Evaluating HOV Plans and Priorities – the Case of Expressways in the GTA

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Abstract

The proportion of High-Occupancy Vehicle (HOV) commuting trips in the Greater Toronto Area has been declining over recent years. In an effort to reverse this decline and make more efficient use of the available infrastructure, the Ministry of Transportation of Ontario has begun to implement HOV lanes on the 400-series highway system. The implementation of HOV lanes on portions of Highway 403 and 404 in late 2005 met with substantial success, being well-used in peak periods.

In support of the planning and prioritization of future HOV lane implementation, the Ministry conducted several studies, one focused on the Greater Toronto Area west of Highway 427 and one focused on the area to the east, to forecast HOV use of potential future HOV network components. The current paper addresses the GTA East study.

The paper begins by providing some background with respect to auto occupancy and HOV use trends in the Greater Toronto Area. The success of the Highway 403 and 404 HOV lanes is reviewed briefly as context to the development and testing of a broader network.

The modeling process used to forecast future HOV use in response to potential HOV lane network configurations is presented as an integrated approach, incorporating both the EMME macroscopic travel demand model and the VISSIM and PARAMICS micro-simulation models. The development and validation of a model to estimate incremental increases in HOV use as a function of travel time savings is presented and the validation of this model, using before-and-after data from the Highway 403 and 404 projects is discussed.

HOV forecasting is not a standardized tool in the transportation planning toolbox. Different approaches have been attempted with varying levels of success. This paper is a useful addition to the literature on the subject in that it discusses some of the key issues encountered and describes the development and adaptation of models and methods to address these issues. Issues discussed include making maximum use of available data, model validation with before-and-after data, and the integration of macroscopic travel demand modeling with micro-simulation to combine the strengths of both approaches.

1. Introduction

Congestion on the expressway system in the Greater Toronto Area (GTA) is a daily occurrence, even on weekends – the only real variable is how many hours the congestion will last on any given day and this has been growing steadily over time. One initiative being pursued by the Ontario Ministry of Transportation (MTO) as a means of managing congestion involves the implementation of High-Occupancy Vehicle (HOV) lanes intended for the use of buses and autos or taxicabs/limousines with multiple (currently two or more) occupants.

Before the decision to implement an HOV lane on a particular highway is made, and as part of the process to prioritize implementation, it is necessary to estimate the likely level of utilization. Not only would under-utilized HOV lanes reduce their effectiveness as a congestion management tool, but they would also weaken support for the retention of existing HOV lanes and the implementation of new lanes. In fact, under-utilized HOV lanes (whether or not this under-utilization is real or perceived) have been converted to "High-Occupancy Toll" (HOT) lanes in some jurisdictions to increase utilization while others have been converted back to "General Purpose" (GP) lanes. While the numbers of existing HOV's on the highway system can be obtained from existing data sources, it is also necessary to be able to estimate the number of new HOV's that might be "induced" due to improvements in travel time and reliability offered through the use of an HOV lane.

In the determination of implementation priorities and timing, it is also necessary to evaluate how well HOV lanes on any given highway might be utilized as stand-alone components. It is also necessary to assess the synergies that might exist if these HOV lanes were to be implemented in conjunction with a more extensive HOV network.

In 2001, the MTO contracted with the McCormick Rankin Corporation to undertake the HOV Opportunities Study to evaluate the feasibility of implementing HOV lanes on the 400-series expressways in the GTA. On the heels of that study, a two-part effort to estimate HOV use on the expressway network under different HOV lane implementation sequencing strategies was initiated. This study was designed to identify "early winners" and critical interdependencies, and evaluate the need for "critical mass" in HOV lane implementation. In December, 2005, HOV lanes were implemented on Highways 403 (eastbound and westbound) and 404 (southbound only – the northbound HOV lane was added more recently). Also in late 2005, MTO retained the McCormick Rankin Corporation to undertake a parallel study for the eastern half of the GTA.

When the current study was originally conceived, the focus was on the determination of implementation priorities and timing with respect to HOV lanes on the GTA expressway system, essentially starting with a clean slate. However, in the meantime, the success of the HOV lanes implemented on Highways 403 and 404 have sharpened MTO's policy focus on their potential role as a travel demand and traffic management tool. In that context, the MTO's ongoing program of planning, designing, and implementing improvements to the GTA highway system has required decisions on whether or not expressway lanes proposed to be added should be HOV or GP lanes. Particularly in cases where the proposed widening takes the highway to its maximum feasible cross-section, the decision to implement the new lanes as HOV or GP lanes cannot be taken lightly. In such cases, initial implementation as GP lanes may make it difficult

to operate HOV lanes in the future due to the political issues associated with the conversion of GP to HOV lanes.

The purpose of this paper is to discuss the framework developed to forecast HOV forecasting and identify some of the opportunities to utilize both existing and newly-available data and techniques in conjunction with the estimation of HOV use for the eastern portion of the GTA. The implementation of HOV lanes on Highways 403 and 404 and the associated collection of extensive before-and-after data provided an opportunity to investigate enhanced HOV forecasting procedures based on local experience. Up till now, including the case of the parallel study of the eastern half of the GTA, models had been largely "transferred" in from the United States or elsewhere. At the same time, rapid growth in the application of micro-simulation to the operational evaluation of GTA highways suggested possible roles for this emerging tool in conjunction with more traditional modeling techniques to improve future HOV forecasts.

