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Managing Traffic through Highway Work Zones: Role of ITS

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Managing Traffic Through Highway Work Zones: Role of ITS

Ata M. Khan (Principal Investigator)

Transportation Research Centre
Department of Civil and Environmental Engineering

Carleton University

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Author(s)	Ata M. Khan
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Ministry Contact	Stephen W. Erwin and Ataur Bacchus, ITS Office, 3rd Floor, Building B, 1201 Wilson Avenue, Downsview, Ontario, M3M 1J8
Abstract	This research investigated the role of intelligent transportation system (ITS) technologies for improving safety of road users as well as workers and for enhancing efficiency of traffic flow in highway work zones. The scope of the project covered methodological innovations and ITS-based concept designs. This research was carried out in a simulation test bed. The study methodology consisted of the following steps. (1) Work zone configuration and characteristics were defined. These were based on Ontario Traffic Book 7 (Temporary Conditions) and geometric design guidelines. (2) Issues of road user and worker safety and road user mobility were defined. (3) Potential solutions based on ITS technologies were identified. (4) For testing ITS-based solutions, a simulation test bed was required. For this purpose, a microsimulator, namely VISSIM, was selected which is capable to taking into account driver behaviour regarding vehicle-following and lane changing movements. Also, this software enables ITS technologies to be looped-in as a part of simulation. The microsimulator was calibrated and validated. Selected work zone configurations were coded in the simulator. Merge options, speed profiles and queueing were investigated by using the simulator. Also, the simulator was applied to generate data for use in the development of models with the capability to predict average speed and queueing of traffic. (5) From simulator-generated data, Artificial Neural Network Models were trained and validated. (6) The concept design of an automated work zone information and traffic management system (AWITMS) was developed which integrates artificial neural network (ANN) models and intelligent transportation system (ITS) technologies. (7) The AWITMS was operated in the simulation test bed. On the basis of the results achieved, conclusions are drawn on the potential of ITS-based methods to enhance safety and mobility in highway work zones. Also, merits of the development and use of simulation test bed for the investigation of the applications of ITS in highway work zones are highlighted.
Key Words	Intelligent transportation systems (ITS), queues, variable speed, merge, construction zone, highway work zone, neural network, simulation, model
Distribution	Unrestricted technical audience.

CONTENTS

EXECUTIVE SUMMARY

The purpose of this multi-year research was to investigate the role of intelligent transportation system (ITS) technologies for improving safety and mobility in highway work zones. The scope of the project was fairly broad. It included the identification of ITS-based measures for traffic management, the development of a simulation test bed so that these measures can be tested in the safe environment of a simulation laboratory, and obtaining results that could form the basis of making recommendations on the role of ITS in highway work zones.

The highway work zone configurations and characteristics were defined on the basis of the Ontario Traffic Book 7 (Temporary Conditions) and geometric design guidelines. From a review of literature and selected interviews, road user and worker safety and road user mobility issues were defined. For addressing these issues, potential solutions based on ITS technologies were identified. In order to develop the capability to study the ITS-based solutions and to generate data for model development, a simulation test bed was required. Given the limitation of macroscopic level methodology, a microsimulator (i.e., VISSIM) was selected which has the capability to take into account driver behaviour regarding vehicle-following and lane changing movements. Also, the design of this software permits ITS technologies to be looped-in as a part of simulation. To ensure realism, the simulator was calibrated and validated.

Selected work zone configurations applicable to Freeways were coded in VISSIM. The simulator was used for a variety of investigations, including merge options, speed profiles, and queueing of traffic. Additionally, from simulator-generated data, Artificial Neural Network (ANN) Models were trained and validated with the capability to predict average speed and traffic queues.

The integration of ANN Models and ITS technologies formed the basis of the concept design of an automated work zone information and traffic management system (AWITMS). The AWITMS was operated in the simulation test bed and on the basis of results and experience gained in this research, conclusions are drawn on the potential of ITS-based methods to enhance safety and mobility in highway work zones. Also, the success of the simulation test bed for the investigation of the applications of ITS in highway work zones is highlighted. It is contended that the outputs of this research are expected to be useful for updating Book 7. Additionally, a preliminary design and operational guidelines for a demonstration study were provided to the MTO Project Officer.

Progress has been made in publishing and dissemination of results. A scientific paper was presented at the ITS World Congress (October 2006 London) and published in proceedings CD. An expanded version of the paper is accepted for publication in the IET ITS Journal (UK). Another paper is accepted for presentation at the 2007 World Conference on Transport Research (Berkeley, California) and publication. Information dissemination in the form of research papers is in accordance with the MTO Guidelines regarding 2006 HIIFP. The papers include the MTO suggested disclaimer and acknowledgement.

1.0 INTRODUCTION

In North America and in many other locations around the world, a high proportion of highways and streets are undergoing reconstruction. In order to avoid severe traffic disruptions and high cost of reconstruction, some lanes are kept open while others are closed to traffic (Figure 1). The Ontario Traffic Manual Book 7 defines a highway work zone (also called construction zone), 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 (MTO, 2001).

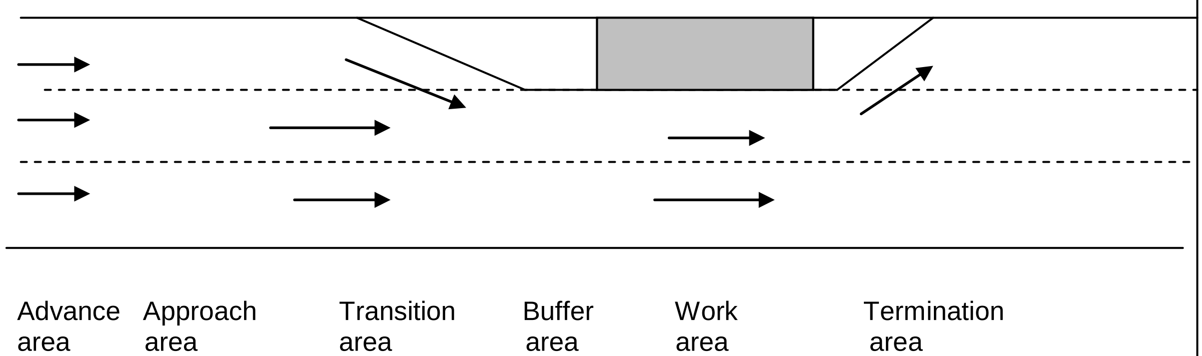

Fig.1. Components of a work zone (Example of three lanes, one closed for construction)

A well-designed work zone consists of the following functional areas (Figure 1). The advance area informs drivers about road work ahead. The approach area advises drivers to take specific action. The transition (also called the taper) area is designed to move traffic out of the closed lane and enables merging movements. The longitudinal buffer area is mainly intended to protect traffic as well as workers. The work area is the site for workers, equipment and material storage. Finally, the termination area returns traffic to the normal travel lanes (MTO, 2001).

