OVERVIEW OF A SIMULATION STUDY OF THE HIGHWAY 401 FTMS

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Many of North America's urban traffic networks experience recurring congestion during large portions of the commuting periods. Non-recurring congestion is also common. In response to the considerable efficiency and safety repercussions of this congestion, many areas have, or are, implementing freeway traffic management systems (FTMS). Though the qualitative benefits of FTMS have long been established, the quantitative benefits have been more difficult to determine as they are system dependent. In addition, it is often not clear which traffic management strategies will result in the greatest benefits at various times during the day. One way to address this problem is to utilize a simulation model as an analysis or evaluation tool. This paper describes the calibration and application of such an analysis tool.

This paper discusses the application of the network traffic simulation model INTEGRATION to a thirty-five kilometer section of Highway 401 in Toronto, Canada. Both the eastbound and westbound directions have been modelled as separate networks. However, only results for the eastbound direction from 4 A.M. to 12 noon are presented herein. In order to model 9 hours of operation on the 239 link eastbound network, approximately 1.5 hours of execution time is required when operating on a 80486 computer operating at 33 MHz.

Existing freeway conditions are quantified using both FTMS detector data and a floating car travel time survey. Variations that exist in observed link flows and trip travel durations over time of day and days of week are examined. The extent to which FTMS data meets the data requirement needs of the INTEGRATION model is examined. As the current FTMS encompassed less than 50% of the network analyzed, complications arise in accurately estimating the prevailing time varying origin-destination demands, as well as in comprehensively validating the simulation model's results. Comparisons that were made between simulation results and FTMS flow data and floating car travel time data, indicate that the INTEGRATION model's results generally fall within the natural day-to-day variations that are inherent within the system.

1.0 Introduction

The Ontario Ministry of Transportation is in the process of implementing an FTMS on Highway 401 for the section that traverses Metropolitan Toronto. To assist in the cost-benefit analysis, as well as in the development of future control strategies, the INTEGRATION model has been coded to simulate this section of freeway in both the east and west bound directions. This paper presents an overview of the steps involved in this process.

Details of the COMPASS system are provided by Korpal [1], while a more general overview of INTEGRATION can be found in the literature [2,3,4,5]. This earlier work has shown that typically the modelling of a system involves five stages.

1. Code the network.
2. Determine appropriate routes or identify appropriate routing behaviour (i.e. user-equilibrium assumption of minimizing user travel times).
3. Determine O-D traffic demands.
4. Calibrate the link speed-flow relationships and capacities.
5. Carry out the desired simulation runs.

To execute the INTEGRATION model within the Highway 401 corridor, six fundamental types of data are required.

1. Network node/zone coordinate data.
2. Network link descriptor data.
3. Signal characteristics data.
4. O-D traffic demand data.
5. Incident descriptor data.
6. Route identification data.

The INTEGRATION model provides both a time series of output data, as well as aggregated results. The time series outputs include link specific flows, user travel times, number of stops, density, speed, and occupancy. These same measures are also aggregated over the entire simulation period. System statistics such as total vehicle time and total vehicle distance travelled are computed. Travel time and the standard deviation of travel time by origin and destination is also provided.

2.0 Data Inputs

2.1 Network coding:

For this study, the Highway 401 network was modelled from Morningside Avenue in the east to Eglinton Ave, in the west. This portion encompasses the entire currently existing express/collector facility. This section of Highway 401 includes 22 interchanges with connecting arterial roads and other freeways.

The Highway 401 study area was coded into a network of directed links and nodes. Links were defined such that a single link existed for each FTMS detector station. Link boundaries were defined such that detector stations were positioned near the midpoint of the link. This permitted an association to be made between the spot FTMS speed measurements, and travel time estimated by INTEGRATION, as detector speeds were assumed to remain constant for the entire link. A summary of the number of links and nodes required to represent the Highway 401 eastbound and westbound network is provided in Table 2.

Figure 2 illustrates the simulation model link and node representation of the Highway 401 network. It should be noted that for each direction, the network plot represents the eastern half of the network below the western half. The network coordinates were coded this way to provide a better aspect ratio of the network for the INTEGRATION model's graphical output. For simulation purposes these two halves are connected and appear to the traffic model as one continuous segment.

2.2 Route determination:

Route identification was not strictly necessary for the INTEGRATION model, but it was required as input for the estimation of O-D traffic demands. The traditional approach of using assignment techniques for determining appropriate paths, was not possible. Assignment techniques require that the O-D traffic demands be known before the determination of utilized routes. For the modelling of Highway 401, neither the utilized routes, nor the O-D demands were known.

The simplest routing selection is to route all traffic along the single shortest path. However, this approach is clearly unrealistic as all traffic demand would either use the collector lanes exclusively, and no traffic would use the express lanes or vice-versa. A more realistic approach is to assume that the two alternative paths that are available are both utilized in some proportion. For the first path (express route), a driver will attempt to access the express lanes at the earliest opportunity, and exit the express lanes at the latest possible point. For the second path (collector route), the collector lanes are utilized for the entire trip. In accepting these two paths as the only route alternatives, it is assumed that drivers do not arbitrarily alternate between express and collector lanes without having a distinct preference for either one or the other.

Though the routes have been identified, the proportion of demand using each route must still be determined. To simplify the problem, it was assumed that the proportion of demand utilizing each route remained constant through both time and space for each direction. Thus, the proportion of demand choosing the express route is the same at the diversion point at Dixon Rd. during the AM period as it is at the transfer roadway at Markham Road during the PM period. The proportional split between routes for the eastbound direction were not assumed to be equal to those of the westbound direction.

2.3 Determining O-D demands:

The INTEGRATION simulation model requires O-D traffic demands be specified. Unfortunately, the true or actual O-D demands that exist for Highway 401 are not known. The only data available are link traffic flow data from vehicle detectors. These data do not provide flow continuity at nodes, nor are these data available for all links. Some means of estimating O-D demands for 15 minute periods was required.

A synthetic O-D demand estimation model, developed at Queen's University, was used to provide static O-D demands for 15 minute periods. This model permits the estimation of static demands based only on observed link traffic flows and specified routes. Details of the model are available in the literature [6] as are the details of estimating the O-D demands for Highway 401 [7].

The O-D estimation model is also capable of estimating dynamic demands. However, this dynamic estimation also requires estimates of link travel times. Dynamic O-D's were not estimated for Highway 401, as accurate link travel time data were not available. FTMS speed data were only available for less than 50% of the network, and 70% of these available data result from only single loop detector stations. These speed data, in particular, are considered to be rather unreliable, the reasons for which are discussed in Section 3.1.

