Planning and Implementing a Full Closure of the Highway 401 Express Lanes with the help of Micro-simulation

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Paper prepared for presentation at the

"Traffic Operations and Management Initiatives" Session

of the 2005 Annual Conference of the

Transportation Association of Canada

Calgary, Alberta

Abstract

Highway 401, through the Greater Toronto Area, is one of the busiest stretches of expressway in North America, with more than 400,000 vehicles per day. In addition to serving commuting flows across the Greater Toronto Area, Highway 401 serves as the primary corridor for passenger and commercial traffic between Quebec and Windsor and points beyond.

In 2003, the Ministry of Transportation of Ontario (MTO) investigated the possibility of closing the eastbound Highway 401 express lanes, between Kipling Avenue and Jane Street, for two weekends in 2004 to rehabilitate the road base. Such a closure would have previously been considered too risky in terms of the impact on traffic flow. However, the alternative construction schedule would involve approximately 70 overnight closures and an additional cost of $1.5 million. A micro-simulation model (VISSIM) was used to assist in the assessment of traffic impacts and the development of a traffic management strategy to keep traffic moving on the collector lanes through the work-zone area.

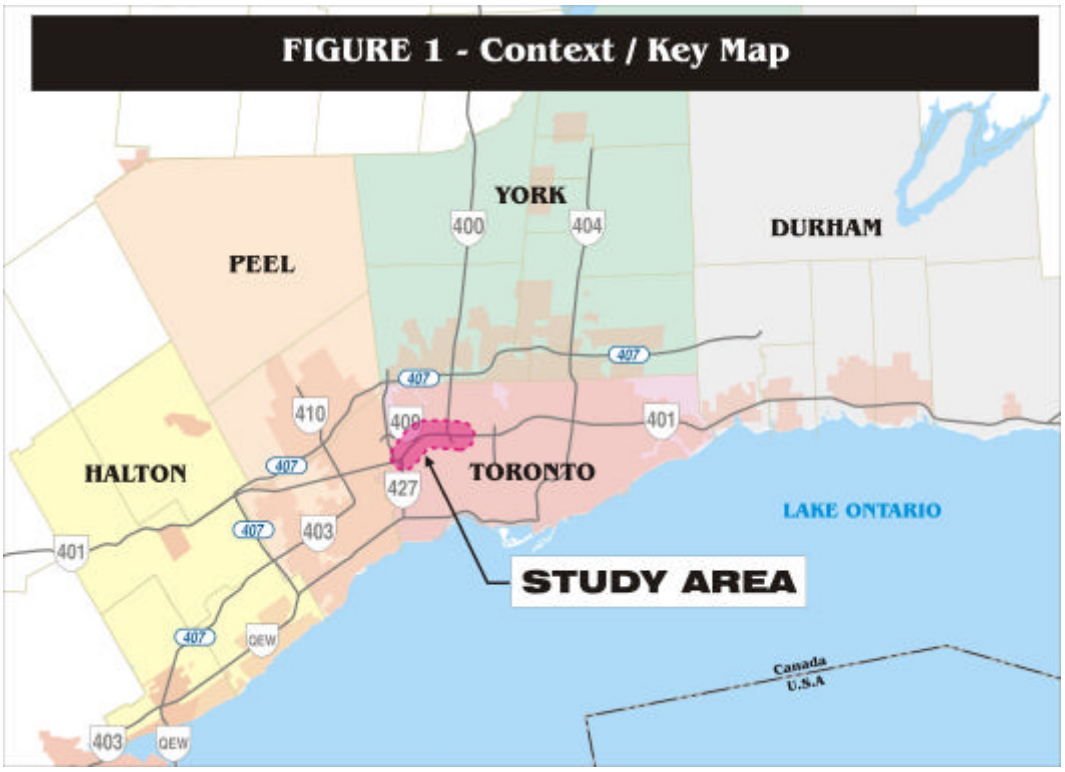
Through micro-simulation, it was demonstrated that the proposed closure was feasible, assuming a combination of a comprehensive public communications plan, selected on and off-ramp closures, an incident management plan, and reduction in traffic levels of 20 to 25% through diversion. Simulated conditions, during peak weekend traffic periods with the closure in place, were projected to be equivalent to or better than typical weekday morning peak-period conditions.

The closure was implemented on the third and fourth weekends of August, 2004. Observed traffic conditions were essentially as predicted, with operation falling in between typical weekend and weekday peak conditions. The projected level of diversion was achieved, traffic was kept moving, and only minor incidents, quickly cleared, were recorded. The construction work was completed on time and met all standards and specifications.

1. *Introduction*

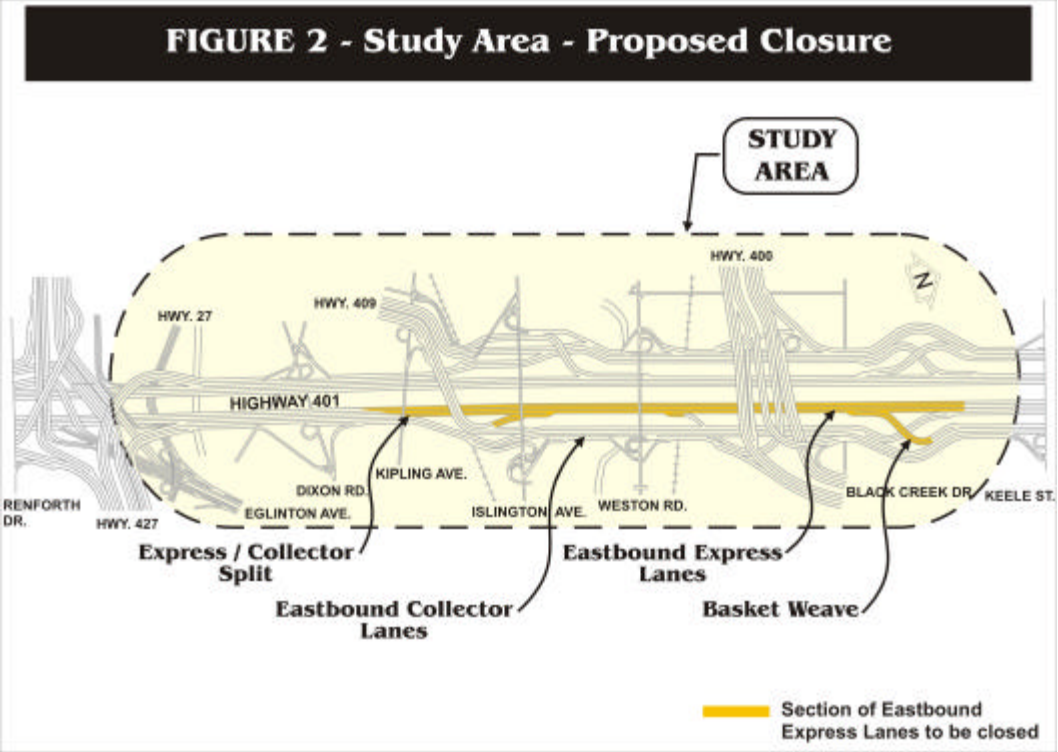
Highway 401, under the jurisdiction of the Province of Ontario, is the primary east-west road connection across southern Ontario, between Quebec and eastern Canada and the border at Windsor, Ontario and Detroit, Michigan. It is also the principal east-west artery tying together the more than 4 million people living in the Greater Toronto Area (see Figure 1). It connects the Greater Toronto Area with Quebec, the Atlantic Provinces, and the central and western states of the United States. The importance of this highway is emphasized by the following facts:

- The peak flow, in the section of Highway 401 through the interchange with Highway 400, is more than 400,000 vehicles per day, making this highway the busiest in Canada and one of the busiest in North America.
- On a daily basis, approximately 20% of the vehicles on Highway 401 through Toronto are commercial vehicles, about 80,000 per day.
- Highway 401 connects Highways 400, 403, 404, 409, 410, 427, the Don Valley Parkway, and many arterial roads within the Greater Toronto Area.
- Highway 401 through much of Toronto consists of an express/collector system with up to 12 traffic lanes plus transfer and speed-change lanes.



The Ministry of Transportation of Ontario (MTO) is engaged in an ongoing program to maintain and rehabilitate this highway, built largely in the 1950's. Managing the maintenance of a major highway such as the 401 while it is in use is a challenging balancing act. Minor closures may be implemented on a 24/7 basis, particularly if additional temporary lanes can be provided, but more significant closures are typically scheduled to occur during the overnight hours, when traffic flows are at their lowest. This increases the cost of construction significantly - not only are labour costs at a premium, but the start-and-stop scheduling and the ability to work for only about five to six hours out of every 24-hour period extends the duration of the work. Notwithstanding the attempt to minimize disruption of traffic by concentrating construction activity in the overnight period, traffic is affected over a protracted period of time.

MTO engineers had identified a pressing need to replace two lanes of concrete road base over a 1.25 kilometre section of the Highway 401 express lanes in the vicinity of Highway 400 (see Figure 2). Normal construction scheduling practice would mean that the work-zone would be closed to traffic each night for almost four months. In an attempt to reduce the duration and cost of this rehabilitation project, the MTO design team decided to investigate the possibility of closing the express lanes for several weekends (Friday evening to Monday morning) during the summer of 2004. Such an undertaking had never been attempted with anything like the current traffic levels on the highway.



The risks involved in implementing a weekend closure of this scale are significant. Unless managed carefully and successfully, such a closure could result in:

- Complete lock-up of both the express and collector lanes which, along with the overflow of traffic onto the arterial road system, would disrupt east-west movement across Toronto as well as north-south movement through the interchanges.
- Major disruption to Greater Toronto Area residents and businesses.
- Significant economic costs associated with delay to both passenger and commercial movement and a likely rash of collisions.
- Public outcry.

On the other side of the coin, the potential benefits included:

- Reduction of the duration of the project by 5 weeks.
- Reduction in the project cost of $1.5 million.
- Elimination of 70 overnight closures that would otherwise be necessary.

This project could also serve as an evaluation testbed for the consideration of similar situations in the future.

This paper describes how the proposed, construction-related closures were analyzed and planned using micro-simulation, the traffic management plan that was developed and implemented, and a comparison of traffic conditions observed during the closure with those predicted beforehand.

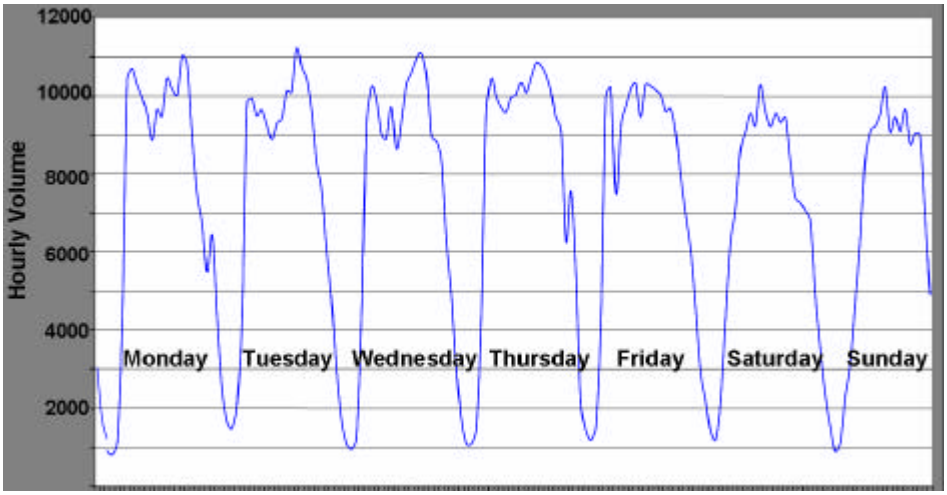
2. Context

The section of Highway 401 for which closure of the eastbound express lanes was contemplated lies between the express/collector split in the vicinity of Kipling Avenue and the basket-weave just west of Keele Street where transfer lanes exchange traffic between the express and collector lanes (see Figure 2). West of this section, there is a discontinuity in the collector lanes extending from the vicinity of Highway 427. To the east the express/collector system is continuous to beyond the boundaries of the City of Toronto. Within this 5-kilometre work-zone, actual construction activity would be concentrated on a 2 lane section over a distance of about 1.25 kilometres. Rehabilitation requirements called for replacement of the concrete road base within this section. However, due to the access-controlled nature of the highway, it was necessary to close all eastbound express lanes between the express/collector split and the basket-weave from Friday evening to Early Monday morning.

Within the 5-kilometre work-zone, there are two interchanges with 400-series highways (Highway 400/Black Creek Drive and Highway 409). There are also two interchanges with arterial roads at Islington Avenue and Weston Road. Evaluation of the traffic impacts of the closure required examination of a larger study area, extended to the west (upstream) to include the interchange at Dixon Road and the ramps from Highway 427, resulting in a study area consisting of about 10 kilometres of Highway 401 (see Figure 2).

Typical eastbound traffic flow on a Saturday afternoon during the summer peaks at approximately 11,700 veh/hr. in the section east of Highway 400. Although Figure 3, is more representative of flows west of Highway 400, it shows quite clearly that peak traffic flow on a Saturday is not significantly less than that during the week.

FIGURE 3 - Daily Traffic Flow Variation on Highway 401 at Weston Road



Examination of the hourly variation in traffic flow for Saturday indicated that the peak period extended from approximately 4 p.m. to 7 p.m. Flow within that period did not vary by much and there was a noticeable reduction either side of this period. In conjunction with the fact that traffic during the proposed closure would be at or close to capacity levels, this suggested that the entire 3-hour peak period should be modelled to enable maximum queue accumulation to be observed.

