 19);
 break;
```

The generalized cost functions are also specified in this same CommercialTripMode.java file. The dispersion parameters (referred to as lightDispersion and heavyDispersion) are parameterized and adjustable without recompiling, as described elsewhere. The “portion on toll facility” parameters (referred to as lightPortion and heavyPortion) are also parameterized and adjustable without recompiling, as described elsewhere. The other parameters in the generalized cost function (the relative weights on time, distance and toll for each vehicle weight class) are as shown in the code below. They can be modified by adjusting the CommercialTripMode.java file and redeploying a CommercialTripMode.class file, as discussed above.

```
switch (myType) {
case "L:NT":
   return getMyCM().lightDispersion*(
        -0.313*noTollTime.getTravelAttribute(origin, destination, timeOfDay, vehicleType)+
       -0.138*noTollDistance.getTravelAttribute(origin, destination, timeOfDay, vehicleType));
case "I:NT":
case "M:NT":
   return getMyCM().heavyDispersion*(
        -0.313*noTollTime.getTravelAttribute(origin, destination, timeOfDay, vehicleType)+
       -0.492*noTollDistance.getTravelAttribute(origin, destination, timeOfDay, vehicleType));
case "H:NT":
   return getMyCM().heavyDispersion*(
        -0.313*noTollTime.getTravelAttribute(origin, destination, timeOfDay, vehicleType)+
       -0.580*noTollDistance.getTravelAttribute(origin, destination, timeOfDay, vehicleType));
case "L:T":
   tollDisutility =
   -0.313*tollTime.getTravelAttribute(origin, destination, timeOfDay, vehicleType)+
   -0.138*tollOptTotalDistance+
   -0.01 * tollCost.getTravelAttribute(origin, destination, timeOfDay, vehicleType);
   return getMyCM().lightDispersion * tollDisutility +
        getMyCM().lightPortion * tollPortion;
case "I:T":
case "M:T":
   tollDisutility =
   -0.313*tollTime.getTravelAttribute(origin, destination, timeOfDay, vehicleType)+
   -0.492*tollOptTotalDistance+
```

```
        -0.01 * tollCost.getTravelAttribute(origin, destination, timeOfDay, vehicleType);
        return getMyCM().heavyDispersion * tollDisutility +
             getMyCM().heavyPortion * tollPortion;
    case "H:T":
        tollDisutility =
        -0.313*tollTime.getTravelAttribute(origin, destination, timeOfDay, vehicleType)+
        -0.580*tollOptTotalDistance+
        -0.01 * tollCost.getTravelAttribute(origin, destination, timeOfDay, vehicleType);
        return getMyCM().heavyDispersion * tollDisutility +
             getMyCM().heavyPortion * tollPortion;
    }
```

6.4.3 CVM Python Program Settings Input File

The settings file specifies:

- Input and skim paths and list of skim file names
- Location and name of zonal properties file
- Location of model scale factor
- List of modes, times and industries
- Operating cost scale
- Zone range for model
- Properties used to calculate accessibilities as described in section 2
- Calibration adjustment scale factors for tour generation

6.4.4 CVM Java Program Run Properties Input File

The run properties file specifies:

- Input, output and program log run directories;
- # of computer threads to be used;
- Name of the zonal properties input file;
- Name of the intermediate tour generation file output by the python sub-program for use in the java sub-program;
- Start and end TAZ numbers of the range of zones to which the CVM is to be applied for this run;
- Name of the travel skims csv input files (see below);
- Names of the CVM specification files to be included in the CVM run (see below).

By convention, the name of the run properties file is ***cvm.properties***, and it has to be located in the overall run directory T:\Transnet2\devel\CVM\sr13\2012_calib2.

In general the contents of this file will not change between different CVM model runs, on the standard SANDAG computing system. An example of a typical ***cvm.properties*** is:

 # location of input files

CSVFileLocation=%SCENDIR%Inputs/

 # input files names

ZonalPropertiesFileName=Zonal Properties CVM

ZonalPropertiesFileName2=CVMToursAccess

UseTripModes = true

 # output file location

TripLogPath=%SCENDIR%Outputs/

TranscadSkimLocation=T:/Transnet2/devel/CVM/sr13/2012_calib2/output_cvm

#These next two are to write new Transcad Matrix files

*TranscadCVMMatrixFile=T:/TransNet2/devel/CVM/sr13/2012_calib2/output_cvm/CVM_TRIPS.
mtx*

ReadOutputMatrices=FALSE

StartZone=13

EndZone=4996

#RunZones=101, 102, 103

nThreads=8

 # Model Specification Coefficient files are FirstPart.csv and SecondPart.csv

FirstPart=FA,GO,IN,SV,TH,RE,WH

SecondPart=MD,AM,PM,OE,OL

6.4.5 Model Specification Input Files

The java CVM program reads in two types of input files:

- Five files defining the calibrated tour start time functions for each time period, applied across all industry types:
  - Early : OE.csv
  - AM : AM.csv
  - Midday : MD.csv
  - PM : PM.csv
  - Late : OL.csv
- Seven industry-specific model specification files that give estimated and calibrated model parameters for the other tour choice sub-models. These files also identify the 35 specific output trip tables to be generated by vehicle type, time period and toll usage, as given in Table 21 below:
  - Industry : IN.csv
  - Retail : RE.csv
  - Service : SE.csv
  - Government/Office : GO.csv
  - Wholesale :WH.csv
  - Transport : TH.csv
  - Fleet Allocator : FA.csv

6.5 Final CVM Output Files

The outputs from the CVM are:

- A set of Transcad matrices, identified in Table 25.

Table 25 : Output Trip Tables

Vehicle Type	Time Periods	Toll choice
Light	Early, AM, Midday, PM, Late	Toll
Light	Early, AM, Midday, PM, Late	No Toll
Intermediate Medium	Early, AM, Midday, PM, Late	Toll
Intermediate Medium	Early, AM, Midday, PM, Late	No Toll
Medium	Early, AM, Midday, PM, Late	Toll
Medium	Early, AM, Midday, PM, Late	No Toll
Heavy	Early, AM, Midday, PM, Late	Toll
Heavy	Early, AM, Midday, PM, Late	No Toll

- a set of “csv” individual trip list files for each combination of industry and time period (e.g. the trip table list for AM peak retail trips is output in a file trips_RE_AM.csv). The fields for each trip record in the output trip list are given described in Table 26.

Table 26: CVM Output Trip Record Structure

Field Name	Description
Model	Model ID (always 3 in CVM output)
SerialNo	Household ID (Same as Tour ID, for CVM)
Person	Person ID (always 1 in CVM output)
Trip	Trip ID
Tour	Tour ID
HomeZone	Home TAZ
ActorType	Actor Type
OPurp	Origin Purpose
DPurp	Destination Purpose
I	Trip Origin
J	Trip Destination
Time	Time period
Mode	Mode ID (=L, M or H for CVM)
StartTime	Start time of trip
EndTime	End time (of trip PLUS duration at stop)
StopDuration	Stop duration
TourType	Tour Type
OriginalTimePeriod	Time period for tour start
Trip Mode	T, NT (T = Toll; NT = No Toll)
Toll Available	true, false

Note: this file output structure was designed to be consistent with the trip list outputs from the other sub-models of the California Statewide and San Joaquin Valley Travel Models. The first three fields (Model, SerialNo and Person) in particular are included to identify the output as from the CVM and provide “filler data” to be compatible with the disaggregate household / person trip models.