2. Background

An analysis of the 1996 and 2001 Transportation Tomorrow Surveys (TTS - a comprehensive travel survey involving 5% of the households in the GTA) indicated that for peak-period, home-to-work trips by persons 18 years or older, the average occupancy dropped from 1.135 to 1.12 over this 5-year period. This analysis utilized a segmentation of the GTA into 14 "super-zones"; the boundaries being based on regional jurisdictions (to reflect differences in transit level-of-service) and on population and employment.

Figure 1 shows the changes in the average number of occupants per automobile for morning peak-period trips originating in the superzones. In only one case was there an increase in the auto occupancy. Although appearing modest, these widespread reductions in auto occupancy imply a noticeable impact on the number of automobiles required to accommodate the daily commute in the GTA. The maximum possible percentage reduction in auto occupancy, if one were to start from an occupancy of 1.13 and drop to 1.00, for example, is 11.5%. This trend has also been noticed in other North American jurisdictions.

In late 2005, MTO added HOV 2+ lanes (for autos with two or more occupants) to the following expressway facilities (see Figure 2 for general location):
1. on Highway 403 from Highway 401 to Winston Churchill Blvd in the Regional Municipality of Peel. This is a two-way facility implemented on the median lanes with a marked buffer zone and delineated access zones near interchanges;
2. on Highway 404 from Highway 7 in the Regional Municipality of York to Highway 401 in the City of Toronto. This is a one-way (southbound only) lane with similar design features as the Highway 403 lanes but also featuring an exclusive, direct HOV ramp connecting with Highway 401 westbound through a tunnel. A northbound HOV lane was subsequently added to Highway 404.

In both cases, new lanes were added to the cross-section to accommodate HOV's.

Also as shown on Figure 2, the new HOV lanes achieved substantial utilization within a short time after implementation (the numbers shown were collected after six months). HOV's as a proportion of total autos increased from a background level of some 14-15% to approximately

20-22 per cent on Highway 403 and 35% on Highway 404, the higher "after" proportion for Highway 404 reflecting the higher level of congestion on that facility. Figure 2 also shows that the travel times for HOV's using the new lanes were reduced by more than 50%.

The first part of the study to estimate future HOV use for various implementation strategies was conducted for the western portion of the GTA, namely the Regions of Peel and Halton. This study made use of the EMME travel demand forecasting framework with HOV utilization being estimated using a logit model with coefficients obtained from similar work undertaken for the I394 project in Minnesota.

The following sections describe the approach used in the second part of the study, conducted by McCormick Rankin Corporation for the eastern portion of the GTA, consisting of the City of Toronto and the Regions of York and Durham. Changing circumstances between the initiation of the first and second parts of this study provided an opportunity to enhance the state-of-the-art through the development of a modified approach to the estimation of the impact of HOV lane implementation on the relative travel times on both the HOV and GP lanes and the resulting effect on the proportion of HOV's in the traffic stream. At the same time, actual HOV volumes using the HOV lanes could be more reliably estimated.

3.   Estimating Future HOV Demand

3.1 HOV Market Segments

For purposes of market segmentation and simplification of the forecasting process, the overall HOV market was divided into the segments shown on Figure 3:

1. "Natural" HOV demand represents background demand that is independent of the presence or absence of HOV lanes. This includes car and vanpools that have formed for convenience, to save money or to participate in "Green Transportation" programs. It also includes individuals that are captive to the auto passenger mode due to lack of access to a vehicle (as a driver), lack of a driver's license, or lack of a practical transit or other alternative mode. Existing HOV demand on the GTA highway system (prior to the implementation of the HOV lanes on Highways 403 and 404) may be categorized as "natural" demand and is shown on Figure 4 at key locations on the GTA expressway system.
2. "Induced" HOV demand represents new demand that is "encouraged" through the provision of HOV lanes. New HOV's may be induced through improvements in mean travel time and/or delay and increased travel-time reliability that might result from HOV lane use. These may be converted former single-occupant vehicles (SOV's) in the same corridor or existing or new HOV's diverted from other corridors.
3. Other components of the overall HOV picture, including taxis, limousines, and various types of buses (inter-city, local, school, etc.), both existing and future.

Each of these components will be discussed separately in the following sections.

When HOV lanes are implemented on a highway, there will also likely be a "backfilling" effect. The addition of new lanes, if the HOV lanes are added rather than converted lanes, and the reduction in the number of autos in the corridor through conversion to HOV's results in under-

utilized road capacity and reduced congestion. This capacity may be taken up by traffic diverting from other corridors or by traffic previously forced into the less congested "shoulder" periods before and after the peak hour.

3.2 Estimating Natural HOV Demand

3.2.1 Existing natural demand

Figure 4 shows the 2004 proportions of HOV's on major highways in the GTA. These proportions represent the natural demand in the sense that this data was collected before HOV lanes were implemented on the expressway system. With only a few exceptions, the "natural" proportion of HOV's on the highways ranges between 7% and 9.5% while the proportion of buses and taxis is typically less than 0.3%.

As indicated previously, there has been a recent downward trend in the natural demand. It is necessary, in the forecasting of total HOV demand, to be able to predict, with some reliability, whether this trend will continue, stabilize, or reverse itself. Two streams of analysis were followed in an attempt to better understand the factors that may be correlated with the recent decline in auto occupancy. Correlation does not necessarily imply causation in the strict sense of the word. However, this will prevent the use of this analysis to help guide our estimate of the likely future trend in HOV natural demand. It is perhaps easier to make assumptions about future trends in household auto ownership, the availability of free parking, and similar variables than it is to make assumptions about future HOV proportions directly. The data for this analysis comes from the 1996 and 2001 Transportation Tomorrow surveys, referenced previously.

