Application of a Multi-Level Logit Function HOV/SOV Forecasting Procedure in the Greater Vancouver Transportation Model

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Introduction

The Vancouver Regional Transportation Model was developed and calibrated in the late 1980's from data collected in a Regional Travel survey undertaken in 1985. The model was substantially re-calibrated in the mid 1990's based on data collected as part of a 1992 telephone interview survey and a 1994 Trip Diary survey.

At the time of the original travel survey and model calibration, there were no HOV lanes in the Vancouver Region, nor were there any serious proposals for implementation of HOV facilities. The original model forecast transit passenger and auto person trips based on a standard logit mode split model. Forecast auto person trips were then converted into auto driver trips for assignment using a vehicle occupancy model.

During preparation of the ***Transport 2021 Study*** in the early 1990's, an extensive Transportation Demand Management (TDM) program was adopted for the Region. This program included plans for construction of a network of HOV lanes.

This paper summarizes the vehicle occupancy model used prior to the Transport 2021 Study. It describes the changes to the occupancy model during the Transport 2021 Study introduced to ensure that the model results were sensitive to HOV lane construction. It describes the development and calibration of the HOV/SOV logit model introduced in 1998. It discusses the difficulties associated with applying the model to conditions considerably outside the range of observations available for model calibration. Finally, it compares the sensitivity of the HOV forecasts to the changes in the variables included in the model.

The current procedure was developed and calibrated as part of a major re-structuring and re-calibration of the model undertaken jointly by the Greater Vancouver Regional District and the BC Ministry of Transportation and Highways. The author's wish to acknowledge the significant contributions made to the development and calibration of the HOV/SOV model by the staff of the Regional District's Strategic Planning Department.

The Original Vehicle Occupancy Model

The vehicle occupancy model in the original calibration was trip purpose specific. The model used for work trips took the form:

$Autocc_{ij} = (1 + (.12 * \exp(-.015 * Audis_{ij}) * (1 + .5 * (Pkcost_i + Pkcost_i))$

Where:

$Autocc_{ij}$ is average vehicle occupancy for work trips from zone i to zone j.

$Audis_{ij}$ is auto distance from zone i to zone j.

$Pkcost_i$ is the parking cost at zone i.

$Pkcost_j$ is the parking cost at zone j.

The occupancy models followed a similar form.

Application of the model provided that forecast occupancies would increase with higher parking charges but decrease with longer distances. This is based on the theory that the opportunity for ride-sharing decreases with increased distance (because there are likely to be fewer total trips) but that the incentive to ride-share increases as out-of-pocket per vehicle trip increase.

The model calibrated reasonably well to observed data given that the range of observed average occupancies was relatively small.

The Transport 2021 Study Adjustment

The original model was clearly insensitive to any measures intended to provide lower travel times for HOV use than for SOV use. Part way through the technical analyses undertaken for the Transport 2021 Study, the study team developed proposals for an extensive network of HOV lanes. The modellers were asked to evaluate the likely effects of this measure together with a comprehensive package of TDM measures.

Neither the study timetable, nor the study budget allowed for any work on re-calibration of the occupancy model. Consequently, an arbitrary adjustment was made to the occupancy model to allow the inclusion of the ratio of SOV time to HOV time. The revised model took the form:

$Autocc_{ij} = (1 + (.12 * \exp(-.015 * Audis_{ij}) * (1 + .5 * (Pkcost_i + Pkcost_i)) * (SOVT_{ij} / HOVT_{ij})$

Where:

$SOVT_{ij}$ is SOV travel time from zone i to zone j.

$HOVT_{ij}$ is HOV travel time from zone i to zone j.

Following completion of the Transport 2021 Study, model re-calibration to improve the synthesis of a number of new policy initiatives was recognized as a high priority by the Greater Vancouver Regional District. Following consultations with frequent users of the model and with the local and provincial government agencies that rely on model forecasts, a work program for model enhancement was developed. A logit function based HOV/SOV model was included in this work program.