3. Planning for the Closure and Assessing its Feasibility

3.1 Criteria for Success

The MTO design team established conditions which would have to be met before the proposed closure could be considered acceptable and the decision made to proceed. Inconvenience to the driving public was to be minimized. Overall, it was required that traffic conditions during the closure on the remaining (collector) lanes would be no worse than those typically experienced during the weekday morning rush-hour. To achieve this objective, the following criteria had to be met generally throughout the closure period:

- Traffic had to be kept moving through the work-zone (on the collector lanes).
- Traffic queues upstream of the work-zone had to be contained within the section of Highway 401 between the work-zone and Highway 427.

The rationale for these criteria was based on the desire to ensure that any traffic congestion resulting from the closure did not "stand out" from the congestion experienced by GTA drivers on a day-to-day basis.

3.2 Potential Management Plan Components

It was obvious to the MTO design team that successfully meeting the criteria described in the preceding section would require a comprehensive and integrated management plan. Initial discussions and some preliminary analysis using the INTEGRATION traffic simulation model led to the following list of potential components of this plan:

- A public communications plan, likely incorporating media announcements and on-road signing, both before and during the closure, to promote the use of alternative routes and trip scheduling, potentially reducing the traffic levels that would have to be accommodated through the work-zone.
- A traffic management plan to be implemented during the closure. To promote diversion around the work-zone, the effectiveness of closing selected interchange ramps upstream of and through the work-zone would be considered. Ramp closures would also minimize the disturbance created by traffic entering and leaving the highway, thus maximizing the capacity of the remaining lanes. From the preliminary construction schedule, it appeared that it might be possible to maintain at least part-time use of one of the express lanes to provide the maximum possible accessibility to Highway 400, the primary connection to "cottage country" and other recreational activities in Ontario's "Near North".
- An incident management plan that would facilitate identification of collisions and other incidents in and around the work-zone as quickly as possible and measures to enable rapid response and incident clearing by emergency service resources.

The next step involved a detailed examination of the potential effectiveness of these plan components towards meeting the "criteria for success". Although the proposed closure had been previously modelled using the INTEGRATION simulation package, there remained some question as to the reliability of the results given that traffic demand in the work-zone area was found to be at or above capacity levels. The MTO design team decided to seek confirmation of the results using the VISSIM micro-simulation package. VISSIM is well-suited to operational studies of this nature and scope. The next section details the set-up, validation, and application of the VISSIM model.

3.3 Micro-simulation Analysis and Evaluation

Setting-up the VISSIM Micro-simulation Model

The work-zone, along with several kilometres of Highway 401 eastbound, including connecting on and off-ramps, upstream and downstream of the work-zone was overlaid on a suitably-scaled aerial mosaic of the study area. This procedure avoided the need for detailed measurement and layout of the network elements. On and off-ramps were left simply as stubs - a simplifying assumption that proved to be valid, given that capacity constraints at the ramp terminals were not violated with the traffic levels and patterns modelled. Consequently, only freeway and ramp operations, and not signalized intersections, had to be represented.

To establish the travel demand inputs for the model, a traversal matrix was developed, summarizing the origin-destination patterns for the study area, using the EMME2 travel demand model. A traversal matrix is a sub-area contraction of the regional origin-destination matrix such that the zones outside the sub-area are collapsed to the road links crossing the sub-area boundary. The travel demand pattern used in the EMME2 regional model is based on the Transportation Tomorrow Survey, a comprehensive household interview survey last conducted across the GTA in 2001 in conjunction with the Canadian Census. Although the regional model is necessarily representative of a typical weekday, it was deemed to be adequate as a "seed" matrix since most of the trips for the relevant period on both Saturday and a weekday would likely have a residential destination. A comprehensive set of freeway mainline and ramp counts was compiled from information recorded through MTO's Advanced Traffic Management System (ATMS). Auto traffic counts on the facilities crossing the study area boundary were used as controls for the traversal matrix using a FRATAR approach, to ensure that the trips into and out of the study area matched observed conditions. Separate medium and heavy truck matrices were produced using data from the Cordon Count Program, a biennial classification count undertaken at major screenlines across the GTA.

Validating the Model

Validating and calibrating a micro-simulation model is a challenging exercise and is subject to a number of issues, particularly where the road conditions being modelled are congested as they are in the Highway 401 corridor.

First, observed traffic throughput on a congested roadway may not reflect the demand for travel on that roadway - simply the number of vehicles that were able to get through. To address this issue, the endpoints of the study section of Highway 401 were set at locations on the highway where queuing is less likely to occur. Thus the traffic demand inputs to the VISSIM model were as close to actual demand as possible, and the link flows generated by the model could be meaningfully compared to traffic flows observed "in real life" at the same locations and during the same time periods. This comparison yielded satisfactory consistency across the board, not surprising considering the relatively small size and simplicity of the network.

Second, when traffic demand is near capacity levels, traffic speeds can fluctuate significantly from lane to lane and from minute to minute as "shock waves" travel through the system. Travel time observations from individual timed runs through the study area exhibited significant variability within an envelope bounded above by something close to the free-flow speed of 110 to 120 km/hr. and below by the speed typically found in slowly-moving queues, about 10 to 15 km/hr. If one tracks the speeds of individual vehicles on a congested road within VISSIM, comparable variability is typically found. Taking time averages of these speeds masks this variability. It is therefore necessary to step back and take a more holistic approach to the validation of traffic speeds. Overall patterns in individual and average speed profiles were compared, particularly with respect to free-flow speed and areas of significant speed change, such as at the start and end of queues. Not only did these comparisons show satisfactory consistency, but the simulated speeds compared well with anecdotal evidence (the work-zone is adjacent to MTO's Downsview office complex and is used extensively by MTO staff).

Finally, patterns in the location of start and endpoints of traffic queues were obtained from the VISSIM outputs and compared favourably with both observed travel time and speed data and anecdotal evidence.

With some minor adjustments and successful completion of the above validation tests, the VISSIM micro-simulation model was considered ready for actual application.

Evaluating the Closure

There were two primary objectives in developing the VISSIM micro-simulation model; to address the question of the feasibility of the proposed closure, and to identify and evaluate the required components of the traffic management plan.

Potential traffic management measures were identified and evaluated using VISSIM as follows:

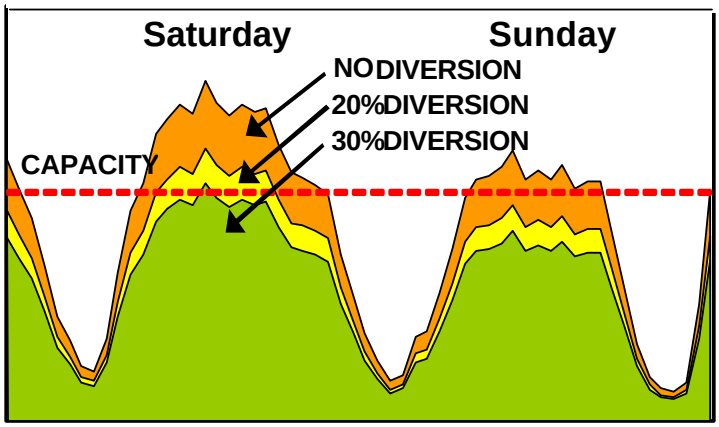
- The most obvious traffic management measure was the closure of on-ramps feeding traffic to Highway 401 within and immediately upstream of the work-zone (at Dixon Road, Islington Avenue, and Weston Road). Closing these ramps could divert up to 3,500 veh/hr. around the work-zone. In addition, the disturbance and associated capacity reduction associated with traffic merging from the on-ramps would be eliminated.