FTMS aggregated link volumes were used as input to the O-D estimation model. However, as the current FTMS does not yet extend east of Yonge Street, no link flows were available for this portion of the network. The demand estimation model does not require that all links have observed flows, but the estimated demands are more accurate when the solution space is constrained. To provide at least some estimate of link flows for ramps, manual traffic counts from 1986 were used. The 1986 flows were scaled to reflect the growth trend in demand that was observed in traffic counts taken along Highway 401 from 1986 to 1992.

O-D demands were estimated based on the previously defined express and collector paths. However, the appropriate split between these two paths was initially unknown. O-D demands were estimated for a series of splits. The split resulting in the minimum squared error between the link flows resulting from the estimated demand and the observed flows was chosen as most representative for the network. The optimal proportion of demand choosing the express route for the Eastbound direction was determined to be 80% while 20% of demand was found to have a preference toward using the collector route. For the Westbound direction, the optimal split was found to be 75% to the express and 25% to the collector.

3.0 Examination and Evaluation of Data Sources

Two primary data sources were utilized for the calibration of the simulation model. The first source was the FTMS detector speed, volume, occupancy data. The second source was travel time data obtained during a speed-delay study conducted on Highway 401. Each of these data sources is described and examined in detail in the following sections.

3.1 FTMS detector data:

The COMPASS FTMS detector stations measure and transmit volume, occupancy, and in the case of dual loop stations, speed data, to the central computer every 20 seconds. Single loop stations cannot measure speed directly, so for each 20 second interval, an average vehicle length that is computed from some nearby dual loop station, is used to compute an estimate of speed. Approximately 30% of the 175 existing operational detector stations are dual loop stations.

Twenty second detector data for the two 24 hour periods of May 1, 1991 and June 8, 1992 were obtained from the MTO. An initial examination of these data was carried out on the data from May 1. This examination revealed that the accuracy of the speeds estimated for single loop stations was at that time rather poor, particularly under low occupancy conditions. Two factors contributed to these inaccuracies:

1. The first is the inaccuracies in the recording of measured station occupancy. At that time, lane occupancy was measured in the field as a real value, but was truncated into integer format before being transmitted to the central computer. This truncated lane occupancy was used to compute the average station occupancy. This average station occupancy was also truncated into integer format before storing the value on tape. The impact of this method is best illustrated using a simple example.

   Consider a three-lane section of freeway from which lane occupancy data is recorded. As illustrated in Table 3, the effect of dual truncation can lead to recorded station occupancies of zero, while in reality the occupancy was 1.6%. The amount of error introduced by this method of recording the station occupancy becomes less significant as occupancy and therefore traffic flows increase.

2. The second factor contributing to speed estimate inaccuracies is the need to have an estimate of average vehicle length for each single loop station. Currently, each single loop station receives an estimate of average vehicle length, every 20 seconds, from a nearby dual loop station. Unfortunately, the average vehicle length at two detector stations, during a 20 second interval, is not strongly correlated, particularly at low occupancies. If a single truck is recorded during a 20 second interval at a dual loop station, then the average 20 second vehicle length at this station might be 20 meters. However, unless a single truck also happens to traverse, during the same time period, the single loop station to which the average vehicle length is being provided, the estimate of average vehicle length will be quite different from the actual average vehicle length. Under heavy flow conditions, more vehicles contribute to the computed average and the probability is lower that average vehicle lengths between stations will be very different.

Another observation was made regarding the recorded total station volumes. The total station flow is reported as the total number of vehicles detected during the previous 20 seconds for all lanes. If one of the lane detectors is inoperative, then it reports -9999 and does not contribute anything to the computed total. If the lane station reports data that is just considered suspect, then it will report the data as negative. If any lane detector reports negative data, then the station total is reported as a negative, as the data may be suspect. For example, consider a three-lane section, in which one of the lane detectors is inoperative. The recorded lane flows might be 3, 5, and -9999 vehicles per 20 seconds for each respective detector. The station total is computed as (3+5) = -8. Clearly, this reported total is less than the actual, as one of the lane detectors input is not considered. Though the station data is marked by making it negative, it is not possible to distinguish between station data resulting from a suspect lane detector and one that is inoperative.

Despite these imbedded data errors, these data represent the only available data source which quantify existing traffic conditions. To gain an understanding of the character of the available data, it is useful to view a graphical representation of typical system data. Figures 3 and 4 illustrate a 22 hour time series of typical 20 second and aggregated 15 minute volume and speed data for a three lane section in the eastbound collector lanes. Significant variations over time are evident in both 20 second volume and speed data. To reduce this variation within the data, to reduce the storage requirements, and to provide a practical period duration over which simulation results could be compared to observed traffic conditions, all data were aggregated into 15 minute average values. As illustrated in Figures 3 and 4 this aggregation significantly reduces the variation remaining in the data.

It is also important to understand the variations that exist between different days. It seems clear that no two days experience exactly the same traffic conditions at the same time of day. However, what is not clear, is the extent of the day-to-day variation. Figure 5 illustrates the variation that exists between aggregated 15 minute FTMS detector volume data collected over three separate days.

3.2 Travel time data:

A primary measure of performance for traffic studies is speed or travel time. Unfortunately, obtaining accurate travel time data using traditional floating car studies is costly and time consuming. The existence of COMPASS on Highway 401, provides an efficient means of obtaining spot speeds and estimating travel times. It is not clear, however, how accurate the estimation of trip travel times from spot speeds typically is, particularly in view of the previously described data inaccuracies.

To determine, if estimating travel time from spot speed data is sufficiently accurate, a traditional floating car study was carried out [8]. The study was carried out on three days; Monday, June 8, Thursday, August 6, and Friday, August 7, 1992. In total, seventy-seven trips were made. Each trip traversed the length of the study network in a single direction. Comparable travel times were estimated from the FTMS data. A correlation analysis of these two data sources indicated that the coefficient of correlation was only 0.423. It was concluded that with the low level of correlation demonstrated by these data, the current FTMS trip travel time estimates are insufficiently accurate to utilize with confidence.

4.0 Model Calibration

Although all simulation model data inputs have been previously described, the determination of three inputs requires further examination. For each link in the network, capacity and the speed-flow relationship must be defined. As well, traffic conditions outside of the study area, that may have impacted the modelled network, must be considered.

4.1 Speed - Flow relationship:

For simulation models, the functional form of the speed-flow relationship must be defined and then this relationship must be calibrated. Much work has been conducted since as early as 1934 to estimate a realistic and consistent speed-density relationship. The simplest and most commonly used is Greenshields' linear model [9]. This model leads to a parabolic speed-flow relationship for which the speed at capacity is one-half of the free speed and the density at capacity flow is one-half of the jam density. This is also the relationship used by the 1985 Highway Capacity Manual (HCM) [10].