The HOV/SOV Model

The Ministry of Transportation and Highways commissioned Edwin Hull and Associates to work with Ministry and GVRD staff to revise and re-calibrate the regional transportation model in 1997. The re-calibrated model was to be used for a series of planning studies broadly centred on the Port Mann Bridge which carries the Trans Canada Highway across the Fraser River. The Ministry wished to include a region-wide network of 3-plus HOV lanes and a limited application of 2-plus HOV lanes as part of the future Base Networks against which to test alternatives. The proposed HOV network is illustrated in Figure 1.

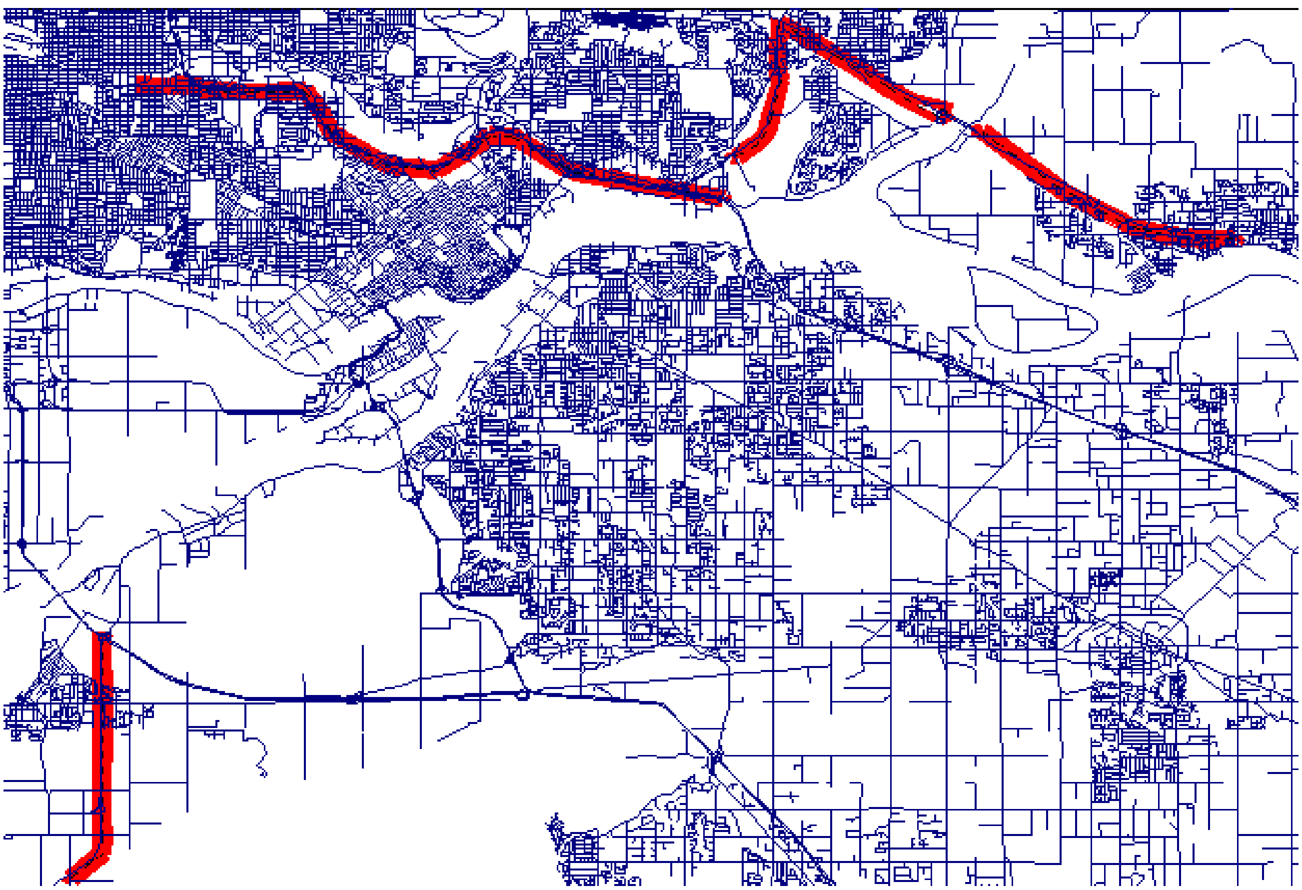

Figure 1 — Proposed 2006 3+ HOV Network in Greater Vancouver

Existing Conditions

Existing HOV use in the Vancouver Region is low, particularly for peak hour work trips. Typically, at major screen-lines, HOV's constitute about 15% of total AM peak hour vehicles, with 3-plus HOV's accounting for 2% to 3% of total volumes. However, a comparison of base year inter-zonal generalized costs for these sub-modes indicates that 2-plus HOV generalized costs are lower than those for SOV and that the generalized costs for 3-plus HOV were lower still. The addition of the impedance associated with parking charges increased the relative advantages enjoyed by HOV users.

The HOV/SOV sub-model described in this paper is based upon the premise that the comparative 'benefits' and 'costs' of each sub-mode can be represented through dummy costs and impedances. Given estimates of generalized cost, or impedance, the decision to carpool can be modelled using the classical logit mode split model.

Clearly any logit function based only on measurable impedances would significantly overstate the proportion of trips made by HOV. It was recognized that there are impediments to ride sharing that cannot be quantified directly from "traditional" impedance computations. We hypothesized that these impediments probably include:

- Lack of opportunity — clearly if the number of trip makers travelling from a particular origin to a particular destination during a particular time period is relatively small, the opportunities to ride-share are limited and the proportion of trip makers in HOV's will be relatively small. We hypothesized that the two major factors affecting the number of trips for any origin-destination would be auto impedance from origin and destination, and trip end density at the "non-home" end of the trip. The impact of increasing auto impedance was provided for in our impedance calculations
- Desire for privacy — it appears that many drivers prefer their own company while commuting, perhaps to listen to the radio, to be free to follow any path from origin to destination, to time their trip without consideration of the timetable of others, or simply to collect their thoughts at the beginning or end of the working day.
- Inconvenience and additional delay — the most common ride-sharing situation probably occurs when two or more people from the same household or from the same workplace are travelling at the same time to the same destination. In such cases, there is little or no inconvenience or additional delay associated with ride sharing. However, when ride-sharing involves two or more people from the same neighbourhood, travelling to destinations in the same general vicinity, additional travel time, waiting time and/or additional vehicle operating costs will often be incurred by one or more trip makers at the beginning and end of the trip.

In order for the model to be calibrated to achieve a reasonable "fit" to existing conditions, it was necessary to identify dummy parameters and coefficients to be included in or applied to the model impedances for HOV.

Model Structure

In order to test the full range of HOV priority measures to be evaluated by the Ministry, it was necessary to model 2-person HOV and 3-person plus HOV separately. This required that three levels of auto occupancy classification were modelled — SOV, 2HV and 3+HV. A nested logit model was assumed in which the decision to ride-share or not was seen as the higher level decision. Ride-share trips are then split into the two modelled HOV categories. The nested structure of the mode choice, including the HOV sub-model is exhibited in Figure 2.