Closure of the Black Creek Drive on-ramp was also investigated but the operational benefits of closing this ramp were out-weighed by the desirability of leaving it open as an alternative route for traffic diverted from the on-ramps that were closed. Closing the on-ramps at Highway 409 and Highway 400 was considered too disruptive and was not evaluated.

- A similar analysis was also conducted with respect to the off-ramps through the work zone. Closing these would also result in diversion around the work-zone. The off-ramp to Dixon Road would be a potential diversion route and its closure was not pursued. The off-ramp to Weston Road serves a significant adjacent retail complex and it was found that the benefit associated with closing this ramp would be out-weighed by the reduction in accessibility to the retail complex. The benefit associated with closing the Black Creek Drive off-ramp was found to be marginal. The off-ramp to Islington Avenue was recommended for closure.
- Based on the proposed construction schedule, it was found to be possible to leave one of the express lanes open to provide additional access on a part-time basis to Highway 400 northbound - ramps feed Highway 400 from both the express and collector lanes. Since the closure would take place in the height of summer and Highway is a key route to Muskoka and other summer recreational areas, this possibility was investigated further and found to offer significant benefit.
- During the course of the evaluation process, it was found that the operational capacity of the remaining collector lanes was influenced to a significant degree by the manner in which the closure was introduced at the entry to the work zone. Consequently, further testing led to optimization of the sequence of lane drops and the organization of the required merges.

Implementing the ramp closures discussed above would result in the diversion to alternate routes of traffic normally using these ramps. A previous analysis, summarized in Figure 4, indicated that between 20% and 30% diversion away from Highway 401 would be required to keep traffic demand below the capacity of Highway 401 during the closure.

FIGURE 4 - Diversion Requirements



Based on select-link analysis for each ramp, undertaken using MTO's EMME2 model, and the simple rules summarized in Table 1 below, the origin-destination matrix used for the evaluation was modified to be consistent with the closures being evaluated. At various locations within the work-zone, it was found that diversion levels based on the ramp closures could be as high as 25%. The increases in traffic on adjacent arterial roads resulting from the ramp closures was estimated to assist the City of Toronto in adjusting traffic signal timing plans to better accommodate the additional traffic.

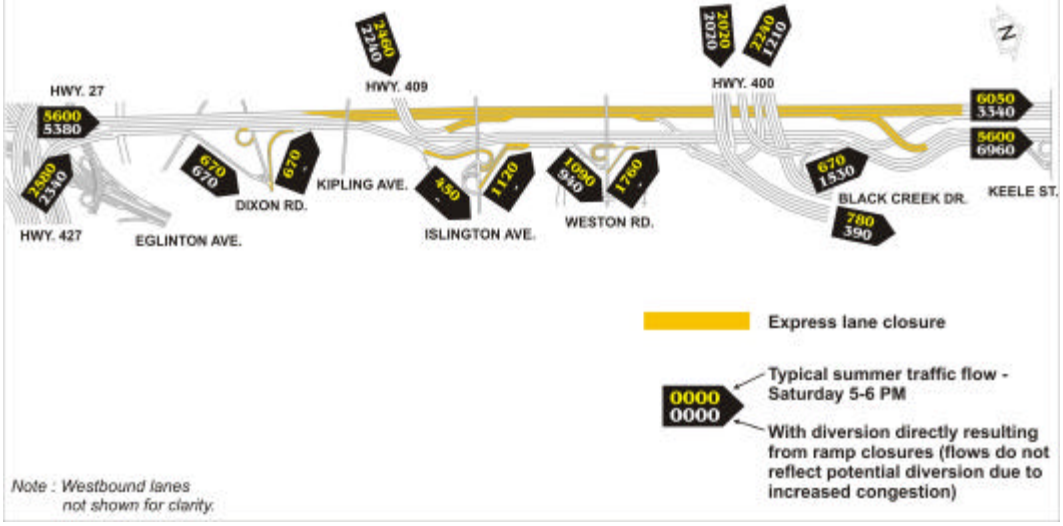
TABLE 1 - Re-routing and Diversion Assumptions applied to Ramp Closures

	For drivers approaching the work-zone on an expressway	For drivers approaching the work-zone on an arterial road
Drivers assumed to know about the closures and plan an alternate route that avoids the work-zone.	80%	50%
Drivers that are unaware of the closures and are forced to react when they encounter the advisory signage.	20%	50%

It was also surmised that congestion through the work-zone area would result in additional diversion to other roads. However, since one of the criteria for success for the closure was to keep traffic moving, it was decided not to assume diversion beyond that caused directly by the ramp closures. It was decided to consider any additional diversion resulting from congestion to be a "safety net" in the event that traffic flows were higher and conditions worse than anticipated during the closure.

Figure 5 shows the baseline Saturday peak-hour traffic flows on Highway 401, together with the estimated flows incorporating the proposed ramp closures.

FIGURE 5 - Traffic Flows - Eastbound Highway 401



3.4 Feasibility of the Closure and the Recommended Management Plan

Feasibility and Potential Risk Associated with the Proposed Closure

The primary conclusion arising from the evaluation discussed in the previous section was that from a technical perspective, there was every indication that the "Criteria for Success" could be met. Micro-simulation of the recommended package of traffic management measures suggested that traffic could be kept moving, that queuing on the highway would not spread beyond Highway 427, and that conditions during the closure would be no worse than conditions during a typical weekday morning rush hour. (See Table 2 below - further discussion is provided in Section 5.)

A risk assessment showed three potentially significant risks associated with the proposed closure:

- The first was the risk that traffic levels through the work-zone would be higher than anticipated due to lower-than-expected diversion away from the work-zone and/or time-shifting of trips. Since expected traffic levels are near or at the capacity limits of the remaining lanes, any appreciable increase in flow would result in major increases in delay and queue extent. The "safety net" in this case lies in the fact that highway operation was evaluated without accounting for the diversion that could be stimulated by congestion or the anticipation of congestion on the part of drivers. As noted previously, only that congestion forced by ramp closures was incorporated in the analysis. The evaluation therefore took a conservative approach.
- The second risk lay in the possibility that diversion to alternative routes would be higher than expected, resulting in the breakdown of key locations on the arterial road system. This was considered unlikely since projected travel times on Highway 401 were projected to be at least as good as those experienced during typical weekday peak periods. Furthermore, weekend drivers would likely be somewhat averse to changing routes since they would be less time-sensitive than commuters, would consist of a higher proportion of out-of-town, and therefore unfamiliar, drivers, would have limited time in which to investigate alternative routes, and may not have paid as much attention to the effect of the closure on what would not likely be a habitual trip. In particular, drivers making longer distance trips on Highway 401 would likely be averse to leaving the highway, only to rejoin it further downstream. To further reduce this risk, consultation was planned with City of Toronto officials to coordinate traffic management initiatives.
- The final risk was that of a total breakdown of the highway resulting from a major incident. The probability of incidents occurring increases in situations with high levels of congestion and variable speeds in stop-and-go driving. To minimize this risk, a comprehensive incident management plan was developed.

