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Managing Traffic through Highway Work Zones: Preliminary Findings

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Managing Traffic Through Highway Work Zones: Preliminary Findings

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Abstract

The overall objectives of this research are to (1) define safe, efficient, reliable and cost-effective means for managing traffic in highway work zones, and (2) develop guidelines for the use of intelligent transportation system technologies for managing delay, defining variable speed limits, guiding the lane merging process, and automated enforcement. This phase of the study, carried out during the April 2004-March 2005 period, used as a starting point the construction zone queue-end warning system research of the Principal Investigator, funded by the Highway Infrastructure Innovation Funding Program of the Ministry of Transportation, Ontario. The study methodology consisted of the following steps. (1) For work zones, traffic management issues were identified and requirements for managing traffic were defined. The requirements include real time information display regarding queues, lane merge advice, and variable speed. Also, enforcement issues were studied. (2) Work zone configurations were based on Ontario Traffic Book 7 and ITS technologies were looped-in. Traffic operations were simulated by using a microsimulator (i.e., VISSIM) capable of taking into account driver behaviour regarding vehicle-following and lane changing movements. (3) From the preliminary results of merge options for a two lane per direction freeway section, speed and queuing implications were studied on the basis of simulation results. (4) The concept design of an information system was defined that integrates artificial neural network (ANN) models and intelligent transportation system (ITS) technologies.

CONTENTS

EXECUTIVE SUMMARY

In order to provide the best possible service to road users and to reduce rear-end collisions and other accidents in construction zones, it is necessary to manage traffic by guiding motorists in the use of lanes in the construction zone and informing them about slow moving or stopped vehicles. While static signs do have a role to play, there is a need for an information system that can give real-time messages in order to alert motorists about traffic conditions downstream and to advise them about the merging manoeuvre. Although sensing queue formation at selected locations can be done using traffic sensors, the simple use of sensors to find the location of queue-end on a real time basis could involve the placement of numerous sensors upstream of the construction zone.

The overall objectives of this research are to (1) define safe, efficient, reliable and cost-effective means for managing traffic in highway work zones, and (2) develop guidelines for the use of intelligent transportation system technologies for managing delay, defining variable speed limits, guiding the lane merging process, and automated enforcement. This phase of the study, carried out during the April 2004-March 2005 period, built on the construction zone queue-end warning system research of the Principal Investigator, funded by the Highway Infrastructure Innovation Funding Program of the Ministry of Transportation, Ontario (Khan et al 2004). The study was carried out in an off-line mode using a modelling and simulation approach. The methodology consisted of four steps. (1) For work zones, traffic management issues were identified and potential solutions were defined. These include real time information display regarding queues, lane merge advice, and variable speed limits (if applicable). Also, enforcement issues were studied. (2) Work zone configurations were defined based on Ontario Traffic Book 7 and ITS technologies were looped-in. Traffic operations were simulated using a microsimulator (i.e., VISSIM) capable of taking into account driver behaviour regarding vehicle-following and lane changing movements. (3) From the preliminary results of applicable merge options for a two-lane per direction freeway section, speed, queuing, and other operational performance measures were investigated. (4) The use of an artificial neural network (ANN) model-based information system was investigated for predicting the operational performance of the work zone in terms of queue formation and speed. Requirements were defined for updating the ANN model-based algorithm developed in the previous phase of this research. In addition to predicting queue end, the algorithm will be able to predict operating speed in selected parts of the construction zone. The concept design for the automated construction zone information system based on ITS technology components was updated so as to include merge advice, queue/delay information, and variable speed limit advice (if needed). The information system is based on the use of two sensors, assisted by the algorithm with the capability to predict performance. A portable variable message sign (PVMS) placed upstream provides merge advice, queue-end location and other relevant messages. Research is in progress involving the detailed study of performance implications of merge options, enhancement of ANN models for speed and queue prediction, improvement of the concept design of the information system, and feasibility of implementation in the field.

1.0 INTRODUCTION
1.1 Background

According to Ontario Traffic Manual Book 7, highway work zones, also called construction zones, are defined as the entire section of roadway impacted by construction activity, from the first advance sign through to the last traffic control device where traffic returns to its normal path and conditions. A well-designed work zone can be characterized by six areas as shown in Figure 1. The advance area informs drivers to expect work ahead. The approach area informs drivers what action to take. The transition (also called the taper) area moves traffic out of the normal path. The longitudinal buffer area provides protection for traffic and workers. The work area is intended for workers, equipment and material storage. Finally, the termination area allows traffic to resume normal driving (MTO 2001).