Safety and mobility problems are frequently experienced in highway work zones. However, well researched measures supported by intelligent transportation system technologies can potentially reduce the impacts of reconstruction (Khan, 2006). Accidents involving workers may be attributed to driver inattention and operating speeds that are higher than safe speeds in the work zone (TAC, 2005). Traffic accidents involving road users occur at the buffer, taper, and advance parts of work zones. The accidents that occur at the taper zone may be attributed to improper (e.g., aggressive) merging manoeuvres. Buffer and advance area accidents could be due to driver inattention, excessive speeding, and "following too close". In many instances, in the absence of advance warning regarding slow moving or stopped vehicles, there is also the element of surprise (i.e., confronted with the unexpected). Therefore it is hardly surprising that a high percentage of work zone-related accidents are classified as rear-end collisions (TAC, 2005; Texas Transportation Institute, 2003).

Sideswipe-type accidents can potentially occur at the taper part of the work zone due to lack of guidance on the merging manoeuvre. Lane merge areas also experience traffic flow breakdown due to lack of merge control. If speed reduction becomes necessary through the work zone, there is lack of a scientific basis on how to set up variable speeds and how to advise road users by using dynamic signs. Furthermore, there may be a problem of compliance with speed limit in the work zone.

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 regarding the use of lanes in the construction zone and to inform them about slow moving or stopped vehicles. While static signs do have a role to play, there is a need for a system that can give real-time messages in order to alert motorists about traffic conditions downstream and to advise them about the merging manoeuvre and speed limit. Although sensing queue formation at selected locations can be done by 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.

2.0 RESEARCH OBJECTIVES

The objectives of this research are to: (1) define safe and efficient means for managing traffic in highway work zones, and (2) investigate the use of ITS technologies for managing delay, defining variable speed limits, guiding the lane merging process, and automated enforcement.

3.0 RESEARCH METHODOLOGY

The research methodology used for the identification and testing of ITS-based systems intended for work zones is presented in Figure 2. Following an understanding of the work zone safety and mobility issues, potential solutions that require ITS technologies were defined. Although there are safety improvement measures that do not directly relate to traffic, the key solutions are of traffic management in nature. In order to investigate these in a simulation test bed, a microsimulator, was calibrated and validated. Additionally, from data generated by the microsimulator, Artificial Neural Network (ANN) models were developed for use in an automated work zone information and traffic management system (AWITMS). The following construction zone cases were studied for simulation and model development. 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. For merge options and speed investigations, the two lanes/direction configuration was studied.

The main features of the AWITMS were tested in a simulation testbed. Finally, conclusions were drawn based on results obtained from all parts of the methodology.

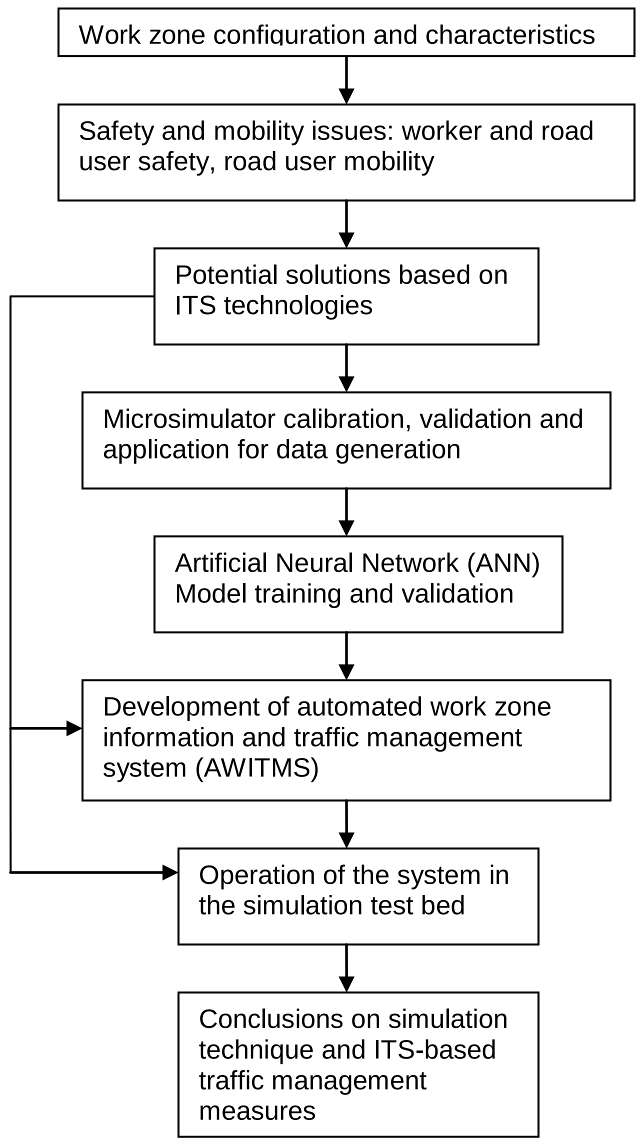

Fig.2. Research methodology

The need for innovations in work zone design and operations, particularly the use of ITS, is highlighted in the literature (FHWA, 2002 and 2004; Scriba, 2005). Table 1 presents potential solutions to problems of worker safety, road user safety and road user mobility. In order to prevent accidents involving workers due to vehicle intrusion in the safe work area, intrusion alarms have been developed and are now undergoing field tests. These are designed to detect vehicles entering the buffer area and warn the workers. Depending upon the speed of the intruding vehicle, a warning time of 4 to 7 seconds may be available. A variety of technologies can be used for vehicle detection (e.g., infrared, microwave, pneumatic tubes) and transmission means include radio and hard-wire systems. The workers are alerted via a loud siren (TAC, 2005; FHWA, 2002).