Recently, Van Aerde [11] has proposed a generalized form of Greenshields' model (Equation 1).

$$D = \frac{1}{\left[c_1 + \frac{c_2}{s_f - s} + c_3 s\right]} \qquad [1]$$

Based on this general form, the speed-flow relationship can be expressed as Equation 2:

$$(1 - vc_3)s^2 + (-vc_1 + vc_3 s_f - s_f)s + (vc_2 + vc_1 s_f) = 0 \qquad [2]$$

where

$$c_1 = kc_2 \qquad [2a]$$

$$c_2 = \frac{1}{D_j\left(k + s_f^{\,-1}\right)} \qquad [2b]$$

$$c_3 = \left(-c_1 + \frac{s_c}{v_c} + \frac{c_2}{(s_f - s_c)}\right) s_c^{\,-1} \qquad [2c]$$

$$k = (2s_c - s_f) \big/ (s_f - s_c)^2 \qquad [2d]$$

where:	v	=	volume (vph)
	v_c	=	volume at capacity (vph)
	s_f	=	free speed (km/h)
	s_c	=	speed at capacity (km/h)
	s	=	speed at volume *v* (km/h)
	c_1	=	fixed distance headway constant (km)
	c_2	=	variable distance headway constant (km^2/h)
	c_3	=	variable distance headway constant (1/h)
	D_j	=	jam density (v/km)
	D	=	density (v/km)

This general model requires that the following parameters be specified; the jam density, free speed, capacity, and speed at capacity. Based on the FTMS data examined, and aware of the substantial variations within these data, the following parameter values were chosen. Note, for this study, no explicit statistical calibration was carried to determine the optimum level of these values.

$$s_f = 110 \text{ km/h}; \; v_c = 2200 \text{ vph}; \; D_j = 125 \text{ vph}; \; s_c = 70 \text{ km/h}$$

The impact of these values on the resulting speed-flow relationship is illustrated in Figure 6 by the curve designated as *INTEGRATION*. The parabolic speed-flow relationship resulting from Greenshields' model is also illustrated. The 20 second FTMS data depicted in Figure 6 were obtained from a dual loop detector on Highway 401. The use of dual loop station data precludes the measurement errors attributable to single loop stations.

Clearly, the speed-flow relationships accepted for use within the INTEGRATION model more accurately reflects the trends within the observed data than does Greenshields' linear speed-density model that is also advocated by the HCM.

4.2 Link capacity:

In conjunction with defining the speed-flow relationship, the link capacities must be defined. For the INTEGRATION model it is not necessary to identify separately all the factors affecting flow, rather it is only necessary to define the maximum flow for each link.

The determination of lane capacity under uninterrupted flow conditions has been a subject of considerable attention and debate by traffic engineers. There has even been contention over a suitable definition of capacity and how it can and should be measured. From empirical experience, the 1985 HCM identifies lane width, traffic composition, driver population, and design speed as factors affecting maximum flow under ideal conditions. In the HCM, capacity is defined as the maximum hourly rate at which vehicles can reasonably be expected to traverse a section of a lane during a given period of time. Typically, the time period used in most capacity analyses is 15 minutes.

Recent research by Van Aerde *et al.* [12] indicates that capacity is not constant, even under constant traffic and environmental conditions. Rather, capacity is dependent on driver type and can be represented by a shifted negative exponential distribution. As further research is being conducted in this area, variable capacity is not considered in this study.

For this study, FTMS data were examined to determine what capacity would be appropriate. To avoid having to compute a unique capacity for each link in the study network, it was initially assumed that all links within the network have the same saturation flow rate. Based on this assumption, a constant saturation flow rate of 2200 vphpl was chosen for all links except for the collector lanes in the construction zone at Keele Street (links 69 - 73). In this area, lane reductions restrict lane width and lateral clearance. The saturation flow rate of this 2 lane section was set to 1650 vphpl.

4.3 Network boundary conditions:

A challenge common to all modelling exercises is the accurate and realistic representation of traffic conditions at the network boundaries. This challenge was particularly difficult in this study as it was discovered that traffic conditions downstream of the study section have significant impacts on the operating conditions within the study section, particularly during the P.M. peak period.

Since FTMS data were available at the study boundary for only the westbound direction, these data were examined. These data indicated that during the P.M. peak period, both the collector and express lanes experience congestion beyond the downstream boundary of the network. As the cause of this congestion is outside of the network being considered, no simulation model, or any other analysis technique, could predict this congestion. Yet, this congestion has significant impact on the traffic conditions within the network during the P.M. period.

To overcome this problem, the capacity of the last downstream link on both Eastbound and Westbound networks was reduced during a portion of the afternoon peak period. This reduction in capacity reflects the capacity of the bottleneck that exists outside of the study network.

5.0 Simulation Results

Having calibrated the speed-flow relationships and link capacities, the model was used to simulate the system for existing freeway conditions for Highway 401 from 4 A.M. to 12 noon. These simulations results were calibrated by comparing them to observed data. Two primary measures of performance were used to quantify traffic conditions predicted by the simulation model -- link flows and trip travel time. In each case, comparisons between simulation results and observed data were made.

For the simulation model to be a credible analysis tool, it must be shown that the model's results accurately reflect reality. This validation must be illustrated both qualitatively and quantitatively. However, before any comparisons can be made, some criteria must be established by which conclusions can be made regarding whether the model does or does not accurately reflect reality. In defining these criteria, it must be recognized that considerable variation exists in system traffic conditions. These variations are both temporal and spatial. The purpose of an analysis tool is to provide insight into expected traffic conditions for some *typical* day. As traffic conditions for a *typical* day vary, the limits of this variance must be used as the benchmark against which the simulation results must be validated. The variations existing within link flows and speeds, as well as trip duration on Highway 401 have already been examined and quantified. These observed variations are used to evaluate the reliability and accuracy of the INTEGRATION simulation model.

First, consider the validation of link traffic flows. Flows are available from the simulation model every 15 minutes for every link in the network. However, observed data as obtained from the FTMS detectors, are only available for the portion of the network west of Yonge Street.

A qualitative assessment of the accuracy of the estimated link flows can be made based on a graphical illustration of observed and estimated link flows. Two links were chosen for which an operational dual loop station existed. Links within the construction zone in both the express and collector lanes were not considered, as alterations to the number of lanes within this section render the FTMS detector data inaccurate. For each chosen link, 15 minute average speed and volume data, as measured by the FTMS detector station over three separate days, are compared with values estimated by the INTEGRATION model. Figure 7 and Figure 8 illustrate the volume and speed data for a 5 lane section of Highway 401 Eastbound just prior to the diverge. Figure 9 and Figure 10 illustrate the volume and speed data for a 3 lane section of Highway 401 Eastbound collector at Avenue Road. As indicated by these figures, the model produced flows for these links that fall within the level of variation existing within the observed data. However, Figure 8 indicates that for this particular link, the model over estimates speeds considerably.