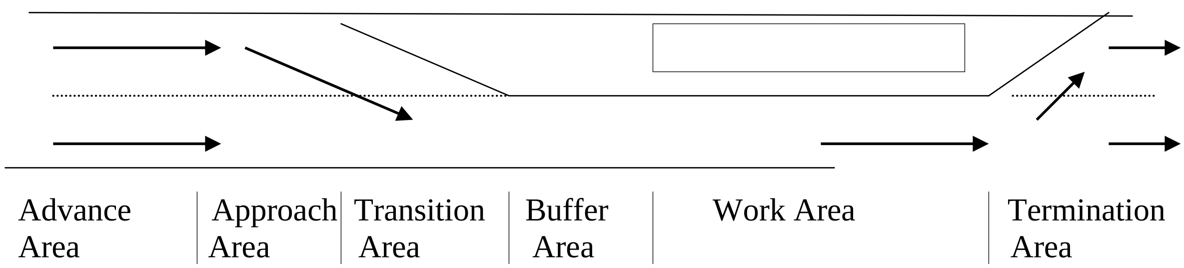

Figure 1: Components Areas of a Temporary Work Zone

Safety and delay problems are frequently experienced in highway construction zones. Due to lane drops or realignment of lanes, queues form during medium and high traffic periods. Accidents occur in the advance and approach areas due to driver inattention and excessive speeding. Accidents in the transition/taper area may be attributed to improper merging manoeuvres (Bushman and Klashinsky 2003). Accidents related to the merge operation occur owing to lack of guidance on the location of merge (e.g., early merge vs. late merge) and driver frustration in the case of queues and delays. In the buffer area, driver inattention, excessive speeding and "following too close" may cause accidents. Studies indicate that, in many instances, in the absence of advanced warning regarding slow moving or stopped vehicles, drivers can be confronted with the unexpected. Given these conditions, it is hardly surprising that a high percentage of work zone-related accidents are classified as rear-end collisions (Texas Transportation Institute 2003). Safety problems could also be encountered in the termination area where construction-related equipment and trucks merge with traffic.

Logically, advanced, real-time, credible warning messages would alert the motorist of traffic conditions downstream. Also, alert messages could be issued about work area-related heavy vehicles. An appropriate response by drivers would considerably reduce the probability of a collision. If drivers are provided with accurate information on traffic queues, perceive the information to be reliable, and take appropriate action in response, safety would be enhanced. According to a 1992 study by Daimler-Benz, even 1 second of additional warning time would go a long way in avoiding rear end crashes (Texas Transportation Institute 2003).

1.2 Research Need

There is a need to investigate the safety and efficiency issues associated with traffic flow in highway construction zones and to develop intelligent transportation system-based solutions to manage traffic and overcome these problems.

2.0 RESEARCH OBJECTIVES AND SCOPE

2.1 Research Objectives

The overall objectives of this research are to:

(1) define safe, efficient, reliable and cost-effective means for managing traffic highway work zones, and
(2) investigate the use of intelligent transportation system technologies for managing delay, the role of variable speed limits, the lane merging process best suited for various traffic conditions, and automated enforcement.

2.2 Scope

Given the diversity of the problems to be solved, a broad view of traffic management was adopted in this research. In this phase of the project, research on queue end warning systems was used as a starting point. Two basic types of system capabilities were considered for addressing the problem of queue detection and informing road users. (1) Display of sensor-detected traffic queues, without the capability of predicting queue formation, queue length and queue dissipation. (2) Assisted by sensors and an algorithm, the capability to (a) predict performance such as speed, queue formation, queue length and queue dissipation, and (b) display of results. Given that the first type of system has limitations and that systems of this type are already on the market, the second type of system was pursued in this research project as a contribution to knowledge. However, innovative applications of the first type of system will be investigated in a later phase of the project.

In terms of research outcomes, the results of the overall study are expected to be useful for updating Book 7 of the Ontario Traffic Manual (MTO 2001).

3.0 METHODOLOGY

3.1 State of Knowledge

In order to address traffic safety and efficiency concerns in construction zones, applications of ITS technologies have been on the rise (McCoy and Pesti 2001; Pearce 2000). The ITS Joint Program Office of the U.S. Federal Highway Administration has published a study on ITS in work zones (2002). Guidelines for the application of portable work zone intelligent transportation systems are described by Fontaine (2003). Based on his review of lessons learned from past experience, Fontaine concluded that more objective research is needed to fully assess the capabilities of these systems in work zone applications.

Some research and development has been carried out on advance warning of stopped or slow moving traffic (Klashinsky and Bushman 2000). Under the sponsorship of the

Strategic Highway Research Program (SHRP), a system known as CHIPS (Computerized Highway Information Processing System) was developed which relies on a queue length detector (Texas Transportation Institute 2003). Ullman and Dudek (2003) have proposed a theoretical approach to predicting traffic queues at short-term construction zones on high volume roads in urban areas. It is based on the interaction between traffic diversion to alternative routes and queue formation. The model is based on a macroscopic fluid-flow analogy of traffic.

Maze and Kamyab (1999) used a microscopic approach to the study of traffic operations at a work zone lane closure site. They were successful in calibrating the model and produced results useful to traffic engineers. However, they did not proceed further in terms of developing a model for predicting queue-end on a real time basis.

While the need for innovation in work zone design and operations is highlighted in the literature (e.g., see FHWA 2003a,b,c; IRD 2003), in-depth studies of traffic management issues have not been carried out. For example, there is a lack of well researched literature on the merits of early versus late merge.