3.2.2 Analysis of aggregate interzonal commuting.

To evaluate relationships at the aggregate level, the GTA was divided into 14 "superzones", designed to recognize, in a general way, differences in accessibility to transit and in transit mobility across the region. For commuting trips by automobile drivers and passengers between each pair of superzones, relationships between the changes, between 1996 and 2001, in average auto occupancy and independent variables representing changes in personal, household, and trip characteristics, aggregated over all commuting trips between the superzones, were investigated.

Two rounds of analysis were conducted after combining TTS trip records, which represent "unlinked" trips, to form complete home-to-home "tours". Trips not involving the automobile, either as a driver or passenger, were not considered. The first used two-way frequency tables and scatter plots within the SPSS statistical package to examine basic relationships between changes in auto occupancy and changes in individual independent variables such as:
- possession of a driver's license;
- access to free parking at work or school;
- living as part of a household where the number of available vehicles is less than, equal to, or greater than the number of commuters (workers and older students);
- variation in working day length;
- making stops on the way to or from work or school;
- local vs. regional vs. inter-regional commuting.

No significant relationships of the correct sign were identified at the 95% confidence level.

The second round of analysis considered combinations of independent variables using a decision tree algorithm, a data mining approach housed in Visual Studio/SQL Server. This is a relatively recent development from the machine learning and artificial intelligence communities. An overview of the methodology is provided in Mitchell (1). The method works by building a decision tree down from the various values of the independent variables. Each succeeding layer or "branch" contains the "best" remaining independent variable, typically measured on the basis of how well the different possible values of the independent variable coincide with different values of the dependent variable. Advantages of this method over the traditional regression (or similar) approaches include the following:

- intuitive interpretation of the analysis results, either as a decision tree or as a series of If…Then rules;
- increased ability to address categorical variables;
- increased ability to accommodate non-linear and/or non-monotonic relationships;
- intuitive "pruning" of the tree to fine-tune the model.

No significant relationships were found as a result of this analysis, leading to the conclusion that changes in auto occupancy, between 1996 and 2001, at the aggregate level, cannot be linked reliably to changes in the independent variables considered.

3.2.3 Analysis of individual tours

At the disaggregate level, individual tours were studied at a single point in time (2001), relating modal options such as driving alone, driving a passenger, or riding as a passenger to a series of independent variables similar to those described in the previous section. A dataset of more than 75,000 individual tours was created from the TTS database. Again, two-way frequency tables, scatter plots, and decision trees were used to evaluate possible relationships.

The most obvious relationship involves the possession of a driver's license in that while only 2.7% of all commuters do not possess a driver's license, 28.9% of auto passengers do not have a license. Looking at it from another perspective, all commuters without a license were captive to the passenger mode while only 6.8% of those with a license were passengers. However, from the aggregate analysis, it was found that overall, there was a slight decrease in the proportion of licensed commuters between 1996 and 2001 which does not help to explain the decrease in auto occupancy.

The propensity to be an auto passenger does appear to vary with the availability of an automobile within the household. While 35.6% of all commuters were from a household where there were fewer automobiles than commuters, 72.4% of passengers were from a similar household. From the aggregate analysis, there has been an increase in auto availability relative to the number of commuters in the household so this variable may provide a partial explanation for declining auto occupancy.

In the case of the availability of free parking at work or school, it was found that of all commuters, 14.2% did not have free parking while 24.0% of passengers similarly did not. From the aggregate analysis, the proportion of commuters with free parking actually declined between 1996 and 2001 so that this variable does not help to explain the decrease in auto occupancy.

No other variables were found to show any meaningful or consistent correlations.

3.2.4 Natural demand estimation – Synopsis

The analysis summarized above does not provide a clear direction towards the estimation of future changes in "natural" HOV demand. Correlations were found to be weak or inconsistent. In addition, there are several potentially key variables not accounted for.

One that comes to mind is the price of gasoline. Figure 5 shows the trend in gasoline prices in Toronto between 1996 and 2001 in actual terms and in approximate "real" terms, factored by the overall Consumer Price Index (CPI). The price of gasoline actually declined between 1996 and 1999 although there was a significant "bump" between 1999 and 2001, resulting in little net change over the 5-year period. How this translates into the observed decline in auto occupancy is not clear – over most of the 5-year period the price was higher in real terms than it was at the beginning of 1999. Recent dramatic increases in gasoline prices may have an impact on both auto ownership and auto occupancy although it is not known if there is a "threshold" which the price of gas has to exceed before its effects are felt.

Other variables not accounted for include:
- the ease with which carpools can be formed, taking into account the places of residence and employment of family members, neighbours, co-workers, etc;
- the availability of measures to promote carpooling such as preferential parking, ride-matching, carpool parking lots, etc;
- the other costs of auto ownership, including purchase, maintenance, operation, insurance, and registration; and,
- the actual proportion of "captive" vs "discretionary auto passengers – the proportion that have little choice due to the lack of alternatives.

It is concluded that a fairly simple yet meaningful method to estimate future "natural" HOV demand is not within reach. It is also not known how close the current average occupancy is to the practical minimum, taking "captivity" into account, although it cannot be far above the minimum if one takes the proportions without licenses, without access to an automobile, or without access to convenient transit service into account.

It was therefore decided that the most prudent course would be to estimate future demand using current HOV proportions as a reasonable baseline level and structure a sensitivity analysis around this baseline, leaning towards a future increase rather than decrease of "natural" HOV demand.