Table 1. Problems and potential solutions

Traffic-related Problem	*Potential Solutions*
Accident involving workers due to vehicle intrusion in the safe work area	Work zone intrusion alarms
Accidents involving workers attributed to operating speeds that are higher than safe speeds in the work area.	Speed limits and enforcement
Accident involving a slow moving construction vehicle leaving the work area	Dynamic message for alerting traffic
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.
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).
Anxiety and stress caused by uncertainty of time required to travel through the work zone	Prediction of travel time in the work zone and display of information on variable message signs; potential role for cellular phone detection system tracking cellular phones (vehicles), filtering process to identify cell phones in vehicles, compiling travel time.
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
Traffic congestion and delay due to incident	Incident management system for reduction of response and clearance time, reduction in congestion due to secondary crashes and rubbernecking.

Work zone speed limits are desirable for the safety of motorists as well as construction workers. Transportation agencies specify safe operating speeds in work areas and attempts are made to enforce such speed limits. However, ITS technologies can play a role in informing the drivers about the speed limits and also can be used to enforce the speed limit. The automated speed enforcement technology is reliable and can be considered for use in work zones (TAC, 2005). Frequently, slow moving construction vehicles leave the work area and join the traffic in the open lane(s) in the termination part of the work zone. Owing to the high speed differential between the merging construction vehicle and the prevailing traffic, there is a risk of a collision. A system can be designed to detect the exiting vehicle and warn the traffic via real time dynamic message displayed on a portable variable message sign (PVMS). Vehicle detection can be done by such technologies as infrared, microwave or pneumatic tubes and radio or hard-wire systems can be used for communication.

As previously noted, rear-end accidents occur in the advance and approach area due to driver inattention and lack of real time information on slow moving or stopped vehicles. A queue-end real time warning system can help to reduce the risk of accidents. Safety in the taper area can be enhanced by dynamic merge advice/control which will reduce forced merges. Additionally it is likely that the average speed will improve, delay will reduce, and aggressive manoeuvres will decrease.

For multilane sections of a highway, if more than one lane is open, road users can be advised by a dynamic message to merge early. The dynamic early merge advises drivers to move to the open lane and does not allow passing from the closed lane to the open lane beyond the end of queue. That is, a dynamic “no-passing zone” is created based on detected traffic volume and back-up. However, in order to be effective, there is a need to enforce the “no passing” zone.

For work zones on highway sections with two lanes and one closed for reconstruction, in addition to the dynamic early merge option, the dynamic late merge is also an option (McCoy and Pesti, 2005; Mayer, 2004; URS, 2004). This traffic management measure requires that drivers should use both lanes to the merge location and take turns for the use of the open lane. An upstream PVMS displays “traffic backup” and “use both lanes” messages. Next, another PVMS advises drivers to “use both lanes to merge point”. At the taper the message is “take your turn, merge here”.

In order to enhance safety, and reduce queues and delays, an AWITMS can be developed with the capability to inform drivers about the presence of queues, queue-end location, and expectation of delays. Also, this system can be used to provide merge directions and speed advice in order to enhance safety and improve traffic flow. The technology required for building and operating the AWITMS consists of sensors for detecting traffic volume and composition for each lane, PVMS for displaying messages, and communication devices. Additional information is presented in a later section of this report.

The AWITMS can de designed to encompass a travel time estimation module which is a combination of real time information and a model-based on historical database (Minnesota Department of Transportation, 2005). Travellers can use the information for enroute travel planning and choice of alternate route. Microwave radar or other sensors and video image recognition systems can be used to collect traffic volume and speed data. An algorithm can be developed to calculate speed profile and provide travel time estimates. License plate recognition systems can also be used to capture licence plate images and match encrypted information to estimate travel times. PVMS and other media can be used to display the information.

Another potential feature of the AWITMS is a module for providing advice on "speed ahead" A variable speed limit module can provide real-time information on appropriate speed for current conditions based on traffic flow, traffic speed, weather and other inputs. An algorithm will be required to analyze current traffic conditions and estimate optimal/safe speeds. The rationale for using variable speed limit is to add credibility to speed limits, increase compliance, reduce speed variance, improve traffic flow, and enhance safety. Given the continually changing nature of work zones in terms of roadway conditions, variable speed limits can be particularly useful for safety and mobility reasons.

4.0 SIMULATION OF TRAFFIC AND NEURAL NETWORK MODEL DEVELOPMENT

Simulation is a suitable approach to develop solutions to work zone traffic-related problems. Simulation methodology is well established and is widely used for assessing the impacts of planned measures such as changes to infrastructure or equipment. For a detailed study of traffic flow improvement measures based on ITS technologies, coarse macro-level analysis tools are of little use because they do not capture the interaction between individual vehicles. In contrast, the microscopic approach facilitates the analysis of many dynamic traffic phenomena, such as shock waves, gap acceptance, and weaving, which are often difficult to capture under non-steady state conditions using macroscopic planning and analysis tools (Van Aerde & Associates, 2003).

Figure 3 presents the main components of a microsimulator (Khan et al, 2005a). Given their ability to model the car-following, lane-changing and route choice decisions of drivers, microsimulators are well-suited for the analysis of ITS-based improvement options for the work zone (Alexiadis et al, 2004). Microscopic approaches are characterized by a description of individual driver-vehicle units, and are therefore capable of modelling the interaction between vehicles on a second-by-second or even fraction of a second basis.

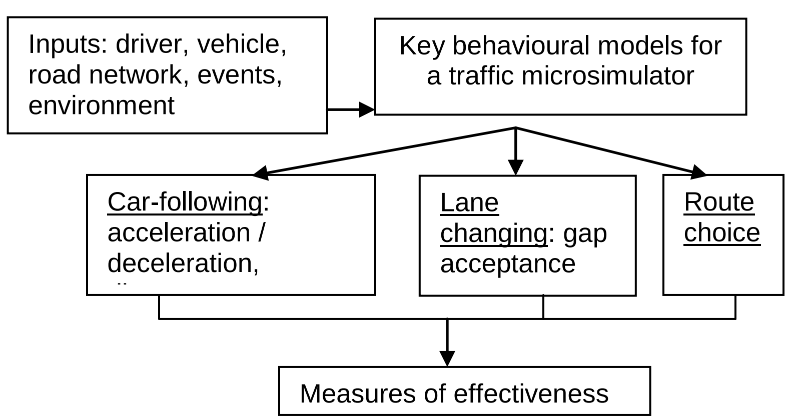

Fig. 3. Major components of a microsimulator
(Source: Khan, et al., 2005a)

The car-following model is supported by the acceleration/deceleration and inter-vehicle distance functions. It determines the acceleration (or deceleration) rate of the following vehicle in a given time interval based on the actions of the lead vehicle(s). Once the acceleration or deceleration rate of the following vehicle is determined, equations of motion are used to compute the speed and the position of the following vehicle. The lane changing model simulates driver decisions regarding gap acceptance and choice of lane. Lane changes can be either discretionary (i.e. to pass a slower moving vehicle) or mandatory. Some simulators also attempt to take driver aggressiveness into account. A driver's level of aggressiveness influences his/her travel speed, acceleration/deceleration rate, and critical gap size when changing lanes (Khan, et al, 2005a).