Tudor, Meadors and Plant (2003) provided a literature review of existing research on smart construction zone technology and also described the deployment of such technology in Arkansas. Design developments and effectiveness results for two of the Automated Construction Zone Information Systems (ACIS) were discussed. They compared ADAPTIER (Automated Data Acquisition and Processing of Traffic Information in Real Time) with CHIPS. Both systems consist of hardware, software, and other equipment necessary to collect, process and display traffic condition data to motorists.

The study of existing research and development of ACIS shows that further research is required to overcome the following knowledge gaps. (1) How to fine-tune the design so as to establish the most efficient and cost-effective number of sensors and their placement for work zones of known features? (2) How to improve the algorithm so as to make the best use of sensor data and produce appropriate outputs, the latter of which requires decision-making regarding the most suitable message to be displayed on portable variable message sign (PVMS) and other media? (3) What improvements to the system design would be useful for the development of a new generation ACIS?

3.2 Research Methodology

This study was carried out in an off-line mode using a modelling and simulation approach. The methodological steps are shown in Figure 2. The following sections provide details on implementing the methodology and the results obtained.

4.0 TRAFFIC MANAGEMENT ISSUES AND POTENTIAL SOLUTIONS

Table 1 identifies traffic management issues and defines solutions. Efficiency and safety problems are encountered in highway construction zones. Since construction activities

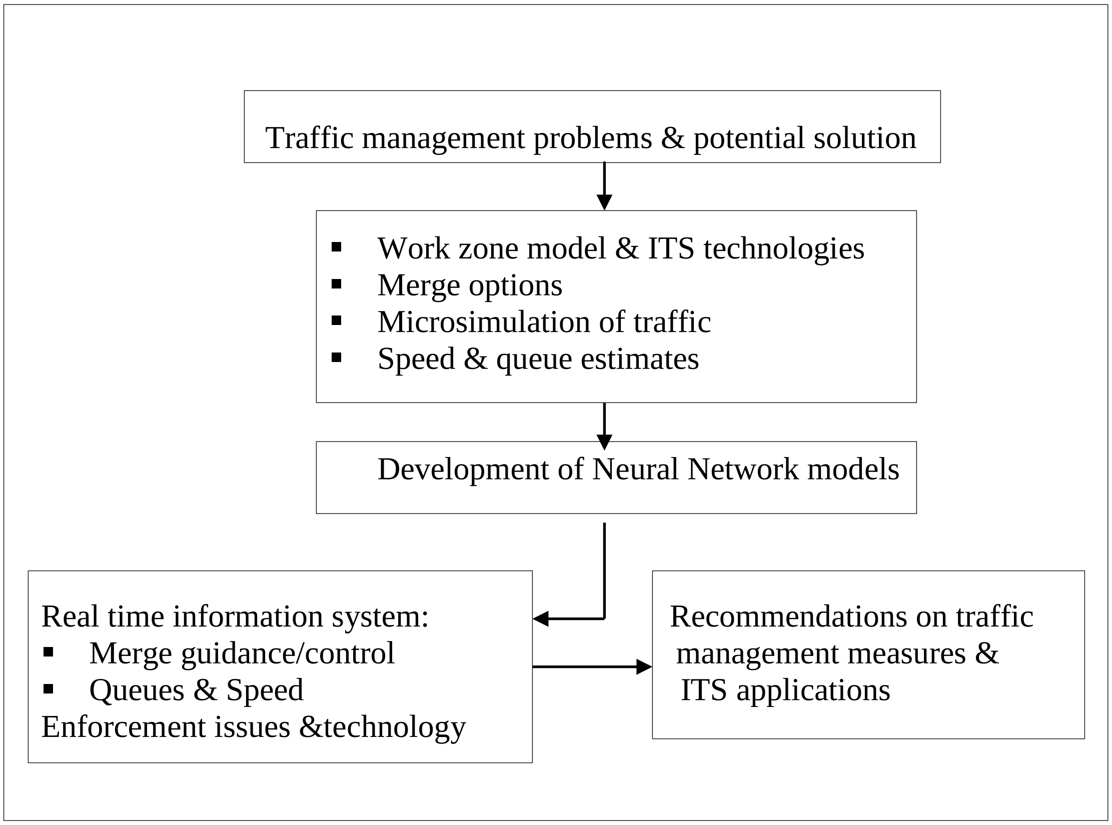

Figure 2: Study Methodology

Table 1 Issues and Potential Solutions

Traffic Management Issues	Potential Solutions
Advance and approach area queues and delays: lack of advance warning, traffic flow breakdown due to lack of guidance on the merge process	Detection of queues and alerting drivers about queues and delays; queue-end real time warning system; merge advice/control; enforcement of "no passing" zone (if applicable).
Advance and approach area accidents: rear-end accidents due to driver inattention, lack of real time information on slow moving or stopped vehicles.	Queue-end real time warning system, dynamic "merge advice/control"; enforcement.
Transition/taper area accidents: side swipe accidents due to aggressive late merge	Dynamic merge advice/control; enforcement
Buffer area accidents: rear-end accidents due to driver inattention, following too close, excessive speed	Variable speed limit; enforcement

take away a part of the roadway, it is a common practice to realign the lanes by paving shoulders and offering narrower lanes. In such cases, the objective is to maintain approximately the same capacity as before the construction activity was initiated. However, closing a lane or lanes may be necessary in temporary work zones for high traffic locations. In such cases, it is inevitable that traffic has to be shifted from closed lane(s) to open lane(s). If the traffic volume exceeds the capacity of the open lane(s), operating speed drops, queues form and delay is encountered. A potential solution to this operational problem is to provide advanced real time information to drivers and guide the merge activity.