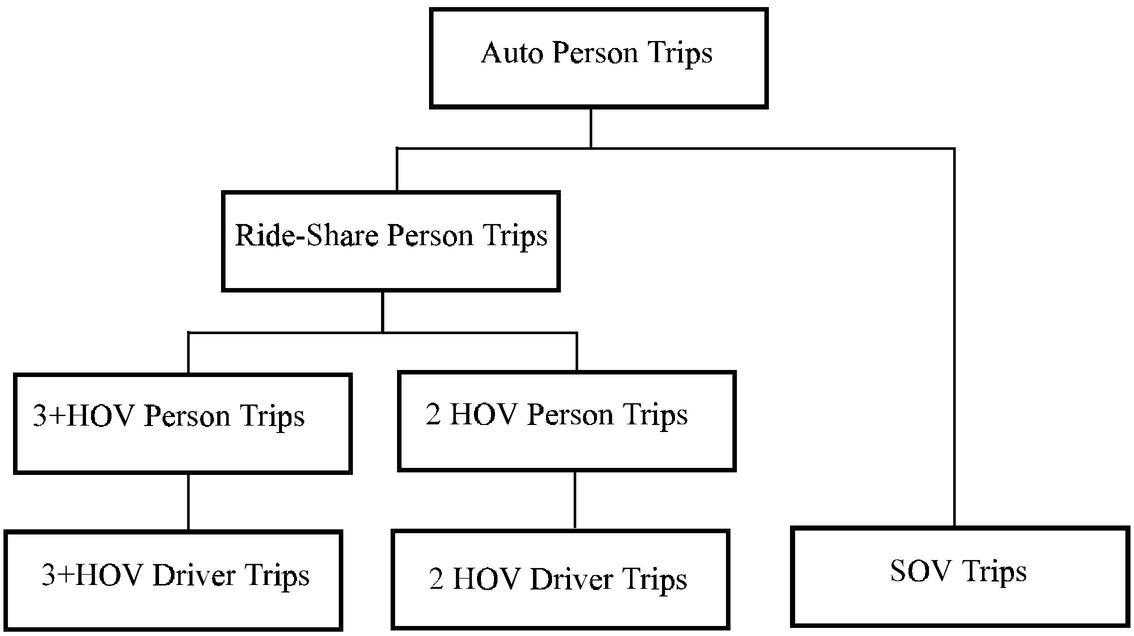

Figure 2: HOV Sub-Model Structure

The splitting of auto person trips into SOV and Ride-Share followed a standard logit function of the form:

$$\mathbf{PROP_{sov} = 1 / (1 + exp (\beta * (IMP_{sov} - IMP_{rs})}$$

Where:
PROP$_{sov}$ is the proportion of auto person trips forecast to be SOV Person Trips
IMP$_{sov}$ is SOV Impedance
IMP$_{rs}$ is Rideshare Impedance

Similarly, Ride-Share trips were split into 2HOV and 3+HOV based on:

$$\mathbf{PROP_{2hov} = 1 / (1 + exp (\beta * (IMP_{2hov} - IMP_{3+hov})}$$

Where:

$PROP_{2hov}$ is the proportion of Ride-Share person trips forecast to be 2HOV Person Trips
IMP_{2hov} is 2HOV Impedance
IMP_{3+hov} is 3+HOV Impedance

2HOV driver trips and 3+HOV driver trips for assigning to the networks were then calculated by dividing the respective person trip forecasts by the assumed vehicle occupancies of 2.0 for 2HOV and 3.25 for 3+HOV.

Impedances for each occupancy class were calculated as follows:

$$\text{SOV IMP} = \left(GC_{SOV} + PK_{SOV} * \frac{60}{VOT} \right)$$

Where:

SOV IMP = SOV Impedance;

GC_{SOV} = Generalized cost from previous auto assignment;

PK_{SOV} = Parking Cost for SOV;

VOT = Assumed value of time for trip purpose.

$$\text{HOV IMP} = WT * \left(GC_{HOV} + PN + PK_{HOV} * \frac{\frac{60}{VOT}}{SH} \right) + \left(\frac{DF}{1 + \frac{AT}{HA}} \right) + \text{Bias}$$

Where:

HOV IMP = HOV Impedance for specific to vehicle classification;

WT = Factor representing reduced Ride-Share opportunity as impedance increases;

GC_{HOV} = Generalized cost from previous model run;

PN = Represents inconvenience and additional delay of making a rideshare trip;

PK_{HOV} = Parking Cost for HOV;

VOT = Assumed value of time for trip purpose;

SH = Number of occupants sharing the parking charge;

DF = Density factor to represent impact of trip density on Ride-Share opportunity;

AT = Number of trip attractions per trip purpose in destination zone;

HA = Destination zone size in hectares; and,

Bias = Sub-modal bias reflecting the desire for privacy.