As the qualitative assessment of the two chosen links may be deemed inconclusive, it is necessary that the system in its entirety be examined. To do this, speed contours for both the express and collector lanes were produced using available FTMS detector data from June 8, 1992 and the model results. The boundaries of the speed classes were chosen to correspond with those classes distinguished by the INTEGRATION model's graphical display. These boundaries correspond with speed at capacity (70 km/h), and the speed at a volume equal to 95% of capacity (50 km/h congested flow and 86 km/h uncongested). Figure 11 provides speed contours for the express lanes, while Figure 12 presents data for the collector lanes. From these contours it is immediately evident where and when congestion occurs.

The contours from the FTMS detector data in Figure 11 indicate that significant congestion occurs on link 11 beginning at 7:30 A.M. and remaining until 10:45 A.M. This congestion is largely due to the heavy merging demands from Highway 409. The congestion caused by this merging demand spills back upstream, eventually moving upstream of the diverge (link 6). The other areas of congestion indicated by the FTMS speed data (links 23 and 30) are suspect as they occur at all times, even at 5 A.M. The INTEGRATION model correctly locates the congestion due to the merging Highway 409 demands. However, this congestion is modelled to begin at 6:30 A.M. and does not spill back as far upstream as is observed.

FTMS speed data in Figure 12 indicate a bottleneck at Highway 400 in the collector lanes. This bottleneck begins at 7:00 A.M. and remains until 10:15 A.M. This congestion spills back until the Highway 409 on-ramp. Congestion also occurs prior to the diverge (links 6-8) likely due to congestion spilling back from the express lanes. Congestion also occurs in the construction zone at Keele Street. The INTEGRATION model results indicate two bottlenecks. This first is the off ramp to Highway 400. Congestion begins at 7:30 A.M., somewhat later than observed, and remains until 10:30 A.M. This congestion becomes severe, spilling back almost until the Highway 409 on-ramp. The second location of congestion is the construction zone at Keele Street. Congestion in this area is estimated to begin at 7:00 A.M. and continues sporadically until 10:00 A.M.

From the comparison of these speed contour plots, it is evident that the INTEGRATION model estimates congestion in the correct locations and approximately the correct times. The largest discrepancy occurs for the express lanes where the model under estimates the congestion effects. Though a qualitative evaluation has now been made, it is necessary that a quantitative assessment be made considering all links for which observed data are available.

Several measures can be defined which quantify the similarity of observed and estimated link flows. The first is simply the mean difference between observed and estimated link flows (Equation 3). The sign of this value indicates whether the simulation model tends to over or under estimate link volumes. The mean absolute link flow difference provides a measure of the true error between observed and predicted link volumes (Equation 4). The relative error provides a measure of the link flow error in terms of the average observed link volume (Equation 5).

$$\overline{E}_F = \tfrac{1}{n} \cdot \sum_{k=1}^{n} \left(F_k^o - F_k^p \right) \qquad [3]$$

$$\left| \overline{E}_F \right| = \tfrac{1}{n} \cdot \sum_{k=1}^{n} \left| F_k^o - F_k^p \right| \qquad [4]$$

$$E_F^r = \frac{\left| \overline{E}_F \right|}{\overline{F}^o} \qquad [5]$$

where: E_F^r = relative link flow error.

$\overline{E}_F$ = mean error between observed and predicted link flows (vph).

$\left|\overline{E}_F\right|$ = mean absolute error between observed and predicted link flows (vph).

n = number of links for which observed and predicted link flows exist.

F_k^o = observed flow on link i (vph).

F_k^p = predicted flow on link i (vph).

$\overline{F}^o$ = mean observed link flow (vph).

For the eastbound direction from 5 A.M. to 11 A.M. the average observed link flow was 2755 vph while the average modelled link flow was 1943 vph. The mean flow error then is 238 vph and the mean absolute flow difference is 399 vph. The relative link flow error was 0.14. From these results it seems that the link flows generated by the model tend to be underestimated.

It is also valuable to examine the duration of trips which traverse the entire 35 km length of the study network. Observed data was obtained during a speed delay study of Highway 401. Modelled data are computed based on the average 15 minute link speeds predicted by the model. Figure 13 illustrates both observed and modelled trip travel times for both express and collector lanes. As indicated by Figure 13, the model tends to underestimate trip durations, particularly for the express lanes during the commuting peak period. This is consistent with the finding made earlier that flows tend to be underestimated. If higher flows were to exist in the model, speeds would decrease, increasing travel times. Based on the above evaluations, it can be said that the simulation results reasonably represent reality. However, some discrepancies exist, particularly for trip travel times. Several factors likely contributing to these discrepancies can be identified.

The O-D demands used as inputs to the INTEGRATION model do not exactly replicate the unknown actual O-D demands. At least two reasons for the imperfect demand estimates can be identified. First, the estimated demands are static. Travel time is not considered when using *observed* flows to estimate the demands. Estimated demands are assumed to instantaneously propagate throughout the network. Clearly, this is not true, and can lead to some inaccuracies in the estimated O-D. Unfortunately, the estimation of time-varying O-D demands is much more complex, and requires the accurate knowledge of link travel times, something not available for the entire Highway 401 network.

The second reason is the lack of accurate link flows for a large portion of the network. As the FTMS is currently operational only west of Yonge Street, observed link flows were not available for approximately half the network. Manual count data from 1986 were utilized to minimize the detrimental impact the lack of link flows would have on the demand estimation process, but clearly, these data are of limited usefulness. As well, due to construction activities, the number of lanes in the collector and express lanes were altered in the vicinity of Keele Street. Though these lane changes were reflected in the model network specification, the FTMS data was affected, as no detectors existed in the added lanes.

A second factor affecting the accuracy of the simulation results is the lack of accurate routing data. The identification of an express and collector route appears reasonable, however, the assumption that the proportion of demand utilizing each route remains constant both temporally and spatially, is restrictive.

Unfortunately, as the estimation of routes, proportions utilizing each route, and the O-D demands must be made concurrently, the ability to estimate accurate route utilization proportions is quite limited.

Other factors that may potentially be contributing to the discrepancies between observed and estimated trip travel times is the use of aggregated estimated link travel times to determine estimated trip travel times. The use of aggregated simulation results removes some temporal variations that exist during shorter periods both in reality and in the simulation results. The production of simulation results for shorter periods, though possible, poses data storage problems. A more accurate and practical approach would be to modify the simulation model to permit the tracking of several *probe* vehicles. A log of link travel times could be output for these selected vehicles. These probe vehicle trips could be specified to correspond exactly to the floating car study trips. The ability to specify the origin, destination and the departure time of each vehicle would also be required.