3.3 Estimating Induced HOV Demand

3.3.1 Induced HOV demand modelling approach

There have been a variety of approaches described in the literature for the estimation of induced HOV demand, including logit (modal split) models, diversion curves, and regression analysis. The predecessor to the current study, covering the western portion of the GTA, estimated induced HOV demand by casting ridesharing as an alternative to driving alone in a nested logit model within the mode split process of the EMME demand forecasting framework. At the time,

this was a logical choice given the lack of "local" experience and data. Due to changing circumstances, including the emerging availability of local data on the impact of HOV lane implementation, and a desire to enhance the overall process, a somewhat different approach was used in the current study although the EMME framework in use in the GTA retained a central role. The primary objectives in developing this enhanced approach were as follows:

1. To make use of the before/after flow and speed data collected in connection with the HOV lanes implemented on Highways 403 and 404;
2. To improve on the ability of the speed/flow curves in the current EMME model to estimate travel-time differential between HOV and general-purpose lanes;

Calibration of a logit mode-split model as was used for the previous study of the west half of the GTA required trip level data which was not available in the context of the before and after monitoring studies undertaken in conjunction with the implementation of HOV lanes on Highways 403 and 404. Consequently, this model form was not pursued. The data that was collected, in the form of HOV and SOV volumes and travel times on those sections of highway where HOV lanes were implemented, suggested an incremental model. Such a model would also preserve information on the "natural" HOV demand. To best utilize the data collected for the Highway 403 and 404 projects, it was decided to pursue a model of the general form:

$$\mathbf{P}_{\text{HOV,after}} = \mathbf{P}_{\text{HOV,before}} + \mathbf{k} * f\left(\mathbf{tt}_{\text{HOV,after}} - \mathbf{tt}_{\text{HOV,before}}, \mathbf{tt}_{\text{SOV,after}} - \mathbf{tt}_{\text{HOV,before}}\right)$$

$$where: \mathbf{P} = proportion$$
$$\mathbf{tt} = travel\ time$$
$$\mathbf{k} = coefficient$$

Calibration of an incremental model of this form requires only knowledge of the changes in flow and travel time resulting from HOV lane implementation, changes which were observable from the data in hand. A further advantage of the incremental model was the fact that assumptions would not have to be made concerning variables such as carpool formation time, assuming that these would not change significantly over the planning horizon of the study. One key decision made early in the process was that HOV's would not be differentiated on the basis of the number of occupants due to the typically low proportion of HOV's with three or more persons.

3.3.2 Model specification

One disadvantage encountered with respect to the incremental model is the impracticality of direct calibration. A trial-and-error approach was adopted instead. Before and after SOV and HOV trip matrices were estimated for the relevant sections of Highways 403 and 404. A record consisting of the before/after SOV and HOV flows and travel times was generated for each origin-destination pair in the subarea trip matrices. A spreadsheet was set up to estimate the "after" HOV proportion from the "before" proportion based on changes in travel times. This calculated proportion was compared to the observed proportion and squared difference and simple difference error terms were calculated and summed.

Several different model forms were tested, including the incremental logit model (the logical starting point), linear functions, and power functions. Based on this analysis, it was concluded that a power function of the form:

$$P_{HOV,after} = P_{HOV,before} + 0.06*((tt_{HOV,after} - tt_{HOV,before}) - (tt_{SOV,after} - tt_{HOV,before}))^{0.5}$$

$$where: P = proportion$$
$$tt = travel\ time$$

led to the smallest combination of summed error terms, appeared to best fit the data qualitatively, had an intuitively reasonable form, and was mathematically tractable in terms of application. In particular, the HOV proportion increases quickly over small initial reductions in HOV travel time relative to SOV travel time, representing the belief that HOV lanes have a certain "novelty" factor and small travel time savings are often over-estimated by drivers. As travel time savings increase, the change in HOV proportion increases at a progressively lower rate, representing the belief that an upper limit exists where other factors play a role in limiting HOV use. Figure 5 depicts the comparison between the observed and estimated HOV proportions for the calibration sample with the chosen functional form. Once the "after" HOV proportion is estimated, the revised SOV volume is calculated using a reduction of 2.1 SOV's for each new HOV created. The function selected for use essentially represents pseudo-equilibrium between the flows induced by the implementation of HOV lanes and the travel times that are associated with this flow pattern.

3.3.3 Application Framework

The overall framework developed to incorporate the HOV estimation model and to achieve several other key objectives is depicted in Figure 7 and described below, emphasizing the enhancements made to the process. This framework was designed to integrate the macroscopic EMME model with the microscopic VISSIM and PARAMICS models in such a way to achieve the benefits of each. In particular, the volume-delay functions within EMME and the assignment procedure they are used within is limited in terms of its ability to reliably estimate travel times, particularly under conditions of congestion and queue spill-back. Since the estimation of the travel-time differential between HOV's and SOV's is critical to the estimation of the change in HOV proportion induced through HOV lanes, and these differentials can be quite small, micro-simulation, using the VISSIM or PARAMICS models, is applied at the corridor level to refine the travel-time estimates.

- Baseline 2006 GTA-level HOV and SOV origin-destination matrices were adapted from those used in the previous study of the western portion of the GTA.
- A series of iterations were run, alternating between application of the HOV estimation model (operationalized as an EMME macro) and a multiclass equilibrium assignment to the overall GTA network of both vehicle classes. An oscillation "damping" modification was required to keep the process within reasonable bounds. It was found that eight cycles, on average, were sufficient to reach equilibrium. In addition to estimating the conversion of SOV's within a corridor to HOV's, this step in the process also estimates the diversion of both HOV's and SOV's to the corridor from other routes. Since the EMME model includes only peak-hour trips, time-shifting of trips into the peak hour to make use of freed-up capacity is not accounted for. However, this is indirectly offset by additional route diversion within the overall equilibrium objective. To ensure that the benefits associated with HOV lane use were represented properly, the EMME network was recoded to incorporate the express/collector systems in place on the highway system. In addition, the HOV lanes were coded with

appropriate access zones as specified in the MTO's design guidelines. Proper location of both the transfers between the express and collector lanes and the HOV lane limits and access zones is essential to reliable estimation of the number of HOV's that can actually make use of the HOV lanes and the distance over which they can use them.