A video animation of the micro-simulation results was prepared to show projected highway operation during the closure. This was presented to senior management of the Ministry for approval. They confirmed that the proposed closure and the projected impacts and risks were considered manageable. The value of using video animation to present the case for the closure was evident – it provided a better 'feel' for the projected traffic conditions than the more traditional graphs and tables.

Based on the micro-simulation evaluation, risk assessment, and video animation of projected operations, MTO's senior officials had a higher comfort level with the idea of the proposed closure and could make the decision to proceed with reasonable confidence that this was not a disaster in the making.

TABLE 2 - Key Traffic Parameters Projected for the Proposed Closure

	During the morning rush hour on a typical weekday.	During the peak (Saturday afternoon) period on a typical Saturday (measured for several weekends before the closure).	Projected for the peak (Saturday afternoon) period during the closure.
Eastbound traffic delay between Highway 427 and Keele Street (approaching/ through the work-zone)	**10.0 minutes**	**1.7 minutes**	**7.0 minutes**
Length of queue on Highway 401	**Queue extends beyond Highway 427**	**Only sporadic and short-term queuing**	**Queue projected to extend to Dixon Road (short of Highway 427)**

The following sections describe the final management plan recommended and adopted for implementation during the closure.

Traffic Management Plan

The measures adopted as part of the final traffic management plan were as follows:

- Closure of the Dixon Road, Islington Avenue, and Weston Road on-ramps;
- Closure of the Islington Avenue off-ramp;
- Part-time operation of a single express lane from the express/collector split at Kipling Avenue to the Highway 400 northbound on-ramp;
- Modified layout of lane drops at the express/collector split (upstream end of the work zone;
- Part-time closure, during actual construction, of the Highway 401 on-ramp from Carlingview Road for exclusive use by construction vehicles and concrete delivery trucks; and,
- Consultation with City of Toronto staff concerning complementary traffic management measures on the arterial road system.

Communications Plan

The plan for public communications consisted of the following components:

- Stakeholder outreach, including the City of Toronto, emergency services agencies, and internal stakeholders;
- Notices of closure on the MTO web-site and through press releases and bulletins;
- Media advisories and public service announcements utilizing both radio and television;
- Advance notice signs at least 7 days in advance at key decision points approaching the work-zone on Provincial highways; and
- Extensive signage immediately before and during the closure on both highways and arterial roads affected by closures. These signs also identified alternative routes.

Incident Management Plan

The incident management plan consisted of the following components (see Figure 7):

- Designation of three incident management zones to better organize incident response;
- Pre-stationed police patrols and tow-truck operators at key points through the work-zone to enable rapid response to incidents (collisions, break-downs, etc). These remained in place at all times during the closure.
- Continuous and real-time video monitoring of traffic operations throughout the work zone by the MTO team, facilitating quick identification and confirmation of incidents and dispatching of police and towing assets.

FIGURE 6 - Traffic Management Plan

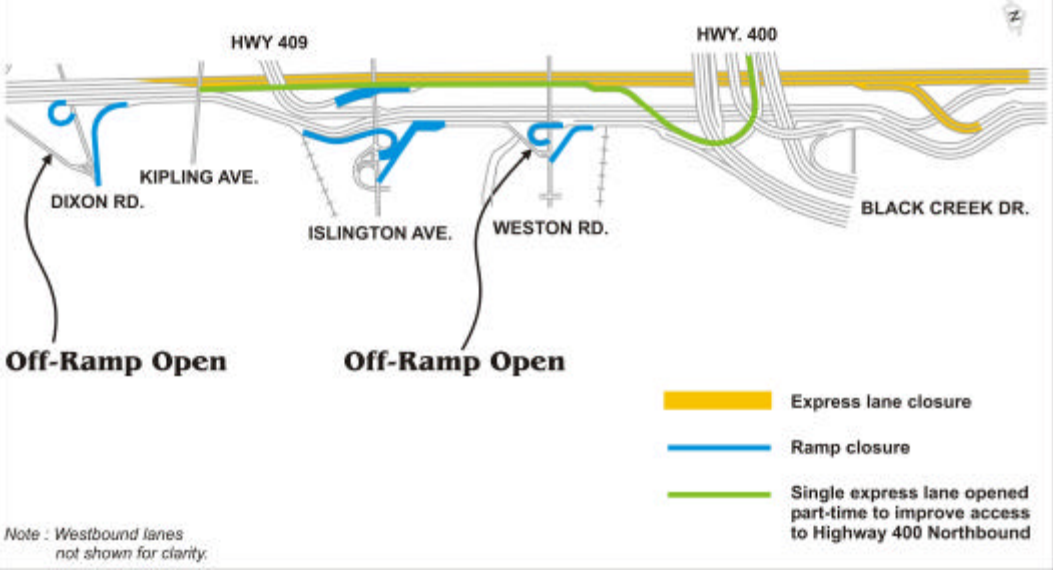
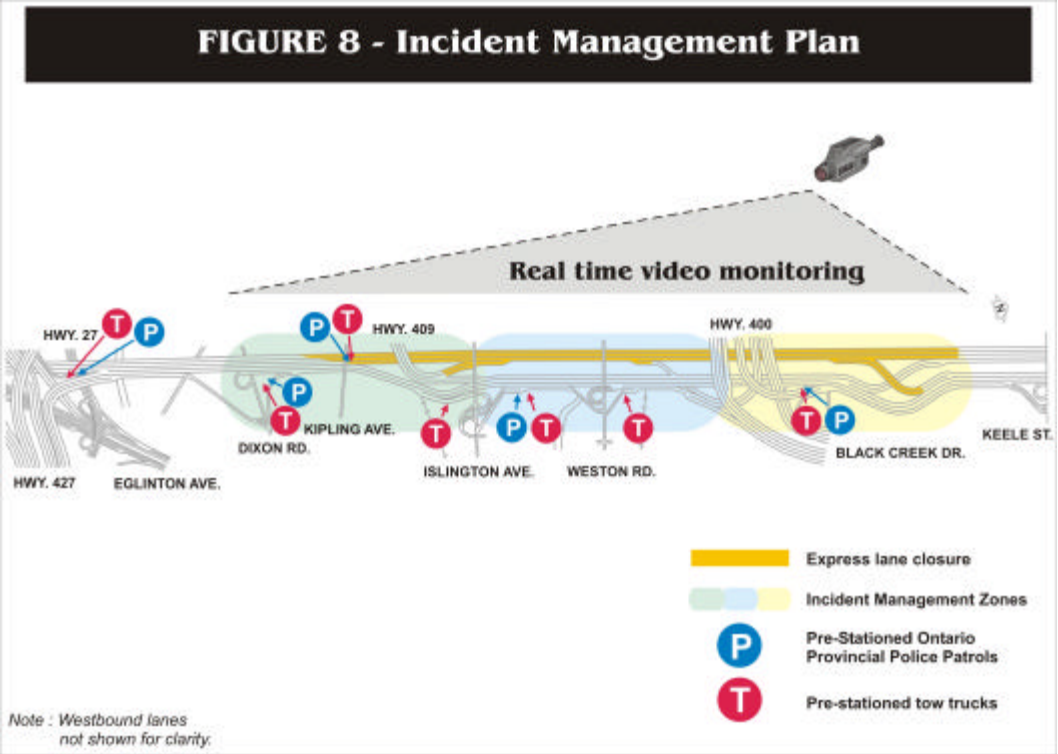