6.0 Conclusions

The simulation model INTEGRATION has been used to model a 35-kilometer portion of Highway 401 in Toronto. Results show that the model can replicate the system dynamics of congestion growth and decay reasonably well. Mean link traffic flows tend to be underestimated with the absolute flow error 14% of the mean observed link flow. The model tends to under estimate trip travel time, particularly for the express lanes during the peak commuting period. Examination of simulation inputs and outputs suggests that most of these discrepancies are due to the inaccurate O-D demands and route use proportions.

The availability of FTMS traffic flow data was critical for the estimation of demands, as well as the validation of simulation results. It is anticipated that when FTMS data becomes available for the entire system, more accurate estimates of O-D demands could be made.

The available FTMS link travel time data is not of sufficient accuracy to be used with confidence. This lack of suitable travel time data prohibits the accurate synthetic estimation of time varying O-D demands.

Considerable difficulty still remains in estimating both accurate O-D demands and appropriate routes. This is largely due to the interdependence of the two problems. Routes are required to estimate the demands, and the demands are required to find the routes.

The network simulation model INTEGRATION provides a unique test environment in which any number of management, incident, or traffic scenarios can be explored.

Future work should concentrate on refining the O-D demand and route determination process. Efforts should be made to produce true time varying O-D demands for the Highway 401 network.

The INTEGRATION model should be enhanced to permit the specification of probe vehicles. These vehicles would provide, upon completion of their trip, a log of trip travel time comparable to that obtained from a floating car study. This would provide a more accurate means of comparing observed and estimated trip travel times.

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[12] M. Van Aerde, L. Aultman-Hall. *Microscopic Modelling of Macroscopic Measures of Stochastic Freeway Capacity.* Presented at the Annual Transportation Research Board Meeting, Washington , D.C. January 1993

Figure - 1: **Location of Highway 401 study site**

Figure - 2: **Highway 401 Eastbound and Westbound networks**

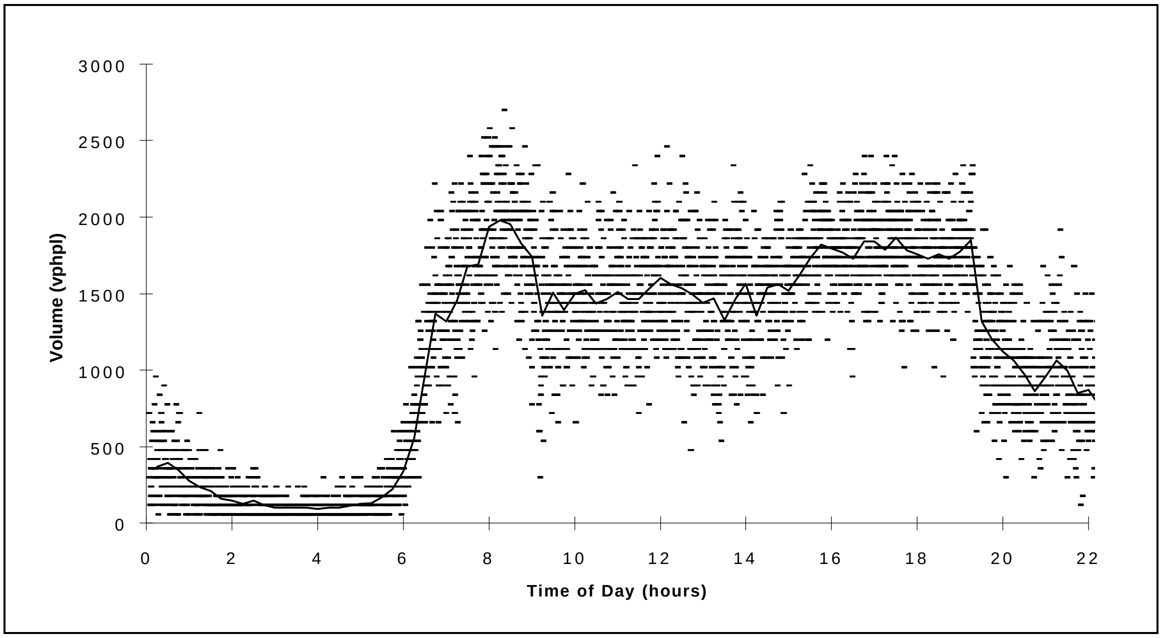

Figure - 3: **Typical 20 second and aggregated 15 minute FTMS detector volume data**
Data from 3 lane section with dual loop detector located in eastbound collector at Avenue Road, May 1/91 (Link 77, Station # 401DE0100DEC)

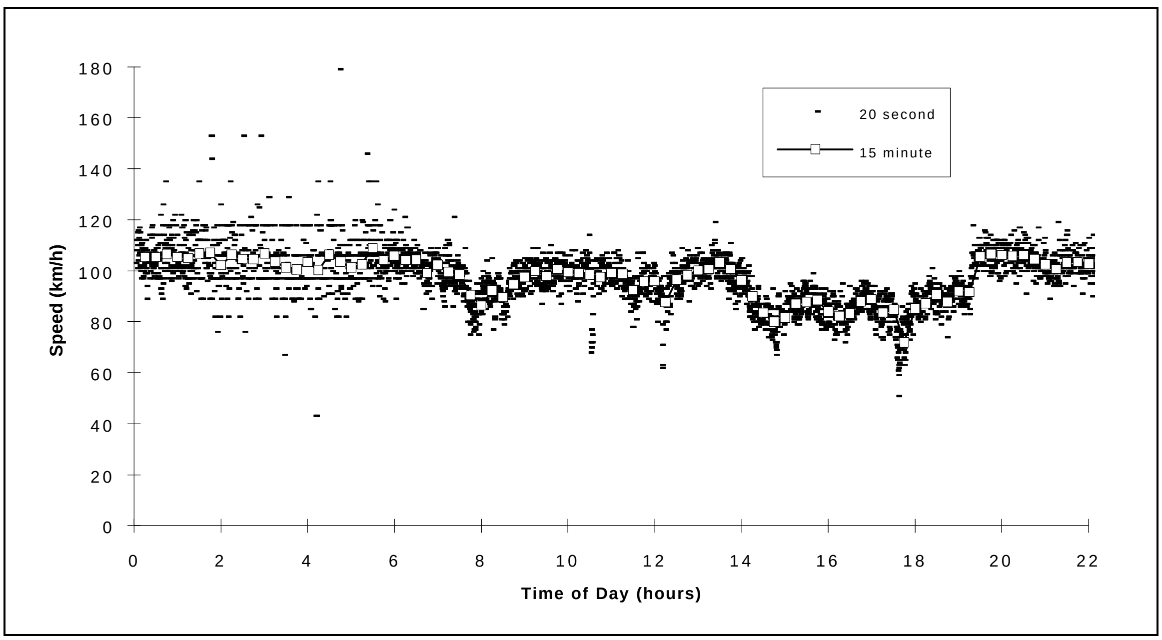

Figure - 4: **Typical 20 second and aggregated 15 minute FTMS detector speed data**
Data from 3 lane section with dual loop detector located in eastbound collector at Avenue Road, May 1/91 (Link 77, Station # 401DE0100DEC)