- Subarea trip matrices or "traversal" matrices were then generated based on equilibrium conditions for each highway corridor. The baseline subarea matrices were adjusted based on recent traffic counts (existing conditions) or factors developed from these counts (future conditions) in a purpose-built spreadsheet to account for under or over-simulation. This step was considered necessary to ensure that the subarea matrices reflected realistic traffic levels for use in the following micro-simulation stage.

- The adjusted subarea matrices were then supplied to a calibrated micro-simulation model for the corridor. Travel times in the HOV and general purpose lanes were obtained from the micro-simulation runs and these were used in a further application of the HOV estimation model in a spreadsheet format. The resulting adjusted matrices were re-run in the micro-simulation model. This process was repeated until equilibrium was achieved between the travel-time differential (between HOV and general-purpose lanes) and the proportion of HOV's as implied by the estimation function. As before, a damping process was incorporated although, being a manual rather than automated process, judgement was used to speed up convergence where possible. Since this step is undertaken at the subarea level, no further diversion from outside the corridor is possible. However, since this is largely a refinement stage

- Outputs were summarized from the micro-simulation runs in the form of flow diagrams and travel-time estimates and, where desired, speed contour plots and other measures of effectiveness.

The process described above is quite demanding as automation possibilities have not yet been fully investigated for the various manual procedures and interfaces. A current MTO initiative, incorporating a mesoscopic layer within a comparable framework, would have been an ideal mechanism for the estimation of induced HOV demand. The emerging mesoscopic simulation models have sufficient detail and the appropriate methodologies to produce reliable travel-time estimates but at the same time be efficient enough to model at the network level rather than the corridor level. However, this initiative is only now gaining momentum and will be reported on at a later date.

3.3.4 Typical outputs from the framework

The use of micro-simulation as the final stage in the modeling framework means that a variety of powerful and detailed outputs are available for analysis. These include the following:

- Speed contour plots (see Figure 8a), showing the evolution of congestion over time and space. Specific operational issues can be identified, including the impact of the HOV lane access zones on the GP lanes.

- Volume summaries (see Figure 8b), showing not only the volumes in the HOV and GP lanes, but also the HOV volumes entering and leaving the HOV lanes at each access zone.

- Summaries of travel times, delays, throughputs, queuing, and other variables can also be produced.

4. Framework Application to the GTA Highway System

As mentioned previously, the framework described above was intended to be applied to the expressway system in the eastern part of the GTA with the objective of determining the likely success of potential HOV lane projects, establishing implementation priorities, and identifying interdependencies. With the pace of the ongoing planning and design program for highway improvements, the focus of the study was shifted slightly to establish justification for designation of planned new lanes as HOV lanes. Nonetheless, the study looked at the various potential HOV lanes in a systemic manner.

Six network scenarios were established to cover a range of possible implementation strategies. These are summarized in Table 1. All of these scenarios were taken through the first (EMME) phase of the framework. Since it was observed that there were not significant differences between the scenarios in terms of estimated HOV use in individual corridors, only two scenarios were carried forward for selective testing through the micro-simulation component of the framework. The first was Scenario 1, which represented an essentially complete ultimate HOV network and which would demonstrate the effects of the associated synergies. The second was Scenario 3, which represented a more sparse network and which would more closely represent the impact of individual projects in isolation and which would be closer to the opening-day situation for individual projects in the early stages of network implementation. Figures 9 and 10 depict Scenarios 1 and 3 respectively.

During the course of the study, planning and design of several highway projects has progressed to the point where decisions are required on the designation of proposed new lanes as HOV or GP lanes. These included, in order of consideration, Highway 427 between Highway 401 and Highway 7, Highway 400 between Highway 401 and the City of Barrie, and Highway 404 between Highway 7 and Highway 9 (actually Green Lane). To this point, only Highway 427 has been analyzed fully, while preliminary results are available for Highway 400.

4.1 Highway 427 (Highway 401 to Highway 7)

A variety of HOV lane configurations were studied in conjunction with a proposed widening of this section of Highway 427, including alternative endpoint locations and treatments for the HOV lanes, and HOV lanes designed with discrete access zones vs. those with continuous access. Some of the observations for peak-hour, peak-direction travel, generalized across the scenarios studied, were as follows:

- HOV proportions increase from 12-14% today to 25-35%;
- HOV lane volumes range from 400 to over 900 vehicles/hour, in most cases and at most locations exceeding the 500 vehicles/hour guideline for minimum utilization;
- Travel time savings of at least 9 minutes were estimated for HOV's, exceeding the 5 minute guideline for minimum savings.
- HOV lanes with discrete access zones were found to be operationally superior to those where continuous access was provided.

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4.2 Highway 400 (Highway 401 to the City of Barrie)

To this point, analysis has focused on the widening of Highway 400 in many areas to accommodate HOV lanes, although there are some sections where lane conversion would be required. Some of the preliminary observations for peak-hour, peak-direction travel, generalized across the 2011 and 2021 planning horizons, are as follows:

- HOV proportions increase from 8-12% today to 20-28%;
- HOV lane volumes range from 600 vehicles/hour to over 1,700 vehicles/hour, in all cases and at all locations exceeding the 500 vehicles/hour guideline for minimum utilization;
- Travel time savings of anywhere from 5 to 25 minutes were estimated for HOV's, exceeding the 5 minute guideline for minimum savings.