It is also a common practice to post static signs that inform drivers of construction ahead and to expect delays. The merge signs indicate the direction of merge (e.g., right lane closed, shift left or squeeze left). Dynamic signs (i.e., portable variable message signs) can be used to provide real time information on guiding the merge activity. However, there is no consensus on the relative efficiency and safety of early merge vis-à-vis late merge under various traffic conditions.

5.0 CONSTRUCTION ZONE CONFIGURATIONS

From the publications of the MTO, field visits of actual sites and information obtained from MTO personnel, construction zone configurations and characteristics were defined. The Ontario Traffic Manual Book 7 (Temporary Conditions) provides geometric features of construction zones (MTO 2001). Chapter J (Miscellaneous) of the Geometric Design Manual is the source of information on maximum posted speeds through the construction zone for highways (MTO 1974).

The following construction zone cases were studied in this research.

- Freeway, 100 km/h posted maximum speed, two lanes/direction, one lane closed.
- Freeway, 100 km/h posted maximum speed, three lanes/direction, one or two lanes closed.

6.0 SIMULATION OF CONSTRUCTION ZONE TRAFFIC

6.1 Microsimulator Calibration

As described in a previous report submitted to the MTO, simulation is a suitable approach to develop solutions to construction zone traffic problems (Khan et al 2004). Highway sections containing a construction zone were coded in a microsimulation software. Construction zone scenarios took into account the number of lanes per direction and whether the inside or outside lane was blocked for construction reasons. The geometric features of the construction zones are in accordance with the Ontario Traffic Manual Book 7, Temporary Conditions (MTO 2001). Other characteristics of construction zones not specified in Book 7 could also be relevant in microsimulation of traffic flow. For example, a construction zone may require that the roadway geometrics be modified temporarily. In the present study, roadway geometrics were assumed to be constant.

Traffic variables that were used in the study include: traffic volume, traffic composition, and speed.

Figure 3 shows the locations of sensors for data capture during microsimulation. Also shown are the ITS technologies required for on-line application of the information and automated enforcement system (if needed).

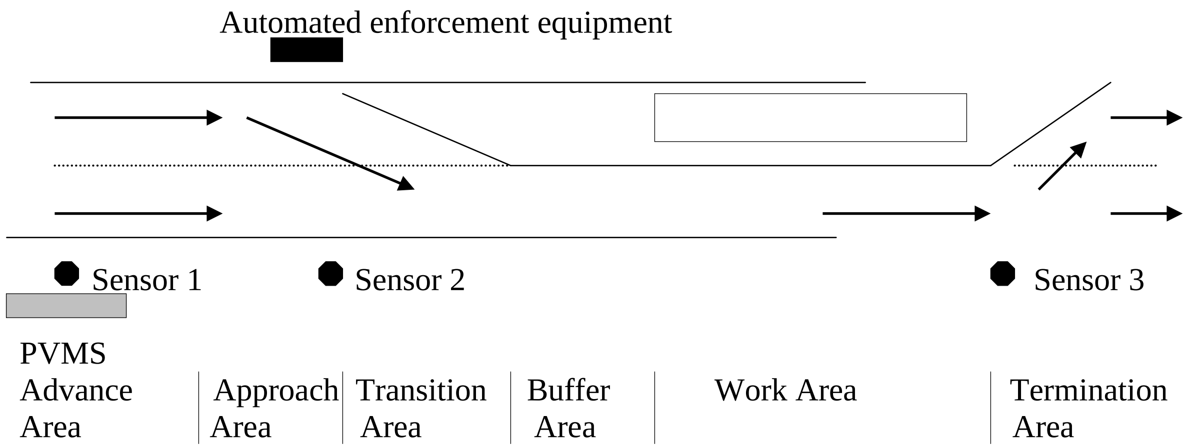

Figure 3: Work Zone Microsimulation with Sensors Looped-in and ITS Installations

Traffic simulation models are well established and are widely accepted tools for assessing the impacts of planned measures such as changes to infrastructure or equipment. For testing the effectiveness of intelligent transportation systems, the use of a microscopic simulation model is necessary.

In this study, a traffic microsimulator, namely VISSIM (developed by the European firm ITC) was used. This software has the capability to model ITS components and strategies, including sensors, variable message signs, incidence diversion, etc. (ITC 2003).