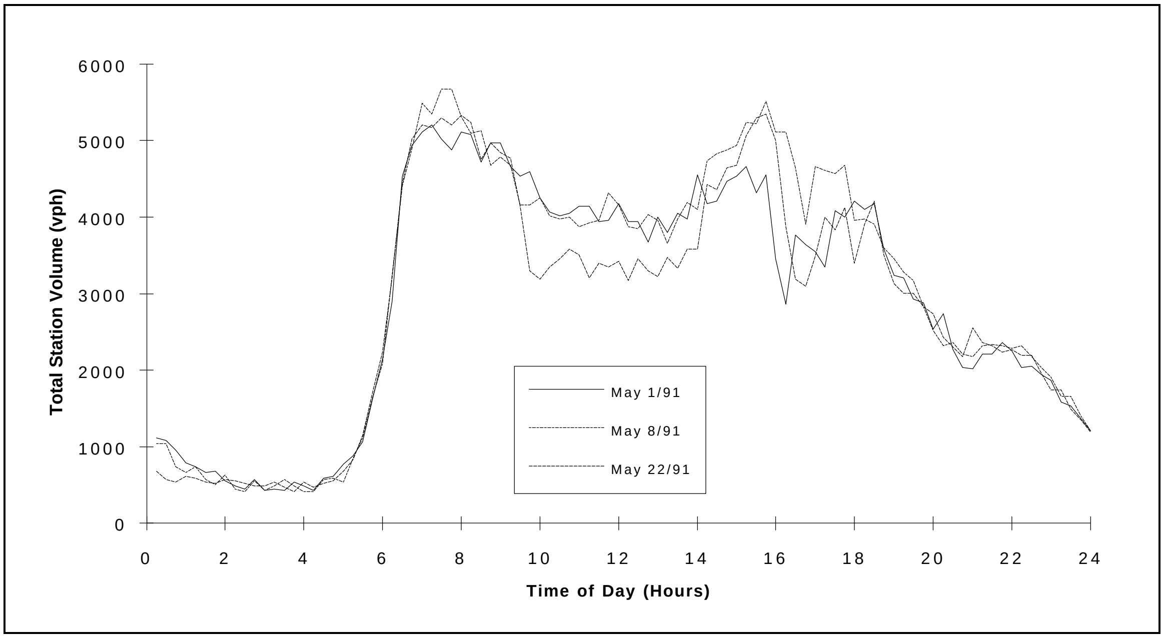

Figure - 5: Variation in observed aggregated 15 minute link volumes
Detector station located in WB Express lanes just west of off-ramp to Allen Road (Link 90, Station # 401DE0070DWE)

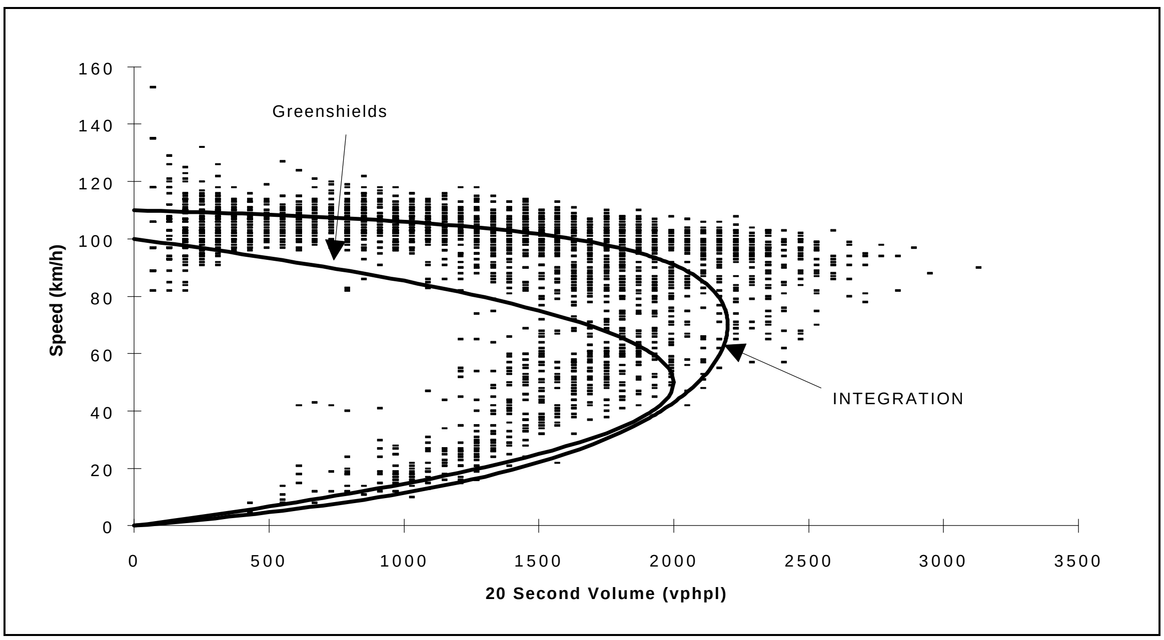

Figure - 6: Calibrated speed-flow relationship compared with observed 20 second data and standard parabolic relationship
Data collected on May 1/91 from dual loop detector station located in WB Express just east of Avenue Rd. (Link 112, Station 401DE0100DWE)