5. Conclusions

An innovative, integrated modeling framework was developed to estimate HOV demand for potential new HOV lanes on expressways in eastern portion of the Greater Toronto Area. This framework incorporates macroscopic (EMME) and microscopic (VISSIM and PARAMICS) components. While a large-scale study like this would normally rely primarily on EMME to provide modeling inputs, the estimation of HOV demand resulting from the implementation of HOV lanes depends heavily on reliable travel time estimates. Since the travel time estimates available from EMME are not sufficiently reliable, micro-simulation was incorporated to enhance these estimates.

An HOV estimation model was developed using before and after monitoring data from two recently-implemented HOV lanes on Highways 403 and 404 in the Greater Toronto Area. This is an incremental model relating travel time changes to changes in HOV proportions. This model is applied at both the macroscopic and microscopic levels to estimate the equilibrium balance between relative travel times and HOV proportions.

The modeling framework is being applied to the expressway network in the eastern half of the GTA to determine whether or not proposed new lanes should be added as HOV lanes or general-purpose lanes. To date, the results support the implementation of HOV lanes on Highways 427 and 400.

References

(1)   Mitchell, T.M. <u>Machine Learning</u>. McGraw Hill. 1997.

Tables

Table 1: Network Scenarios
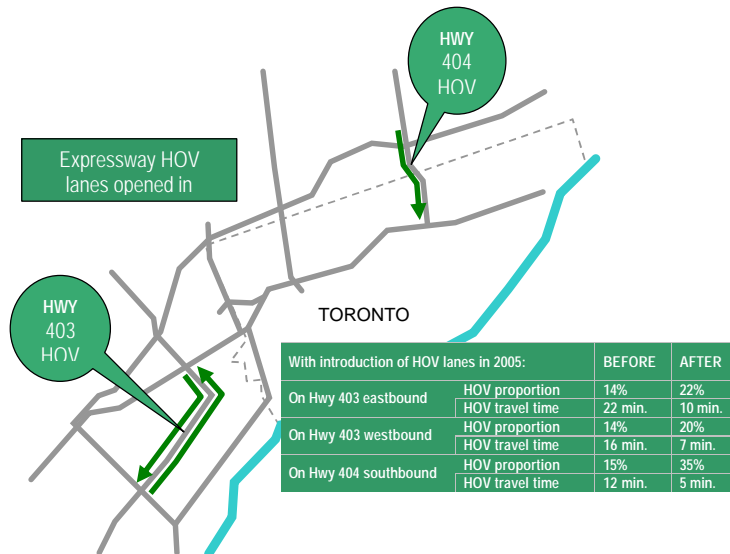
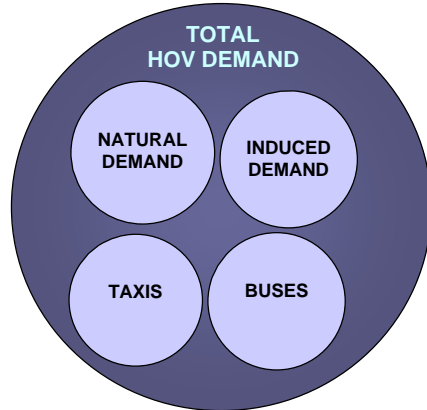|	SCENARIO	SECTIONS OF HIGHWAY INCLUDED					
		HWY 401	HWY 427	HWY 400	HWY 404	HWY 409	HWY 407
1	Complete Mainline	Hwy 427 to Hwys 35/115	Hwy 401 to Hwy 7	Hwy 401 to Barrie	Eglinton to Hwy 9	Hwy 401 to Hwy 427	Brock Rd to Hwys 35/115
2	Core Network	Hwy 427 to Rouge R.	Hwy 401 to Hwy 7	Hwy 401 to Hwy 9	Hwy 401 to Maj.Mackenzie	Hwy 401 to Hwy 427	*not included*
3	Radial Corridors	Rouge R. to Hwys 35/115	Hwy 401 to Hwy 7	Hwy 401 to Barrie	Hwy 401 to Hwy 9	*not included*	*not included*
4	Widening Opportunities	Lake Ridge to Hwys 35/115	Hwy 401 to Hwy 7	Maj. Mackenzie to Barrie	Eglinton to Hwy 9	*not included*	Brock Rd to Hwys 35/115
5	Hwy 401 Spine	Hwy 427 to Hwys 35/115	*not included*	*not included*	Hwy 401 to Hwy 7	*not included*	*not included*
6	Hwy 401 Spine + Feeders	Hwy 427 to Hwys 35/115	Hwy 401 to Hwy 7	Hwy 401 to Maj. Mackenzie	Eglinton to Hwy 7	*not included*	*not included*

Figures

Figure 1: Changes in average auto occupancy between 1996 and 2001 for morning peak-period commuting trips originating from 14 super-zones.
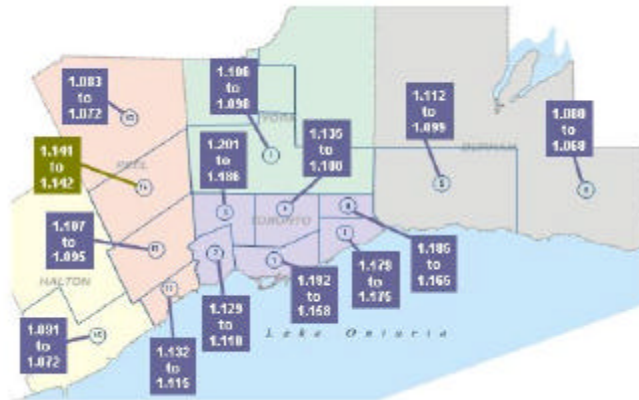
Figure 2: Changes in HOV proportions and travel times when HOV lanes were implemented on Highways 403, 404.