VISSIM is a microscopic, time step and behaviour based simulator. It uses the psycho-physical driver behaviour model developed by Wiedemann to simulate traffic flow by moving "driver-vehicle-units" through a network. It is suitable for simulating traffic flow through a construction zone of specified configuration. Traffic speed and queue formation are obtained for given traffic and other inputs. The traffic inputs include data on traffic volume and the composition of the vehicle fleet using the facility in question (i.e. percent of light-duty vehicles, percent of heavy-duty vehicles).

Probability distributions are used by the software for modelling the stochastic nature of traffic. Likewise, on the basis of the user-specified maximum posted speed(s), the software works with a probability distribution of speeds to simulate speed variability between individual vehicles in the traffic stream.

6.2 Microsimulator Validation

The procedure for validating the microsimulation model was as follows. A large number of microsimulations were carried out using different values for certain key variables (i.e. traffic volume, traffic speed and headways), and the resultant maximum capacity inside the construction zone was quantified for every simulation and compared with its average value described in the literature.

Table 2: VISSIM Validation

- It can be observed that the simulated capacity compares well with HCM (2000) suggested values.

Descriptive Statistics	
Mean	1452.38
Standard Error	6.84
Median	1465.50
Mode	1469.00
Standard Deviation	72.38
Sample Variance	5238.59
Kurtosis	-0.21
Skewness	-0.68
Range	347.50
Minimum	1236.50
Maximum	1584.00
Sum	162666.50
Count	112.00
Confidence Level(95.0%)	13.55

For short term work zones, the Highway Capacity Manual (HCM 2000) suggests a capacity of 1,600 passenger cars/hr/lane for all types of lane closure configurations (TRB 2000). For long term construction zones, the Highway Capacity Manual shows that the capacity is about 1550 vehicles/hr/lane for a two-lane directional section with one-lane closed for construction. For the three-lane case with two lanes open, an average capacity of 1860 vehicles/hr/lane is indicated (TRB 2000). Al-Kaisy et al (2000) reported preliminary results for a three-lane section of freeway with one lane closed during construction. They show an average capacity of about 1940 vehicles/hr/lane. For the case involving a two-lane cross section with one lane closed, the original source material used for the HCM (2000) suggests an average capacity of 1350 vehicle/hr/lane.

Selected results of the VISSIM validation are shown in Table 2. These results show that the simulated capacity compares well with the values shown in the HCM (2000).

In construction zone cases where the number of lanes is maintained (e.g. by paving shoulders or lane width reduction), higher average capacity values are applicable (Transportation Research Board 2000). Such cases are not covered in this study.

7.0 SIMULATION OF MERGING OPTIONS

A preliminary study was carried out to compare merging options for a freeway with two lanes per direction. The purpose of the simulation was to study the effectiveness of different merging options and to identify the best merging option on the basis of the following performance criteria: average speed of vehicles passing a point of interest, delay time, queue length (maximum and average), and number of stop and go movements. Comments on safety are offered later in this section.

The traffic volumes used in the simulation were: 3000 veh/hr (approximate capacity of two lanes under prevailing conditions), 2400 veh/hr, and 960 veh/hr. The traffic composition was held constant at 90% passenger cars and 10% trucks.

The following test scenarios were used: (1) Base case, early notification of lane drop, no advice on merge operation. (2) Late merge. (3) Early merge.

The microsimulator VISSIM was set up to model the test scenarios. Random seeds of 10 and 50 were used. Sensors were located as shown in Figure 3. Queue counters were placed 8 km upstream of the beginning of the taper, and at the beginning of the taper. The section used for monitoring performance (i.e. travel time and other measures) starts 8 km upstream of the beginning of the taper and ends at the end of the construction zone. This distance is used to measure delay. Delay is defined as the difference in travel time under prevailing conditions and that experienced under free flow operation.

The base case is the simulation of merge with early notification. A static warning sign is posted 8 km upstream of the merge location notifying drivers of the work zone ahead. Drivers are informed about the closed lane, but no merge advice is given. The choice of travel lane is not guided by a static or dynamic sign. In the simulator, drivers are cautious about the work zone, but they can move to the open lane at will. However, they will not change lanes just to pass slower moving vehicles. Mean speed results for the base case are shown in Figure 4.