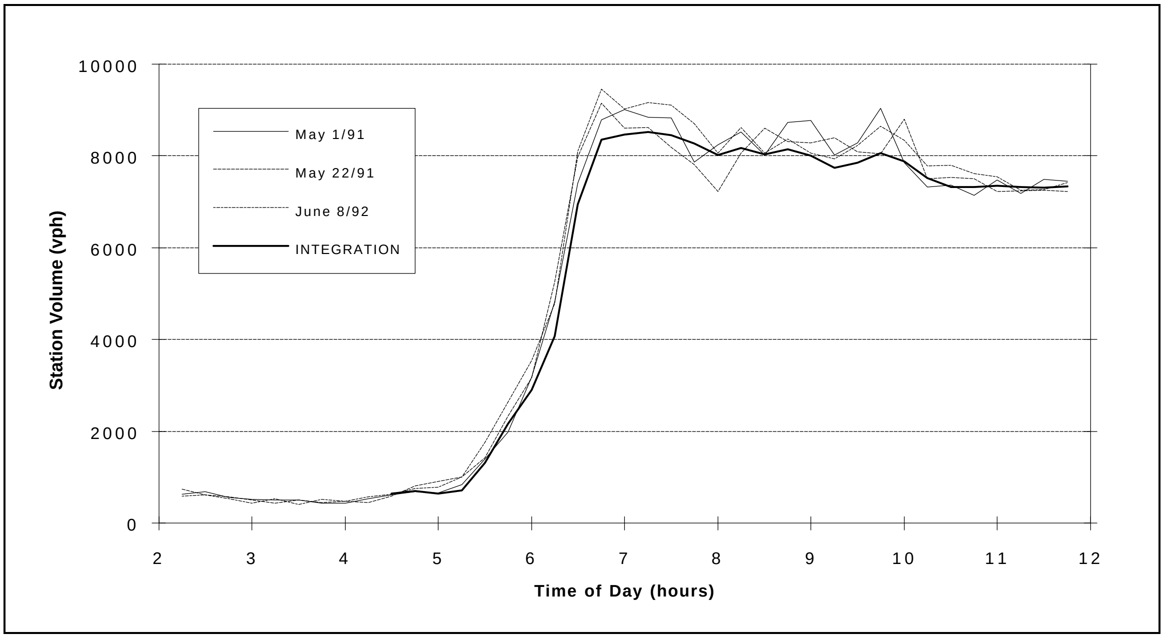

Figure - 7: Estimated and observed aggregated 15 minute link volumes for Eastbound lanes prior to diverge
(Link 8, Station 401DW0010DES)

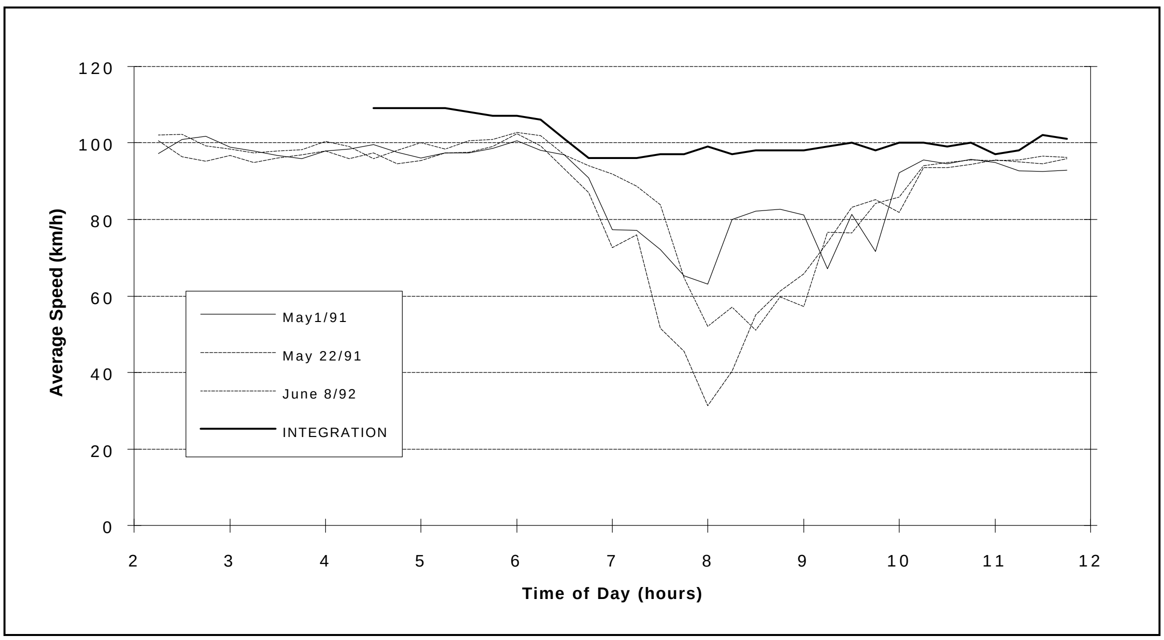

Figure - 8: Estimated and observed aggregated 15 minute link speeds Eastbound lanes prior to diverge
(Link 8, Station 401DW0010DES)

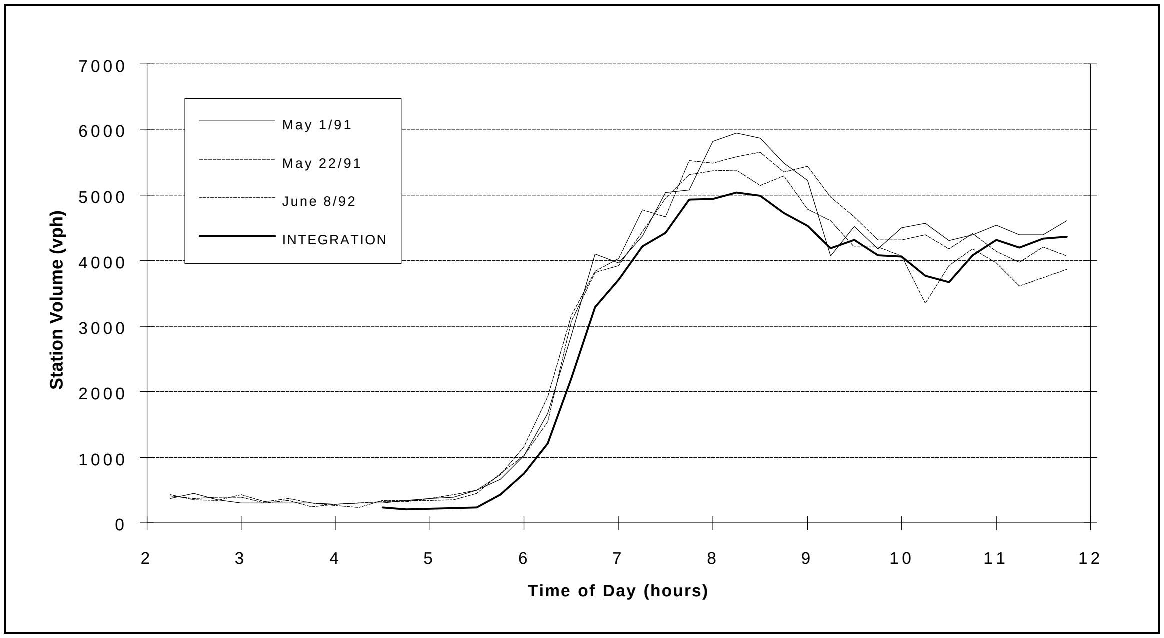

Figure - 9: **Estimated and observed aggregated 15 minute link volumes Eastbound Collector lanes at Avenue Road**
(Link 77, Station 401DE0100DEC)