There are many variables of traffic flow that are random in nature (e.g., time of vehicle entry in the network, vehicle type, driver characteristics). Therefore, microscopic traffic simulation models utilize random numbers, generated from a random number seed, to determine values of variables during a simulation run.

In this study, a traffic microsimulator, namely VISSIM marketed by PTV America Inc. (2005) was used. This software has the capability to model ITS components and strategies, including sensors, variable message signs, incidence diversion, etc. VISSIM is a time step and behaviour based simulator. It uses a psycho-physical driver behaviour model to simulate traffic flow by moving "driver-vehicle-units" through a network. It is suitable for simulating traffic flow through a work 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) (PTV America, 2005).

The shock wave caused by the lane change and other actions of drivers and its propagation upstream are to be studied under different traffic conditions. The microsimulation of traffic flow generates data which can be used for the prediction of queues and queue-end location. A large number of microsimulations are to be carried out by using different values of the variables.

To prepare a microscopic simulator, the analyst must enter the required input data into the software system and code the transportation network files. After the model has been developed, selected parameters are adjusted to fine-tune the model so that the simulated traffic conditions provide an acceptable representation of the real world traffic flow. Following this calibration step, it is validated with an independent set of data. For the calibration and validation of the microsimulator, observed traffic flow distributions were used. The free flow speed used in the simulator was 110 km/h for freeway, which is consistent with the characteristics of the modelled facility.

4.1 Microsimulator calibration

Accurate estimates of traffic volumes and capacity of highway work zones are critical for obtaining reliable predictions of performance measures such as queue lengths, average speed, and stop-and–go movements. In VISSIM, the traffic capacity of freeway segments during simulated incident-free conditions depends primarily on the car-following sensitivity factor parameters. Therefore, the purpose of the calibration process was to find the most adequate parameter values that accurately reproduce the traffic volumes on a freeway.

A section of Highway 417 in the Ottawa (Ontario) region was used for model calibration purposes. The most relevant model parameter, namely headway time, was systematically varied so as to obtain a good match with actual traffic volume. The calibrated model was able to produce known traffic volume at the 95% level of confidence. In order to work with an alternate set of calibration factors, the VISSIM calibration parameters proposed by Park and Qi (2004) were used. This resulted in a second simulation model of the work zone with two lanes and one lane closed for reconstruction.

4.2 Microsimulator validation

The procedure for validating the microsimulation model was as follows. A large number of runs were carried out using different values for key variables (i.e. traffic volume, traffic speed and headways), and the resultant capacity inside the work zone was quantified. The capacity result obtained from simulation study was compared with the value found by field studies reported in the literature.

For short term work zones, the Highway Capacity Manual (HCM 2000) suggests a capacity of 1,600 passenger cars/h/lane for all types of lane closure configurations. For long term work zones, the Highway Capacity Manual shows that the capacity is about 1550 vehicles/h/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/h/lane is indicated (Transportation Research Board, 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/h/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 vehicles/h/lane.

Selected results of the VISSIM validation are presented in Table 2. These show that the simulated capacity compares well with the values shown in the HCM (2000). In work zones where the number of lanes is maintained (e.g. by paving shoulders or lane width reduction), higher overall capacity values are applicable (Transportation Research Board, 2000). However, such cases are not covered in this study.

Table 2. VISSIM validation

Selected Descriptive Statistics (in terms of veh/h/lane)			
Mean	1452.38	Standard Error	6.84
Median	1465.50	Mode	1469.00
Standard Deviation	72.38	Range	347.50
Minimum	1236.50	Maximum	1584.00

Source: Khan, 2006

4.3 Simulation of merge options

For a work zone with two lanes/direction and one lane closed, dynamic merge options were studied against a base case in which notification of lane closure was provided by a static sign (i.e., without merge directions). Simulations were carried out by using the following traffic volumes: 3000 veh/h (approximate capacity of two lanes under prevailing conditions), 2400 veh/h, and 960 veh/h. The traffic composition was held constant at 90% passenger cars and 10% trucks. 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. As expected, speed drops at the taper area.

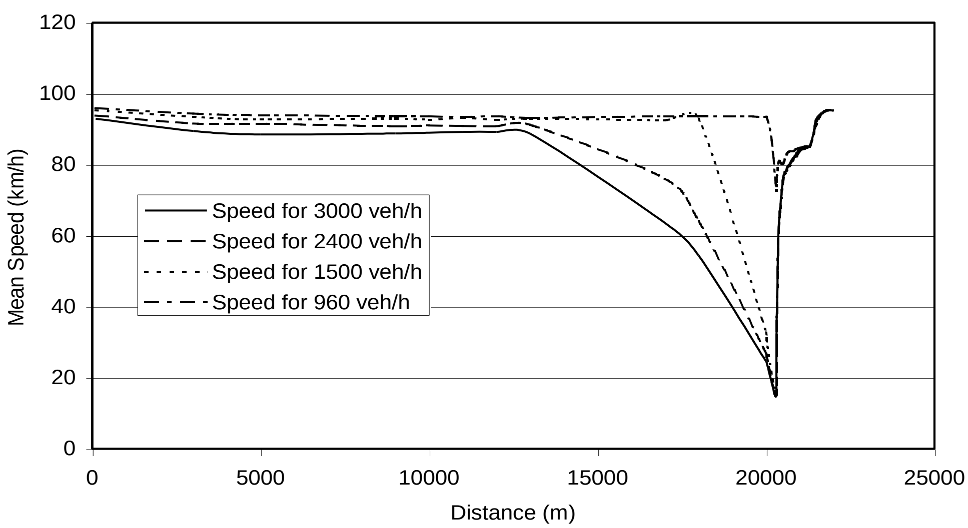

Figure 4: Base case merge option
(Khan at al, 2005b)

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

In the early merge scenario, advance notice is posted at 8 kms distance upstream of the lane closure and drivers are advised to move toward the open lane ahead of the taper (i.e., merge early). In the microsimulator, "direction decision" in the open lane instructs drivers to remain in the open lane, while the "direction decision" in the closed lane instructs drivers to merge towards the open lane. To simulate driver behaviour in the microsimulator, these "direction decisions" were placed at 100m intervals. The results of the early merge scenario are presented in Figure 6. Since merging takes place over a considerable distance, the drop in average speed at the taper is not well pronounced.