Ride-Share Impedance was calculated as a weighted mean of 2HOV impedance and 3+HOV impedance, namely

$$IMP_{rs} = \ln(\exp(-\beta * IMP_{2hov}) + \exp(-\beta * IMP_{3+hov})) / -\beta$$

Calibration

Two sets of data were available for model calibration:

- The 1992 Home Interview Survey (2% sample)
- The 1996 screen-line traffic and vehicle occupancy counts from roadside observations

The Home Interview Survey provided data on vehicle occupancy by trip purpose. Unfortunately, with a 2% sample rate, the number of reported HOV trips, particularly 3+ HOV trips, was quite small. Even with reported trips aggregated to nine regional superzones, the reported values for AM peak hour work trips were not statistically significant for more than 50% of the 81 cells in the superzone matrix. For the other modelled purposes — Post-Secondary, Grade School, Business and Other — the reported values were statistically significant in less than 10% of the superzone matrix cells.

Despite these concerns, assigning the synthetic matrices based on calibrating the model to the Interview Survey data produced a reasonable fit to total HOV use at regional screen-lines. Unfortunately, the 2HOV/3+HOV split showed considerable deviation from the screen-line occupancy counts. The 3+HOV synthetic volumes were typically between two and four times the observed volumes. Discussion with the Ministry’s traffic data manager indicated that a low level of confidence in the roadside observations of occupancy. In particular, it was considered likely that many 3+HOV's’could have been recorded as 2HOV's’because of the difficulty in seeing back seat passengers in high-speed vehicles on multi-lane highways and bridge approaches.

Consequently, it was decided to calibrate the parameters to generate screen-line volumes consistent with the total HOV’s reported by the roadside counts. However, the breakdown of HOV’s into 2-person and 3-plus-person was calibrated to 3+HOV volumes approximately midway between the observed counts and the values derived from the Home Interview Survey.

It was also observed that there was relatively little variation in the percentage of vehicles in each occupancy category, either from screen-line to screen-line or among the cells in the superzone matrix derived from the Home Interview Survey. We recognize the difficulties inherent in attempting to calibrate so many parameters from a limited range of observations. Consequently, although the model based on the “calibrated” parameters provides a good fit to the target screen-line volumes, the values assigned to each co-efficient owe as much to professional judgement and intuition as to any rigorous evaluation of the sensitivity of the forecasts to changes in the relative values of the coefficients.

The narrow range of observed values also raises concerns about application of the model to future conditions. The network of HOV facilities planned by 2006, in combination with other TDM measures intended to increase out-of-pocket costs for SOV use, will radically change the relationship between SOV and HOV impedances. This means that the model will be applied to conditions well outside the range of observations available for calibration. Clearly, there is a need for a comprehensive data collection and monitoring program to complement the implementation of the HOV lane program in the region. The data collected in this program will allow the coefficients used in the HOV/SOV model to be refined.

Table 1 summarizes the parameters used for the HOV impedance calculations for four of the five trip purposes. Note that the HOV/SOV split for grade school trips is determined based on fixed percentages for all origins and destinations.

Table 1: AM HOV Impedance Calculation Parameters

	Work	Post Secondary	Other	Business
2 person weight	1.1	1.05	1.1	1
2 person penalty	5	8	10	5
2 person density factor	32	26	7	15
2 person HOV bias	11	5	10	16
3+ person weight	1.2	1.1	1.15	1.1
3+ person penalty	12	15	15	10
3+ person density factor	36	30	8	25
3+ person HOV bias	17	8	12	20
SOV/Rideshare β	0.075	0.07	0.08	0.05
2HOV/3+HOV β	0.085	0.08	0.085	0.06

Sensitivity of Forecasts

Application of the model to 2006 scenarios indicated a significant increase in HOV use, particularly 3+HOV use. Examination of the SOV and HOV generalized costs and impedances indicated that the relative difference between SOV and 3+HOV impedance had changed by up to 30 impedance units in favour of HOV in some cases. The “typical” change in relative impedance was in the order of ten impedance units.