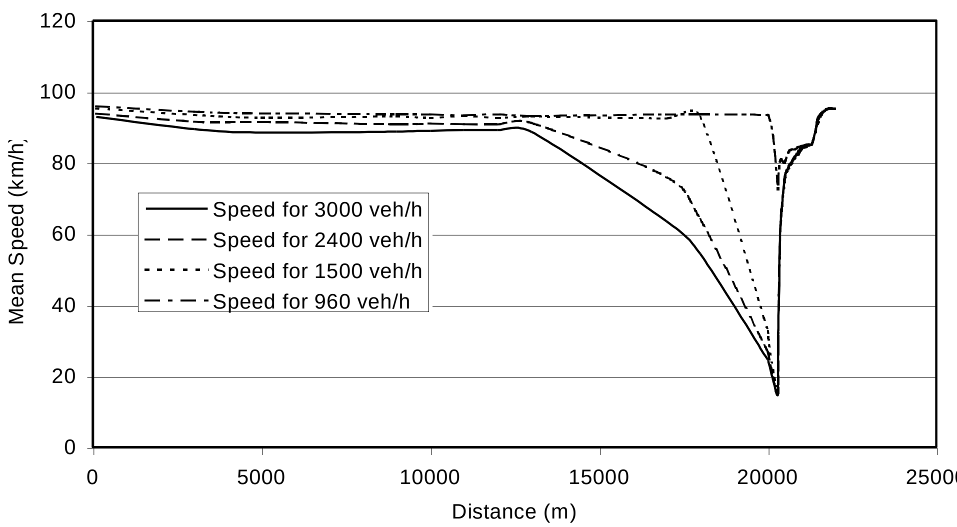

Figure 4: Base Case: Merge with Early Notification

In the late merge scenario, drivers are assumed to stay in their current lane until they reach the taper, regardless of whether their lane will be open or closed through the construction area. Once the taper is reached, merging begins. In the microsimulator, "direction decisions" are placed in both lanes 8 km upstream of the taper. The direction decisions direct traffic to stay in their respective lanes. Mean speed results for the late merge case are presented in Figure 5.

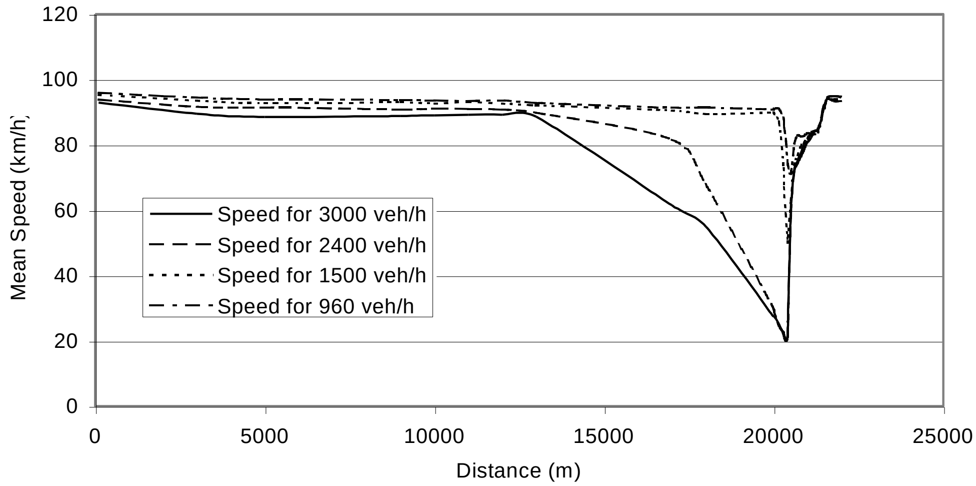

Figure 5: Late Merge Case

In the early merge scenario, advance notice is posted at a selected distance upstream of the lane closure. Drivers are advised to move toward the open lane ahead of the taper (i.e., merge early). In the microsimulator, "direction decisions" are placed in the travel lanes starting 8 km upstream of the taper. The "direction decision" in the open lane instructs vehicles to remain in the open lane, while the "direction decision" in the closed lane instructs vehicles to merge towards the open lane.

To simulate driver behaviour in the microsimulator, "direction decisions" were placed at 100 m intervals. At each decision location, 1.3% of vehicles crossing that point merge towards the open lane. This ensures gradual early merging, similar to what would occur in the real world. At 500 m upstream of the lane closure, higher percentages were applied to direct all residual vehicles to merge. The results of the early merge scenario are presented in Figure 6.

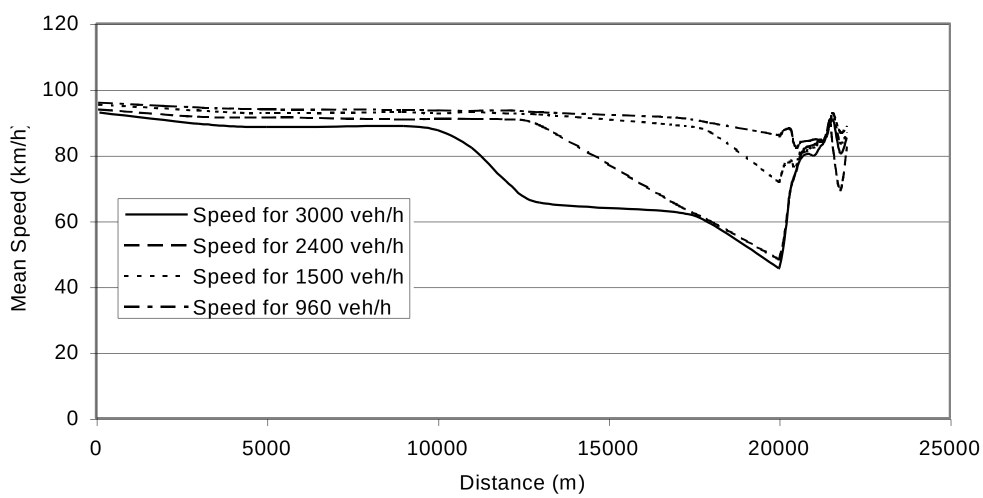

Figure 6: Early Merge Case

A comparative analysis of selected results was made in order to check the relative performance of the construction zone under the three merge scenarios. Table 3 presents average queue length 8 km upstream of the taper and Table 4 shows average queue length at the taper.