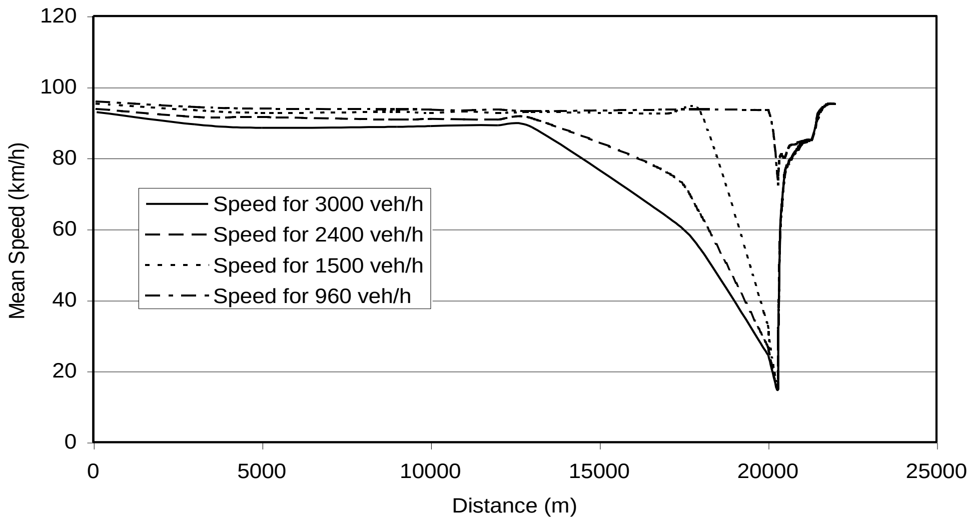

Fig. 5. Late merge case
(Khan et al, 2005b)

An examination of simulation results presented in Figures 4 to 6 shows that dynamic merge options offer better quality of service than the base case. According to the literature, some transportation agencies in the U.S.A. apply the early merge option for medium traffic conditions and use the late merge option for traffic volumes at and above the prevailing capacity of the open lane. In this research simulations of the two types of dynamic merge were carried out during a simulated time period (i.e., dynamic early merge and dynamic late merge were used). The simulation was repeated for the base case in which no merge direction was provided. Figure 7 shows a comparison of the number of stop-and-go movements that occurred under the base case scenario and dynamic merge scenario. It can be observed that under identical traffic conditions, the simulated dynamic merge provides improved service and is likely to be safer than the base case scenario.

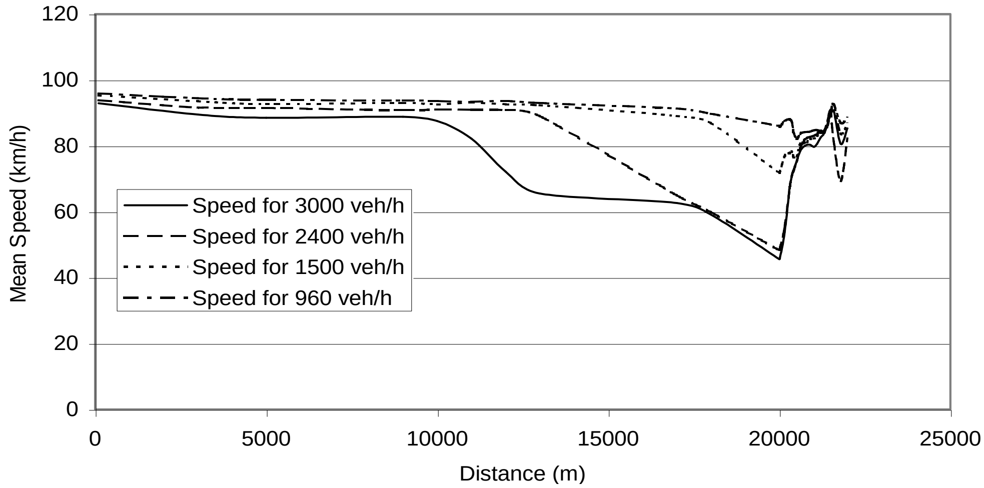

Fig. 6. Early merge case
(Khan et al, 2005b)