For some cells, the reduction was entirely due to a relative reduction in the HOV generalized cost generated by the auto assignment. For other cells, with significant increases in employment, the reduction was due in part to an increase in the trip end density at the destination zone.

We examined the sensitivity of the percentage of work auto person trips forecast to be made by 3+SOV to changes in generalized cost for a typical trip from an origin in an inner suburb to downtown Vancouver. When the generalized cost for 3+HOV, for 2HOV and for SOV are all equal, the effects of the various weights, coefficients and biases is such that the percentage of auto person trips forecast to be 3+HOV is approximately 6% (equivalent to approximately 2½% of vehicle trips).

The forecast percentages of auto trips by 3+HOV for generalized cost differences ranging from +10 impedance units to –10 impedance units are shown in Figure 3.

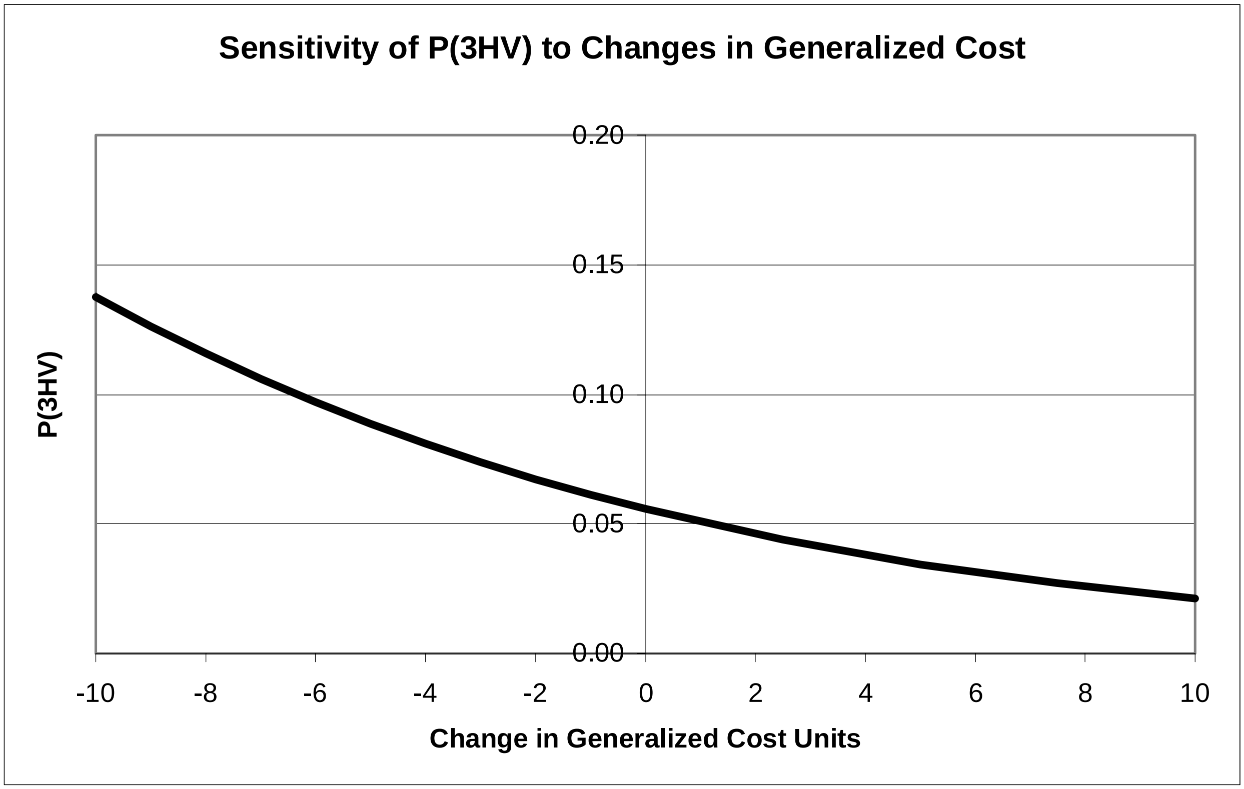

Figure 3

It can be seen that a 10-impedance unit reduction in the relative generalized cost of 3+HOV compared with the respective generalized costs of SOV and 2HOV would increase the forecast 3+HOV from 6% of auto person trips to 14% of auto person trips. The generalized cost of travel for each sub-mode is the sum of the travel time by that mode and the share of vehicle operating costs and other out-of-pocket costs incurred by each vehicle occupant.

A 10-minute reduction in 3+SOV travel time compared with SOV time would be sufficient to effect a 10-impedance unit reduction in comparative generalized cost. To achieve the same effect through increased vehicle operating cost would require an increase of $1.90 per vehicle trip. The observed mean trip length for AM peak hour work trips is 13.7 km. To achieve the required cost increase per trip would require an increase in vehicle operating cost of approximately 14 cents per km — almost 2½ times current costs. This would require that gasoline taxes be increased by a factor of four — a tough political sell in any democracy.

Similarly, an increase in daily parking charges of approximately $5 would also reduce the relative impedance for 3+HOV by 10 impedance units. However, to achieve this impedance advantage for all trip origins and destinations would not only require existing parking charges to be dramatically increased, but would also require the $5 daily charge to be introduced to areas currently enjoying free parking.