Table 3 Average Queue Length 8 km Upstream of the Taper

Scenario	Volume (veh/h)	Average Queue (m)	
		Seed 10	Seed 50
Merge-Notified: Base Case	3000	0	0
	2400	0	0
	1500	0	0
	960	0	0
Late Merge	3000	91	0
	2400	0	0
	1500	0	0
	960	0	0
Static Early Merge	3000	336	282
	2400	0	0
	1500	0	0
	960	0	0

Table 4 Average Queue Length at the Taper

Scenario	Volume (veh/h)	Average Queue (m)	
		Seed 10	Seed 50
Merge-Notified: Base Case	3000	2729	2779
	2400	1706	1693
	1500	368	287
	960	8	0
Late Merge	3000	3004	2357
	2400	2320	1338
	1500	8	8
	960	0	0
Static Early Merge	3000	2	0
	2400	0	2
	1500	0	0
	960	0	0

A number of other measures of effectiveness were studied as well, however, due to space limitations, they are not reported here.

On the basis of the comparative analysis of the preliminary study of merging options, the following observations can be drawn:

- Early merging provides smoother operation due to multiple merging locations as compared with other options.
- From the speed profile diagrams, it was found that the lowest speed in the early merge scenario is always higher than the minimum speed reported for the other types of merges.
- Queues formed under different traffic flow conditions were generally found to be shortest in the early merge scenario.
- Early merging provides lower delay compared to the late merge option.
- The smallest number of stop-and-go movements occurred under the early merge scenario.
- For congested flow, the average speed past the taper was in some cases higher than the average speed at the beginning of the study area. The reason for this behaviour is that drivers found ample space to speed up from a queued or complete stop condition. It

should be noted in this regard that the geometrics of the open lane and lateral clearance were not altered in the simulation. A reduction in lateral clearance or less optimal geometry through the work zone could presumably impact this behaviour in the real world.

A number of comments can also be made regarding the safety implications of various merge options. In low traffic flow conditions with no queues, the base case (i.e., no advice on merging) is applicable and can be regarded as reasonably safe. Under medium traffic flow conditions, minor queue formation is likely to occur. In this situation, the early merge option offers the smoothest operating conditions and is also likely to be safer than the other merging options. Under high traffic flow conditions, queues will form and traffic gaps for merging will not be in abundance. Although, from an operational performance perspective, the early merge option is better than the late merge option, the highly regimented late merge option may be safer.

8.0 ARTIFICIAL NEURAL NETWORK (ANN) MODELS

In the previous phase of this project, ANN models were developed for predicting queue end. The final report submitted to MTO in June 2004 provides details of the ANN model development process (Khan et al 2004). Due to space limitations, the ANN model training and validation are not covered here.

9.0 AUTOMATED CONSTRUCTION ZONE INFORMATION SYSTEM (ACIS)

9.1 The ACIS Architecture

An ACIS can be developed so as to provide information on merge guidance, queue end warning, and variable speed. Of course, only a subset of these items can be displayed to road users. The ACIS configuration, shown in Figure 7, includes (a) Portable sensors located on the roadside, mounted on the PVMS stands or on their own stand, (b) PVMS board, (c) Computer situated in a roadside construction office or mounted on a PVMS stand, (d) Communication links.

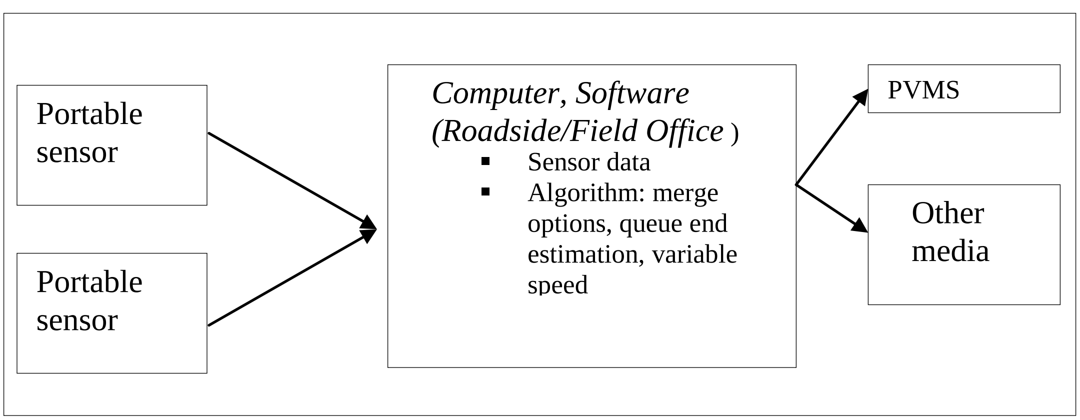

Figure 7: Automated Construction Zone Information System

Notes: (1) The upstream detector is mounted on the PVMS stand. (2) Since no PVMS are used downstream, the downstream detector has its own stand. (3) The arrows show wireless communications. (4) Solar power is assumed for system operation.