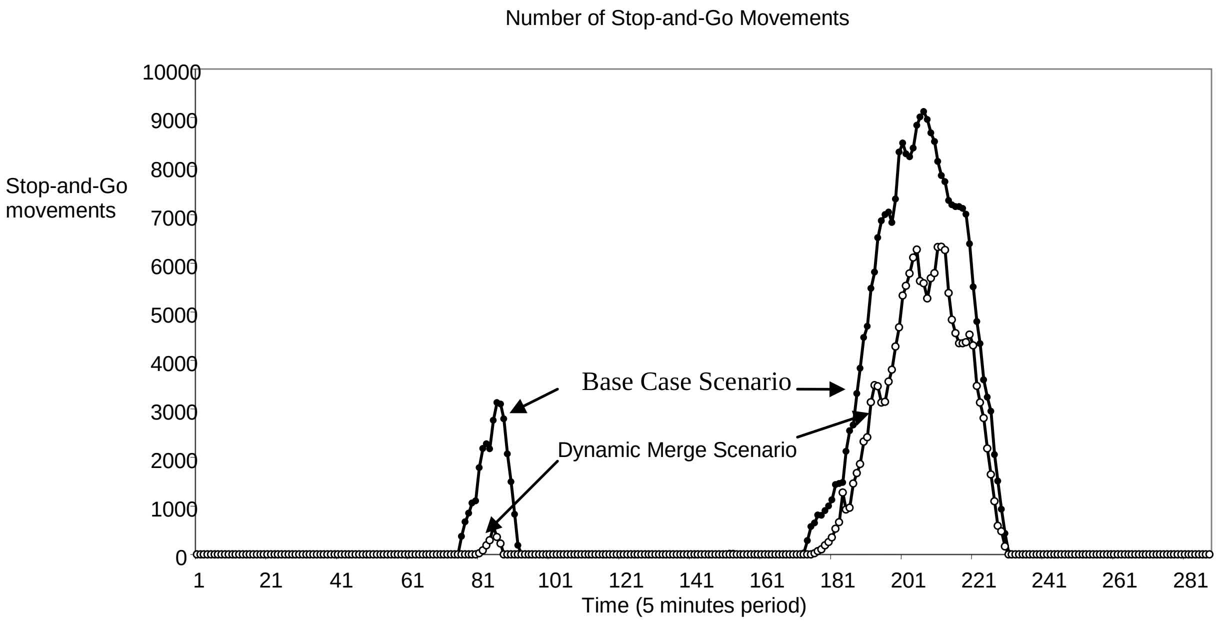

Fig. 7. Comparison of dynamic merge and base case scenarios

4.4 Artificial Neural Network (ANN) models for queue length and average speed prediction

Data were generated by the microsimulator with the intent to use these for developing queue prediction models. Highway sections containing work zones were coded in VISSIM. The work zone scenarios took into account the number of lanes per direction and whether the inside or outside lane(s) was blocked for reconstruction reasons. Traffic variables that were included in the study are vehicular traffic volume, traffic composition (i.e., percentages of light vehicles and heavy vehicles), and speed. Traffic sensors were looped-in the simulator in the advance and termination areas and a queue counter was placed at the outset of the taper area. The simulated traffic sensors generate data on the rate of flow of various vehicle types and speed of vehicles. The queue counter is intended to record the number of vehicles in moving or stopped queues. Queues are detected (by noting stopped or slow moving vehicles) through simulated detector action in the software.

Also, data were generated for the development of models of speed prediction models. For the two lane section of the highway, a total of five sensors were loped-in at 3 locations in the simulated work zone. The first two sensors were placed at 8 kms upstream of the taper in both the closed and the open lanes. These as a group collect the number of vehicles entering the work zone site. Another two sensors were placed at the taper for collecting the mean speed readings. Another sensor was placed in the open lane of the construction area to measure the mean speed of the traffic stream. Two sets of data were generated. For training data, the simulator was run with one seed designation and for the validation data the simulator was run with another seed number.

On the basis of the study of merits of the ANN Models vis-à-vis the statistical method, it was decided to use the ANN modelling approach in this research (Khan, 2006). The problem of multi-colinearity in statistical models is well known and it is not encountered in ANN models. In recent years, artificial neural networks have been successfully applied to transportation problems in which the input/output relationships are non-linear, and/or involve high-order correlations among the input variables.

The development of an ANN Model consists of the training and testing (validation) steps. Figure 8 shows the methodological framework followed for ANN model development. From repeated simulations of each work area configuration, data were generated for the development of the ANN Models of queue formation and average speed in various parts of the work zone Variables to be included in the ANN models were identified in VISSIM inputs and outputs. According to the requirements of neural computation algorithm, data were pre-processed and input variables were scaled through data transformation (The Mathworks, 2004).

A neural network model with a feed-forward structure was selected for queue prediction purposes. The training and testing processes were performed by using the MATLAB Neural Network Toolbox (NNT) (The Mathworks, 2004). The ANN Models were trained with the inputs to the microsimulation model and its outputs. The ANN Model training process was successful. Very high correlations between queue length answers estimated by VISSIM and the ANN Model were achieved in all cases, which suggest highly satisfactory models.

Next, the ANN models were validated. To ensure that the ANN models are capable of predicting queue length and their dynamic changes, a new set of data had to be selected. Traffic volumes for a section of Highway 417 (Ottawa region, Ontario), that were not utilized for ANN model training were used to calculate queue length by using VISSIM and the trained ANN models. Validation results showed very high correlations between model outputs and VISSIM results. These indicated that the trained ANN models are capable of estimating queue formation, length of the queue and its termination time.

The ANN models were represented in terms of weights and biases so that these could be coded in the algorithm for computing queue length. Finally, the post processing step was completed and the ANN models were obtained for use in the work zone information system. A second ANN model was developed for the two lane case for application in merge decision part of this research. A quantitative comparison was made between the expected queue (in meters) calculated by VISSIM and the values predicted by the ANN model for a dataset not used in the training process. Very high correlation coefficients were obtained which indicate the existence of a strong relationship between VISSIM and ANN results. A comparison in the simulation form shown in Figure 9 was also successful.

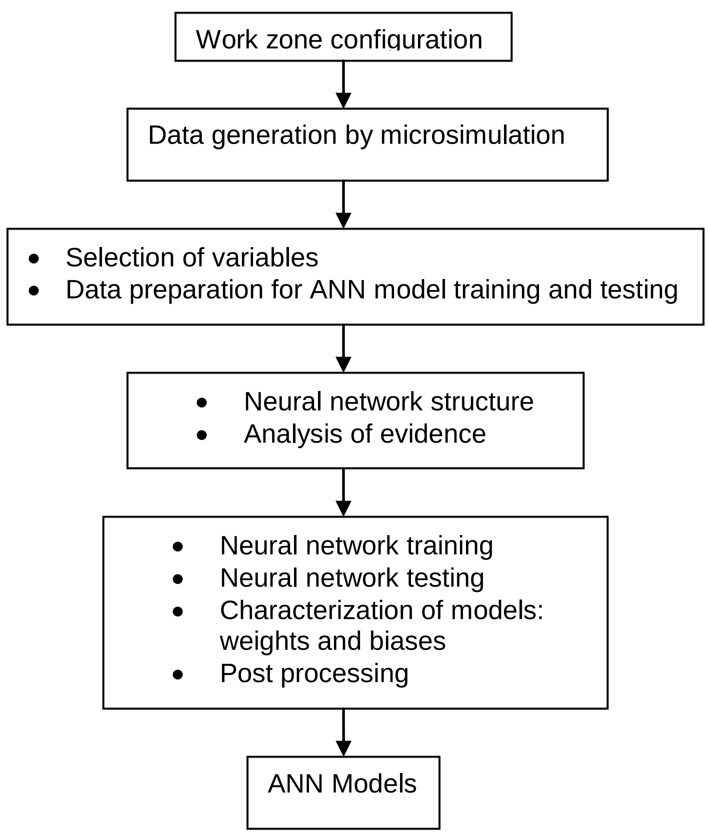

Fig.8. Methodology for Neural Network Model development

Models were developed that can predict the mean speed of traffic stream at selected locations in the work zone. Data were generated by using VISSIM microsimulator and ANN models were trained and validated in terms of their prediction capabilities. Two ANN models were developed. The first was for predicting mean speed in the taper area and the other for mean speed in the construction area. After completing the training step, the models were used to predict the mean speed using the traffic input. Figures 10 and 11 show the results. From the figures it can be inferred that the ANN models can be used to predict the average speed in those two locations.