FIGURE 7 - Signing Plan



4. *Implementing and Monitoring the Closure*

4.1 Implementation

Construction

The closure was implemented on two successive weekends – August 21, 22 and August 28,29, 2004.

The objective of this rehabilitation project was to replace almost 10,000 sq.m. of concrete road base and the overlying asphalt. During several overnight closures prior to the weekend closure, the contractors removed the existing asphalt (about 90 mm) and made saw cuts to transform the concrete base (200 mm) into smaller slabs to facilitate its removal.

During the weekend closure, the following tasks were completed for the 1.25 km., 2-lane section:

- Removal of the existing concrete base.
- Removal of 20 to 30 mm. of sub-grade (about 700 tonnes of material) to accommodate the new, thicker (230 mm.) concrete base. The sub-grade was then proof-rolled.
- Placement of Load Transfer Devices (LTD), dowel baskets secured by anchor rods.
- Placement of concrete using a slipform multi-function paver. The 7.3 metre-wide slab was placed in a single pass, complete with tie-bars, 2% cross-fall, and initial finishing. Concrete was supplied to the immediate work area by spreader and by a fleet of open trucks. Since the concrete being used had to be placed within 30 minutes of batching, a nearby (8 km.) concrete plant was utilized. The third express lane, along with the on-ramp from Carlingview Avenue (closed to other traffic), was utilized exclusively for construction vehicles and the trucks bringing concrete to the site, resulting in an average delivery time of 14 minutes.
- Final finishing of the concrete base, including wet-burlap dragging, edge-finishing, and sealing.
- Insertion of relief cuts.

Figure 9 depicts some of the phases of the construction sequence.

FIGURE 9 - Removing and Replacing the Concrete Road Base



Traffic Operations

From a traffic operations perspective, traffic was slow on the first Saturday, August 21, as drivers adapted to the unprecedented closure. Over the three remaining days of the closure (Sunday, August 22, Saturday, August 28, and Sunday, August 29), traffic flow showed improvement as drivers took alternate routes or made their trips at different times of the day.

Some observations made during the closure were as follows:

- Traffic did keep moving through the work-zone area, typically at 40-60 km/hr;
- Queuing on Highway 401 did not often extend beyond Dixon Road. The queuing itself was dynamic in nature with traffic typically in more-or-less constant motion;
- There was a fairly constant queue of about one kilometer in length on Highway 409;
- As might be expected, the area of most noticeable congestion was at the lane drops entering the work-zone at the express/collector split. However, more drivers than expected attempted to use the single express lane kept open on a part-time basis to provide access to northbound Highway 400. Whereas it was anticipated that the primary queue would begin, as usual, in the vicinity of the ramps leading to and from Highway 400, drivers attempting to enter the single express lane resulted in the formation of a dynamic queue at the express/collector split. Eastbound traffic was effectively "metered" at this point, resulting in smoother traffic flow downstream.
- There was no significant congestion on the surface-street system as a result of diverted traffic.

Incident Management

During the four days of the closure, there were only ten minor collisions; no major incidents, injuries, or fatalities. Centralized monitoring by the MTO team of the ATMS video feeds and the ability to instantly notify and coordinate the incident response assets meant that the minor collisions that did occur within the closure area were cleared from the travelled way in only 3 to 5 minutes, thus minimizing the additional strain on the remaining open lanes.

The success of this incident management strategy exceeded the expectations of the MTO design team.

4.2 Monitoring

During the closure, a Ministry team monitored traffic conditions in real time and directed the deployment of the incident management assets. As part of the monitoring plan, they undertook travel time surveys on a more-or-less continuous basis, using global positioning system (GPS) technology. Traffic flows were monitored using ATMS loops and tracking systems.

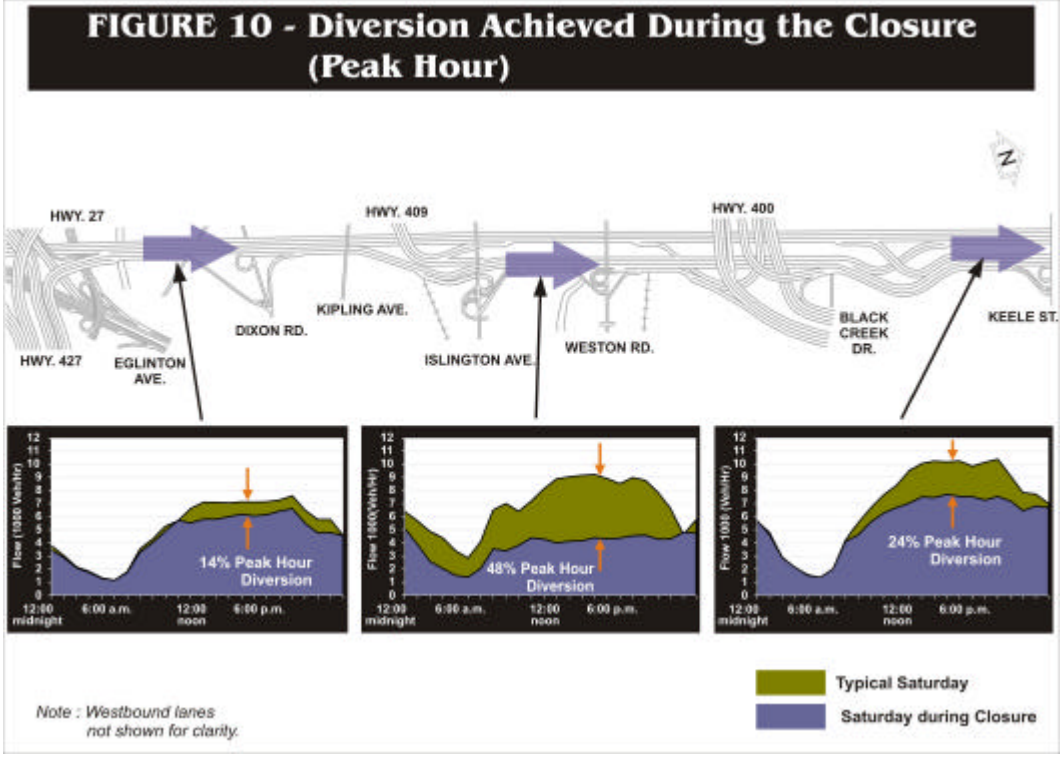
5. Post-evaluation of the Closure

Following the closure, an analysis was undertaken of traffic performance during the closure. Comparison of the observed performance with the "Criteria for Success" and with the performance projected using the VISSIM micro-simulation model is discussed below.