With introduction of HOV lanes in 2005:		BEFORE	AFTER
On Hwy 403 eastbound	HOV proportion	14%	22%
	HOV travel time	22 min.	10 min.
On Hwy 403 westbound	HOV proportion	14%	20%
	HOV travel time	16 min.	7 min.
On Hwy 404 southbound	HOV proportion	15%	35%
	HOV travel time	12 min.	5 min.

Figure 3: HOV market segments
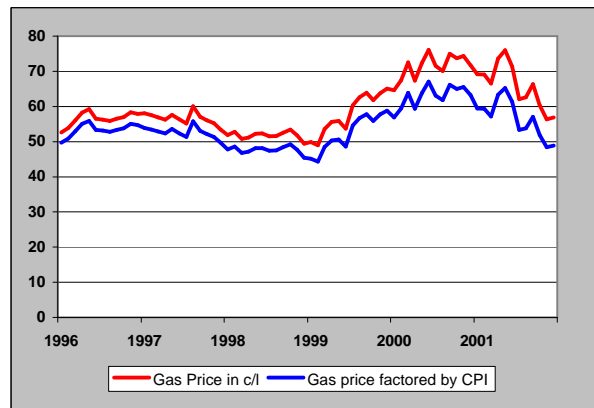

Figure 4: HOV use of GTA highways prior to HOV lane implementation (2004 afternoon peak period, peak direction)