The ANN models for the prediction of queues and speed were tested in an off-line mode. Figure12 presents an example of how the ANN model is used in a simulation testbed to predict queue formation and dissemination over time on the basis of traffic input data provided by the sensors. The traffic and queue information is presented in terms of 5 minute time intervals. The simulated queue formation and dissipation results appear logical. As expected, during low traffic periods, there are no traffic queues. When higher traffic volumes cannot be served by the available capacity of the work zone, queues form. Queue dissipation follows a drop in traffic measured by sensors placed in the work zone as shown in Figure 13.

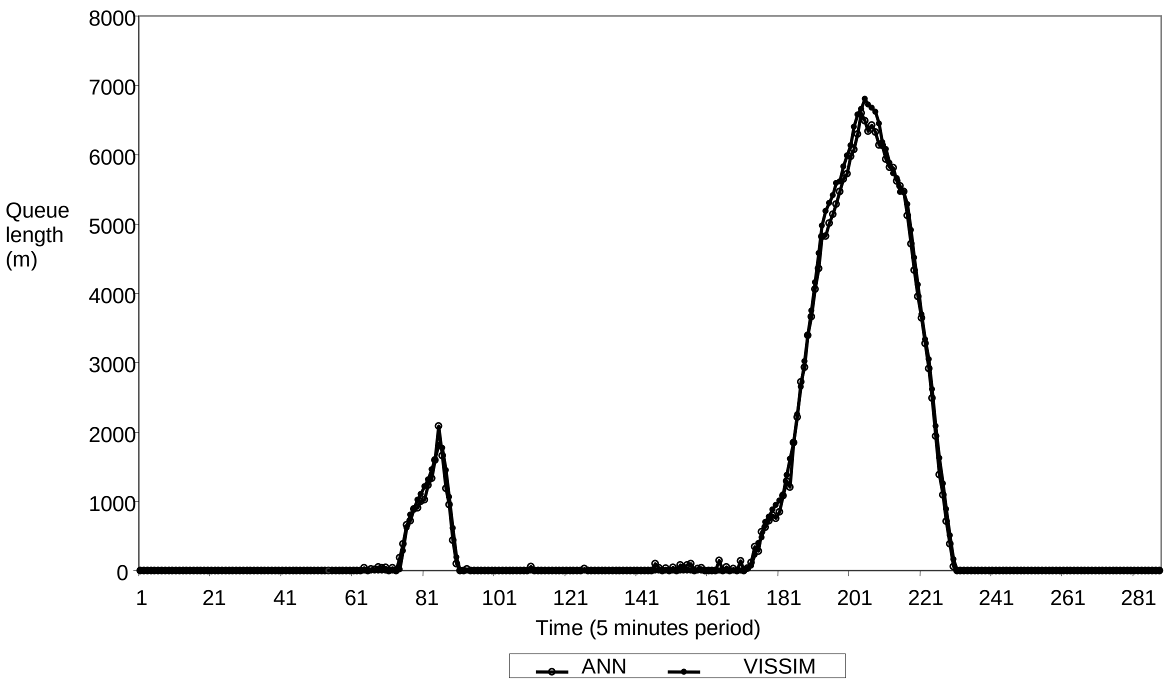

Fig. 9. ANN model and VISSIM comparison: work zone of two lanes/direction, one closed

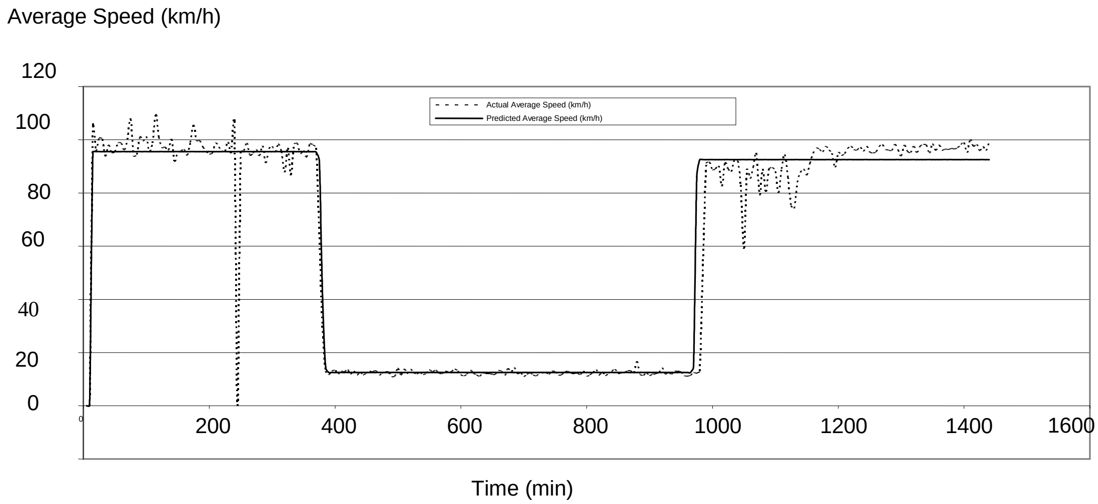

Fig. 10. Average speed simulation at the merge area
(Khan et al., 2005b)