5.1 Traffic Levels and Diversion

In the planning phase, it was concluded that approximately 20 to 25 per cent of all trips normally on Highway 401 through the work-zone would need to be diverted to alternative routes.

The actual diversion achieved, in large part due to the implementation of the communications and traffic management plans, averaged 22 to 26 per cent. It varied throughout the work-zone as shown in Figure 10 below. An actual breakdown of the diversion; that required directly by ramp closures vs. "discretionary" diversion prompted by congestion or even the anticipation of congestion is not possible.



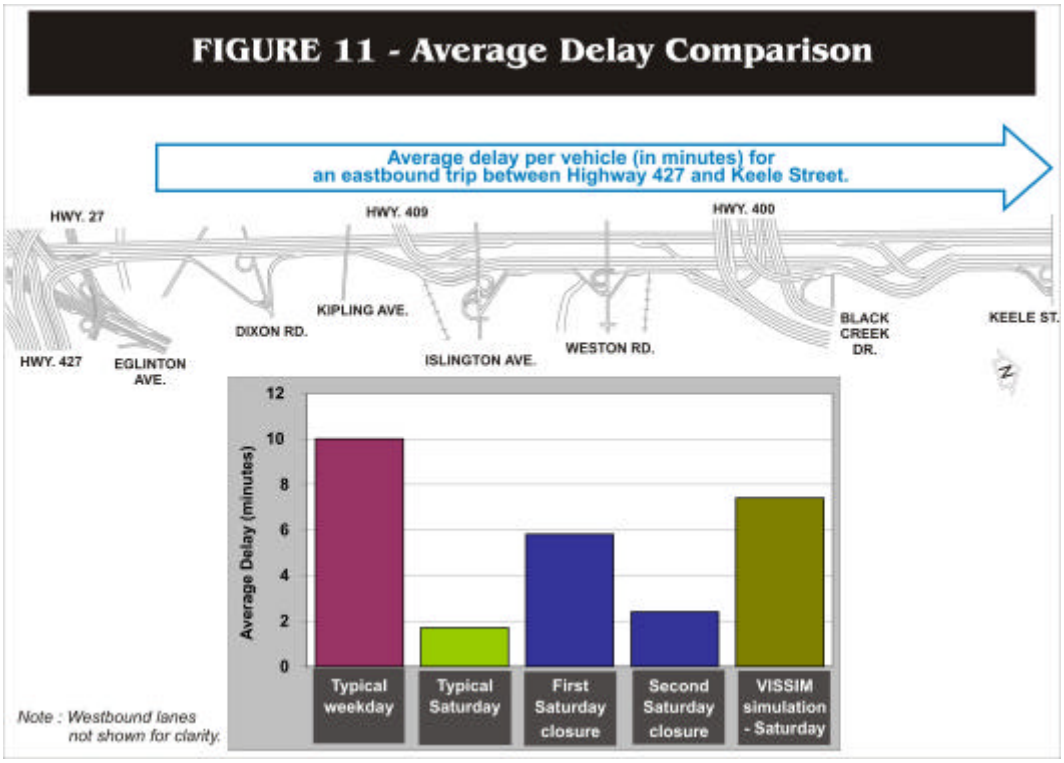
5.2 Traffic Conditions - Verification of the Simulation Results

This project represented a unique opportunity to verify the results of a micro-simulation analysis. Not only was the implementation of the closure only a matter of months after the development of the micro-simulation model and its application to the planning and evaluation process, but comprehensive monitoring of traffic variables was undertaken before and during the closure. The results of the micro-simulation evaluation of the closure were compared with observations of what actually happened - this comparison is provided below.

Delay Comparison

Figure 11 reports delays for Highway 401 approaching and through the closure area (from Highway 427 to the basket-weave west of Keele Street). Delays are compared for a typical weekday, a typical Saturday (before the

closure), and the two Saturdays during the closure. These are compared with simulated travel times for the closure. Travel times are averaged over the morning peak period (6 am to 9 am) for the weekday and over the afternoon peak period (3 pm to 6 pm) for Saturday. This graph shows that the Ministry's objective of achieving traffic operating performance during the closure that was at least as good as that during the weekday morning peak period was satisfied. For travel through the study area (between Highway 427 and Keele Street), an average of 4.1 minutes delay was experienced during the closure (5.8 minutes for the first Saturday and 2.4 minutes for the second), compared to typical weekday morning delays of 10 minutes. In fact, the graph shows that some of the delays observed during the closure were closer to those recorded during a weekend before the closure (1.7 minutes).