According to our design concept, the (RTMS) data are transmitted by wireless (radio) link to a file in the computer. The algorithm uses the input data and produces outputs, which are transmitted by wireless (radio) link to the VMS and other media.

The following are the functional requirements of the system. (1) Real-time operation (2) Credibility (i.e., its ability to effectively capture motorists' attention and promote credibility of signs and messages), (3) Portability, ease of installation, adaptability (to different types of construction zones at different locations). (4) Compatibility with Ontario construction zone protection guidelines, (5) Open architecture (so that it is compatible with any new detector (surveillance) or dissemination tools that may evolve in the future, (6) Information to be available to practically all the traffic (e.g. PVMS, a future Canadian 511/HAR, internet, information kiosks, etc.), (7) Cost-effectiveness (minimum number of sensors used), (8) Use of solar-powered boards and PVMS components with low maintenance requirements, (9) Reliability (no failure, no false alarm, extremely reliable software, extremely reliable hardware), (10) All weather and day/night operation.

As for the type of sensor to be used, according to information provided by EIS Inc. (2003), the Remote Traffic Microwave Sensor (RTMS) appears to have the capability to provide the following data: volume per lane, composition of traffic (i.e. presence of heavy vehicles), and speed. Additional information can also be obtained (e.g. occupancy).

As noted below, the cost of the information system is estimated to be reasonable. The following prices were obtained from industry sources.

- Portable solar powered VMS $30,000
- RTMS X3 with built in digital spread spectrum modem (DSS) (900 MHZ) with Yagi antenna $8,000/unit (two RTMS units will be required)
- DSS master controller modem with antenna (this unit will communicate with the RTMS and computer) $3,850 (two will be required)
- Solar power kit (contains 1-75 W solar panel, 1-voltage regulator, 2-100 AHr deep cycle batteries and enclosure) $2,000 (two will be required).
- Computer $2000
- Trailer for the downstream RTMS unit $13,500
- Total of the above items $73,200

9.2 Software

Software coded in Visual Basic was developed in the previous phase of this research project. In the follow-up phase, the software will be upgraded to include the merge advice/control, no-passing zone information (if applicable), and variable speed information. The functions of the algorithm, as shown in Figure 7, are to (1) process input data obtained from the sensors, (2) activate the ANN model so as to estimate average speed, queue formation, queue length, and queue dissipation, and (3) decide on the message.

10.0 CONCLUSIONS AND RECOMMENDATIONS

(1) The microsimulation approach is effective for the study of construction zone traffic management problems and for generating data for Artificial Neural Network (ANN) models.

(2) On the basis of the preliminary research carried out for a rural freeway with two lanes per direction and one lane closed for construction, the following conclusions can be drawn:

(a) Early notification of construction and lane drops provided in the form of a static sign placed in the approach area results in driver choice of the location of merge. This situation results in queue formation at the transition/taper area under medium and high traffic flow conditions. In low traffic conditions with no queues, the case of "no advice on the location of merge" can be regarded as safe.

(b) In low traffic flow conditions, all merge options result in similar performance. Therefore, there is no need to guide or regulate the merge process.

(c) Under medium traffic flow conditions, minor queue formation is likely to occur in all merge cases. In relative terms, early merging offers the smoothest operating conditions and it is also likely to be safer than other merging options.

(d) Under high traffic flow conditions, queues will form in all merge cases and merging opportunities will be scarce. In this case, the early merge is better than the late merge and "no merge advice" options in terms of operational performance. However, due to the fact that in the late merge option, the vehicles will merge at very low speed near the transition/taper area, the late merge option may be the safest of the three options.

(3) The ANN modelling approach is suitable for simulating traffic operations in a construction zone. The calibration and verification steps were successful and applications of the model produce logical results.

(4) There is a role for ITS technologies to improve the safety and performance of highway construction zones. The automated system developed as part of this research has the capability to estimate queue end location and inform drivers accordingly. Moreover, the capabilities of the system can be extended by adding merge and other information that can be communicated to drivers. The system works well in the off-line mode, and with a small amount of additional development resources, it will be able to serve its intended function in field operations.

(5) The construction zone queue end information system design is cost-effective. It requires a very limited number of traffic sensors and relies upon the ANN-based algorithm to perform its function.

(6) It is recommended that further development work be carried out so that this information system can be tested in the field.

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12.0 PLAN FOR PUBLICATION AND`DISSEMINATION OF RESULTS

The results of this project will form the basis of conference and journal papers.

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