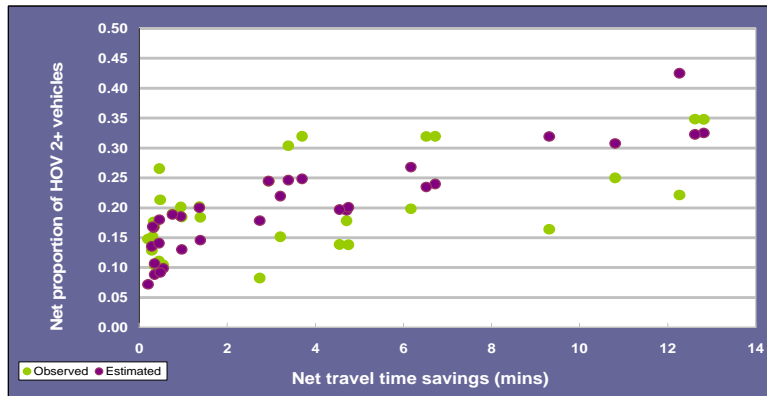| 7.5% | HOV 2+ as a percentage of total autos |
| 0.3% | Buses, taxis as a percentage of total vehicles |
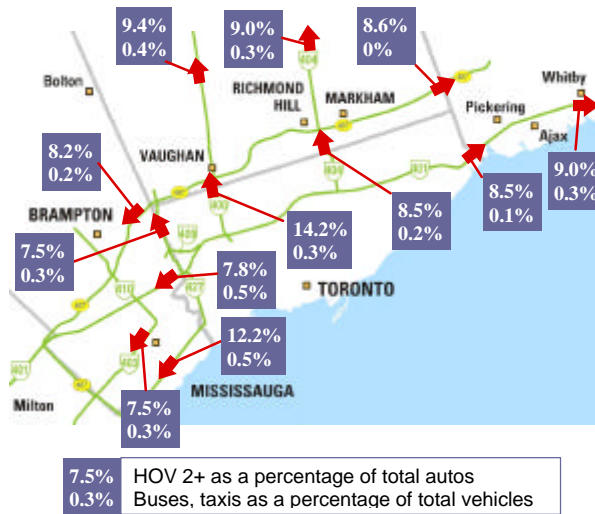
Figure 5: Gasoline price trend in Toronto – 1996 through 2001
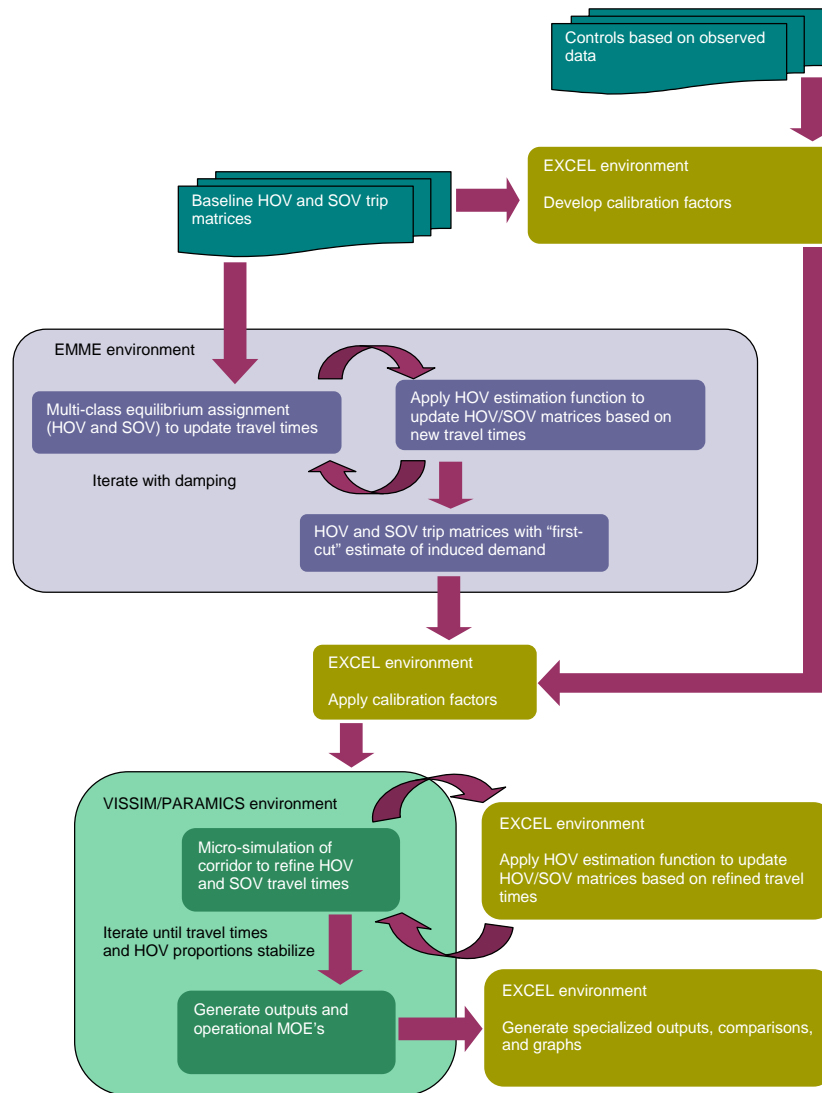
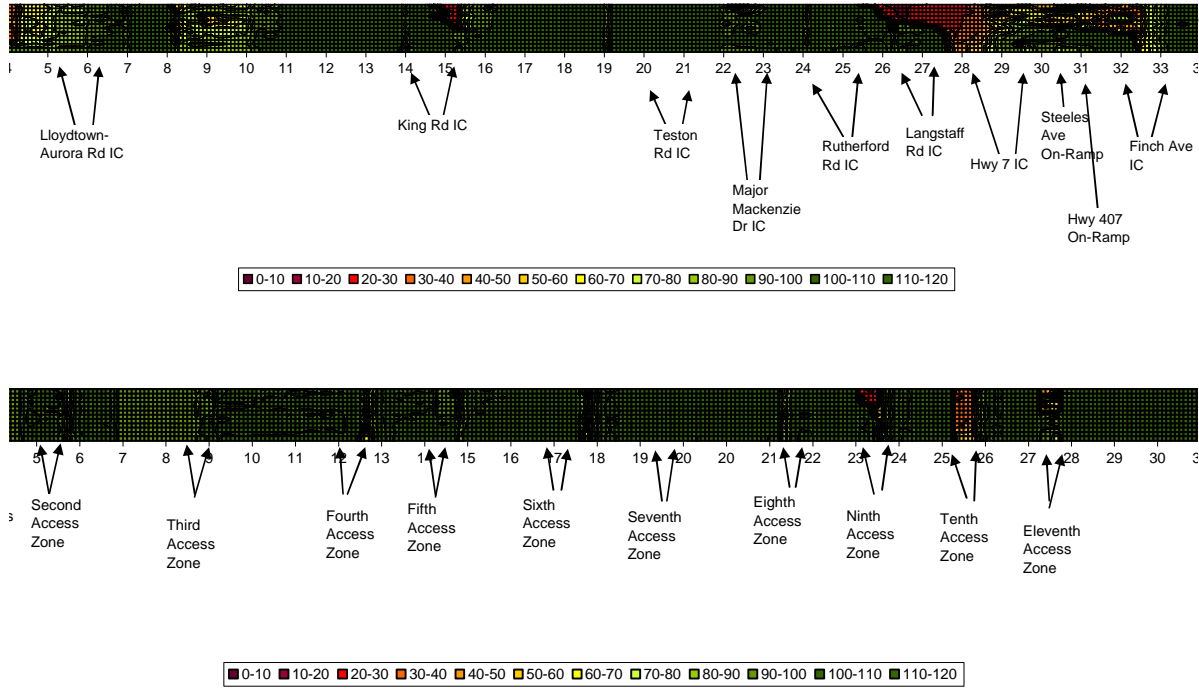**Figure 6: Comparison of observed and estimated HOV proportions**

Figure 7: Flow diagram showing the key steps in the estimation of induced HOV demand

Figure 8: Typical outputs from the HOV estimation process

Figure 8a: A typical speed contour plot – GP lanes and HOV lane

Lloydtown-Aurora Rd IC

King Rd IC

Teston Rd IC

Major Mackenzie Dr IC

Rutherford Rd IC

Langstaff Rd IC

Hwy 7 IC

Steeles Ave On-Ramp

Hwy 407 On-Ramp

Finch Ave IC

0-10 10-20 20-30 30-40 40-50 50-60 60-70 70-80 80-90 90-100 100-110 110-120

Second Access Zone

Third Access Zone

Fourth Access Zone

Fifth Access Zone

Sixth Access Zone

Seventh Access Zone

Eighth Access Zone

Ninth Access Zone

Tenth Access Zone

Eleventh Access Zone

0-10 10-20 20-30 30-40 40-50 50-60 60-70 70-80 80-90 90-100 100-110 110-120

Figure 8b: A typical volume summary plot

Teston Rd

Major Mackenzie

Rutherford Rd

1385 0 1520 140 1390 160 1300 95

5445 5430 5715 6230

1515 125 1520 0 1635 60 2030 410

6960 6950 7350 8260

22% 22% 22% 25%

7285 7285 7690 8645

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Figure 9: Network Scenario 1 – Complete Mainline

Figure 10: Network Scenario 3 – Radial Corridors