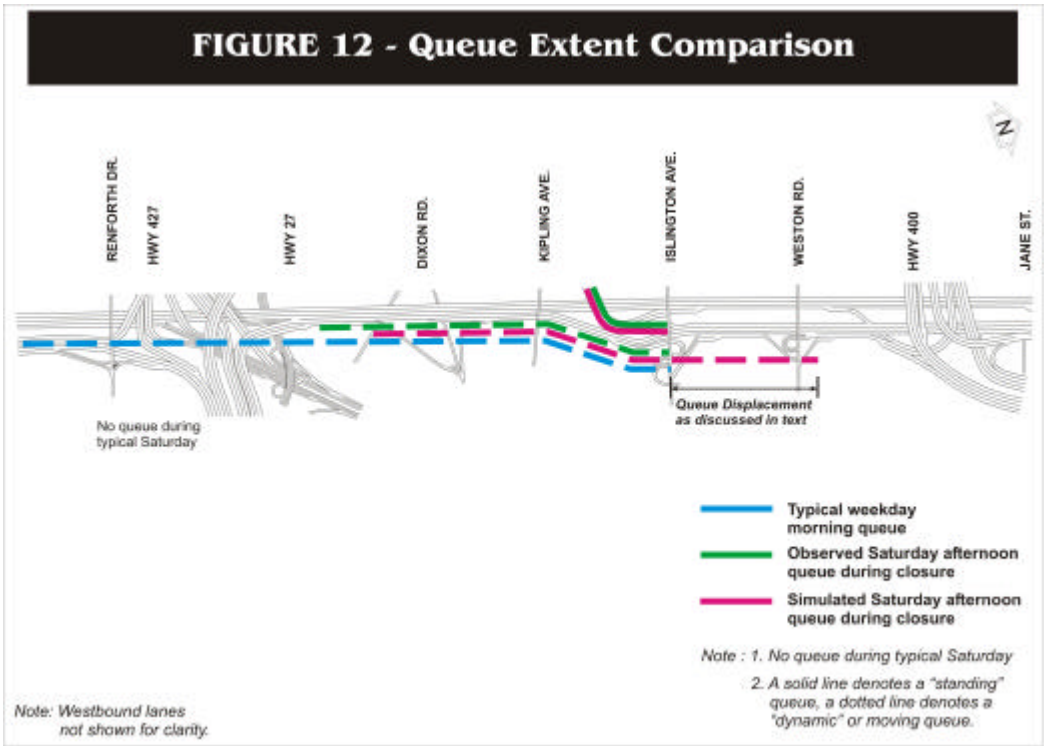


Queue Extent Comparison

Figure 12 shows the queues observed for a typical weekday morning peak period as well as those simulated for the Saturday afternoon peak period and the observed Saturday afternoon queue during the closure. The travel-time survey undertaken on a typical Saturday afternoon before the closure did not indicate any appreciable queue accumulation. It is important to note that neither the queue simulated on Highway 401, nor that experienced during the closure, were standing queues - traffic flowed more-or-less continuously, albeit at relatively slower speeds. In contrast, the queue observed on Highway 409 was essentially a standing queue, characterized by stop-and-go conditions.

The Highway 401 queue, as predicted by the VISSIM simulation, extended essentially from the merge of Highway 400 with Highway 401 back westward to Dixon Road. Recall that the MTO design team desired to have the queue extend no further than Highway 427. Due to congestion at the express/collector split (see discussion in Section 4.1), the observed queue during Saturday afternoon originated between Kipling Avenue and Highway 409 and extended back to a point between Dixon Road and Highway 427. Although the simulated queue and that actually experienced were of similar average length, they occurred in different locations.

In both the simulated and observed situations, the queue on Highway 409 originated near the merge with Highway 401 and extended to the northwest for approximately one kilometre.



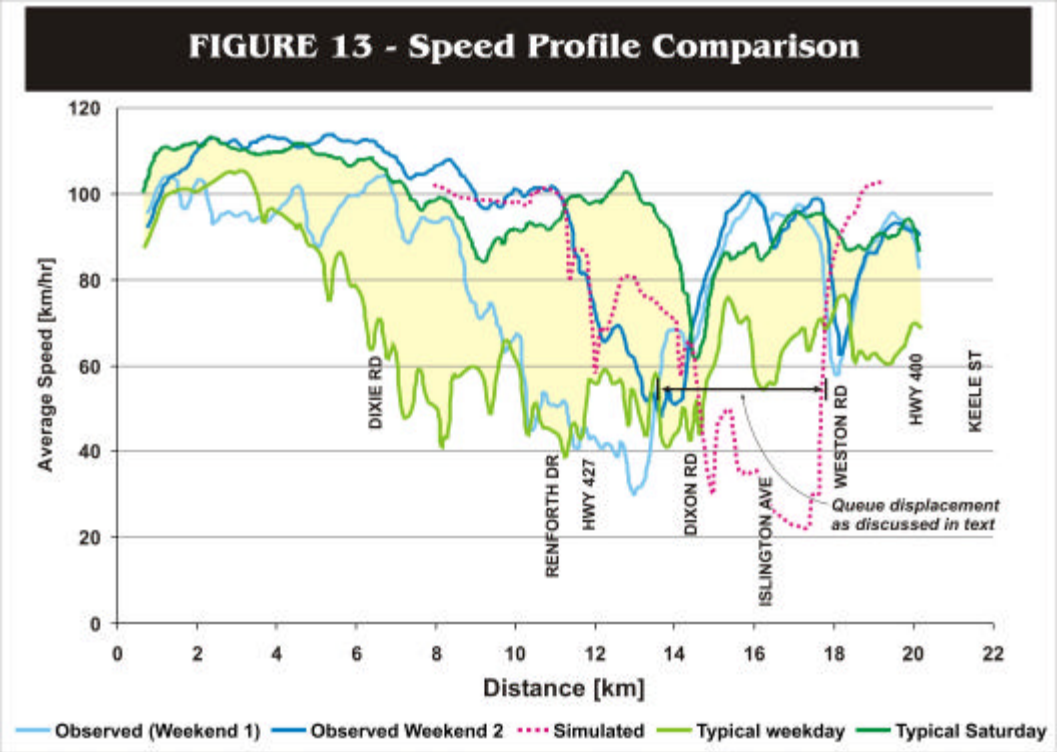
Speed Profile Comparison

Figure 13 compares the relative speed profiles for the observed and simulated conditions, as well as for typical weekday and weekend peak-period conditions. The observed profiles for the two Saturday afternoons when the express lanes were closed generally lie above (higher speed) the profile for a typical weekday morning peak period and, in the case of the second weekend during the closure, the profile approximates that for a typical Saturday.

The simulated profile is very similar in shape to that for the first weekend of the closure except that it is displaced approximately 2 kilometres to the west - this is consistent with the discussion in the previous section.

Visual Comparison

Figure 14 provides several side-by-side comparisons of frames extracted from ATMS video shot at various locations throughout the closure with frames extracted from the VISSIM simulation for approximately the same times and locations. The visual correspondence between the two, best considered in terms of vehicular density, is quite striking, notwithstanding the differences in queue location mentioned previously.



6. *Conclusions*

The successful closure met all planning and design criteria and no complaints were received from the public.

Significant savings in cost and time can be achieved through compression of road maintenance and rehabilitation project schedules. In reconstructing the pavement on a portion of the Highway 401 express lanes, $1.5 million in cost was saved, more than 70 overnight closures (and the consequent prolonged impact on the driving public) were avoided, and the project was completed five weeks earlier than would otherwise have been possible.

Large-scale closures of major facilities are feasible and can be implemented without traffic chaos provided that a comprehensive management strategy is implemented. In the case of this project, the overall strategy consisted of:

- A communications plan, including media coverage, advance signing at key decision points on the road system, and intensive signing around the work-zone to promote diversion of traffic away from the work-zone or to off-peak times of the day. In this case, traffic levels were reduced by about 25% compared to a typical weekend, partly due to the communications plan and partly due to interchange ramp closures..
- A traffic management plan, incorporating selected interchange ramp closures, careful design of the lane drops at the entrance to the work-zone, and part-time retention of a single lane to provide access to Highway 401.
- An incident management plan which included pre-stationing of police and towing assets and real-time video monitoring of the work-zone by the MTO design team to ensure that incidents could be managed quickly and effectively, with little resulting impact on traffic flow.

Micro-simulation is an effective tool for assessing the impact of lane and ramp closures on major roadways and for assessing alternative traffic management strategies. Video animation of simulated conditions during a closure can be a particularly effective input to the decision-making process.

FIGURE 14 - Visual Comparison of Observed vs. Simulated Conditions