This analysis has implications for policy makers. It would appear that providing priority for HOV's to reduce travel time compared with SOV would be more effective and more politically acceptable than further increases in travel costs. Such priority measures will be cost-effective if worthwhile timesavings can be achieved by selective construction of queue-jumper lanes at major bottlenecks rather than a comprehensive network of HOV lanes.

The impact of increased density on HOV use was assessed by consideration of forecast Ride-Share trips from selected origins to three destinations with 1996 work trip end densities (AM peak hour work trips per hectare) of 1.1, 13.8 and 87.4 respectively. In each case, the proportion of Ride-Share trips was re-calculated assuming that trip end densities increased while all other factors affecting SOV and HOV impedances were held constant.

Two levels of density increase were evaluated — a two-fold increase and a five-fold increase. The results are summarized in the Table 2.

Original Trip End Density	Ride-Share Change for 100% Increase in Density	Ride-Share Change for 400% Increase in Density
1.1	6.6%	14.3%
13.8	1.8%	2.9%
87.4	0.3%	0.5%

Table 2 — Sensitivity to Trip End Density

We were initially surprised to note that the model was most sensitive to density increases at the lower end of the density scale. We are not able to ascertain whether this is because there is an upper limit beyond which increased density does not increase ride-sharing opportunities or because of the manner in which we have chosen to represent the impact of density in our impedance calculations.

Conclusions

Modelling HOV demand within a conventional travel demand model is complex and requires the implementation of a number of “dummy” variables to represent attitudinal bias and other factors that militate against more widespread HOV use.

Calibration of these variables with any degree of certainty requires a comprehensive set of data covering a sufficiently wide range of conditions to allow the various model parameters to be calibrated adequately.

In the absence of any alternative procedure, the use of an impedance-based nested logit function appears to be the most suitable model for use as part of a regional forecasting model.

In Greater Vancouver, a significant data collection exercise is required to allow the refinement and re-calibration of the HOV/SOV model to improve the degree of confidence in model forecasts.

Notwithstanding the above reservations, it appears likely that HOV priority measures to provide a travel time advantage for HOV users will be more effective than increasing user costs in improving average vehicle occupancy.