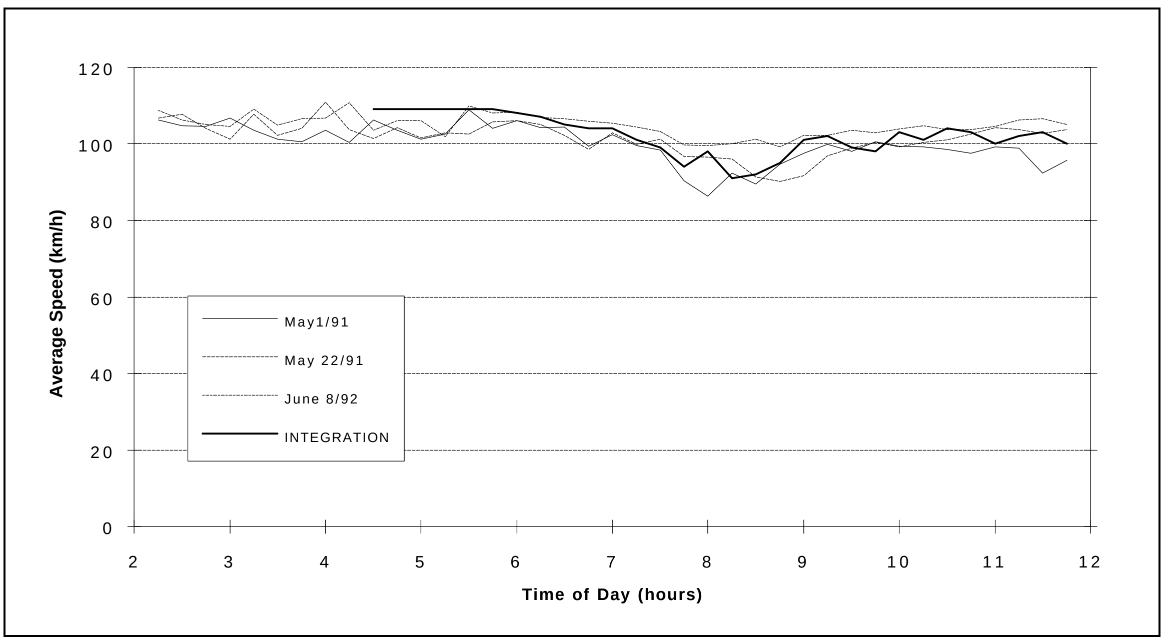

Figure - 10: **Estimated and observed aggregated 15 minute link speeds Eastbound lanes prior to diverge**
(Link 77, Station 401DE0100DEC)

Figure - 11: Aggregated 15 minute FTMS and modelled speed data for Highway 401 eastbound - express lanes
(FTMS data collected on June 8/92)

Figure - 12: Aggregated 15 minute FTMS and modelled speed data for Highway 401 eastbound - collector lanes
(FTMS data collected on June 8/92)

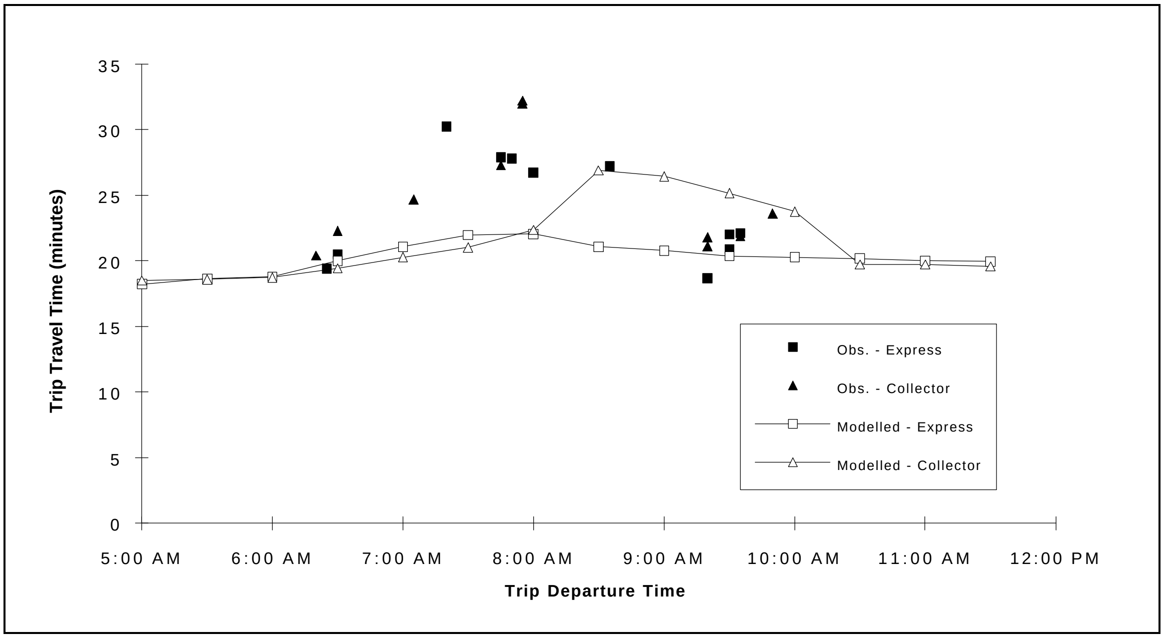

Figure - 13: Estimated and observed eastbound A.M. trip duration by time of departure

Table - 1: Logged incidents for June 8, 1992

#	Start Time	Duration (minutes)	Severity (lanes)	Location	Type
1	2:05 AM	2.5	1	EB express at Allen Rd.	Disabled Veh.
2	7:43 AM	13.5	2	EB Collector at Hwy 400	Accident
3	11:40 AM	11.5	2	EB Collector at Keele St.	Disabled Veh.

Table - 2: Number of links and nodes within the INTEGRATION networks

Nodes/Zones	EB	WB	Links	EB	WB
Origins	43	36	Single	10	13
Destinations	35	37	Express	48	41
Intermediate Nodes	147	140	Collector	57	60
			Ramps	115	105
			Transfer	9	10
Total	225	213	Total	239	229

Table - 3: Truncation effect on recorded station occupancies

Lane Occupancy (%)		Station Occupancy (%)	
True	Recorded	True	Recorded
0.9	0	(0.9+1.9+1.9)/3	(0+1+1)/3
1.9	1	= 1.57	= 0
1.9	1		