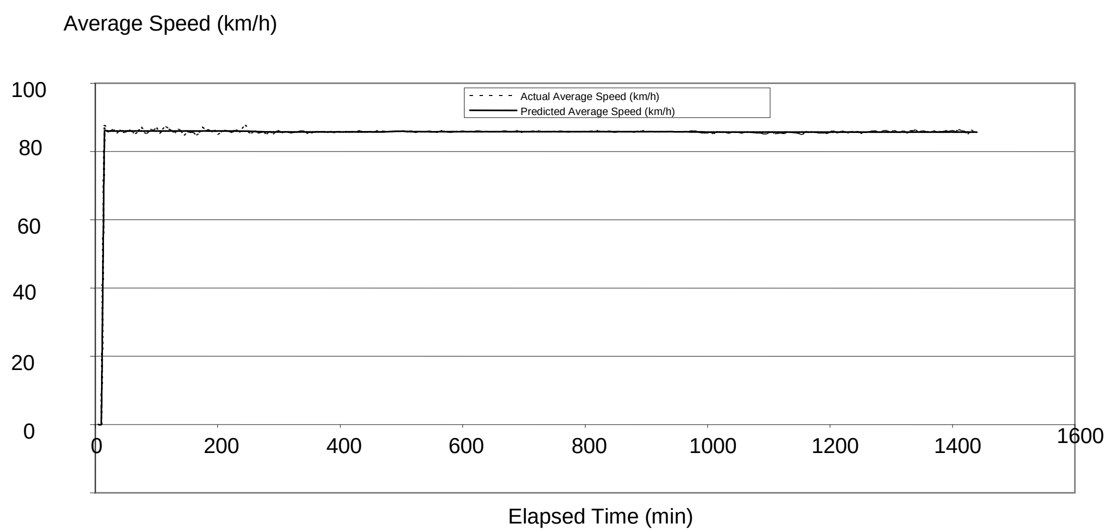

Fig. 11. Average speed simulation at the work area
(Khan et al., 2005b)

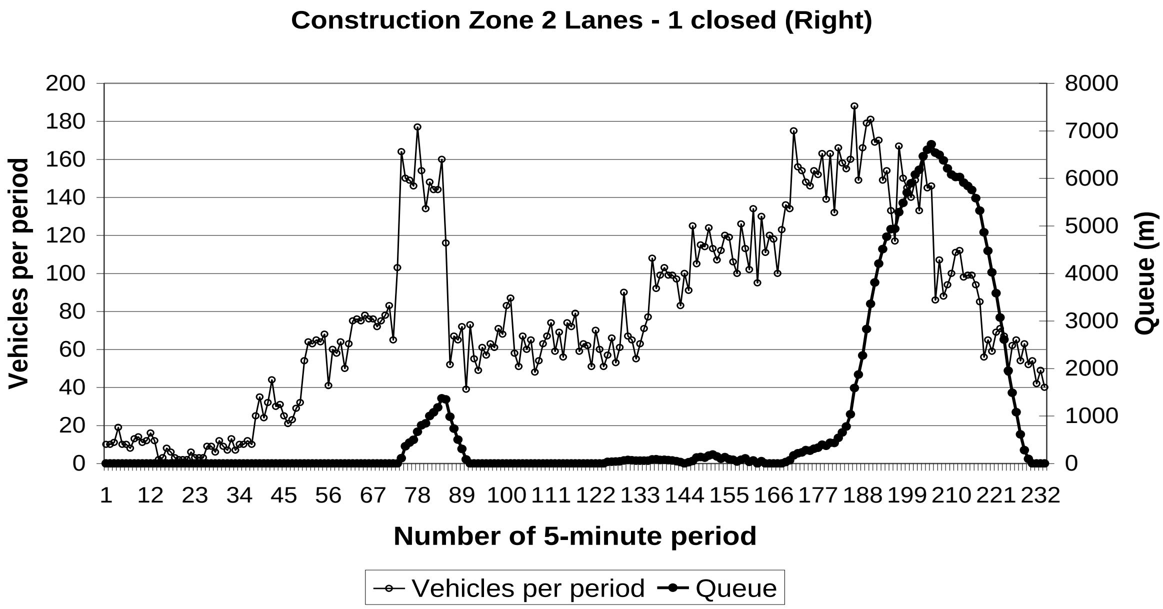

Fig. 12. Prediction of queue formation (Two lanes/direction, right lane closed) (Khan, 2006)

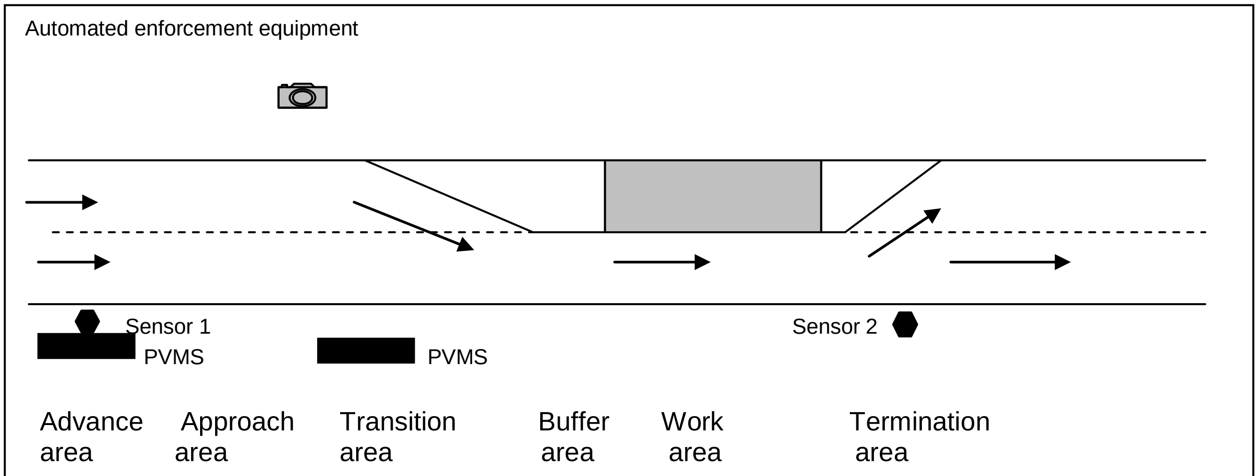

Fig.13. Location of sensors, PVMSs & enforcement equipment

5.0 AUTOMATED WORK ZONE INFORMATION AND TRAFFIC MANAGEMENT SYSTEM (AWITMS)

The AWITMS configuration is shown in Figure 14. It includes: (1) portable remote traffic microwave sensors (RTMS) located on the roadside, mounted on the portable variable message sign (PVMS) stands or on their own stand, (2) PVMS boards, (3) Computer situated in a roadside construction office or mounted on a PVMS stand, and (4) Communication links.

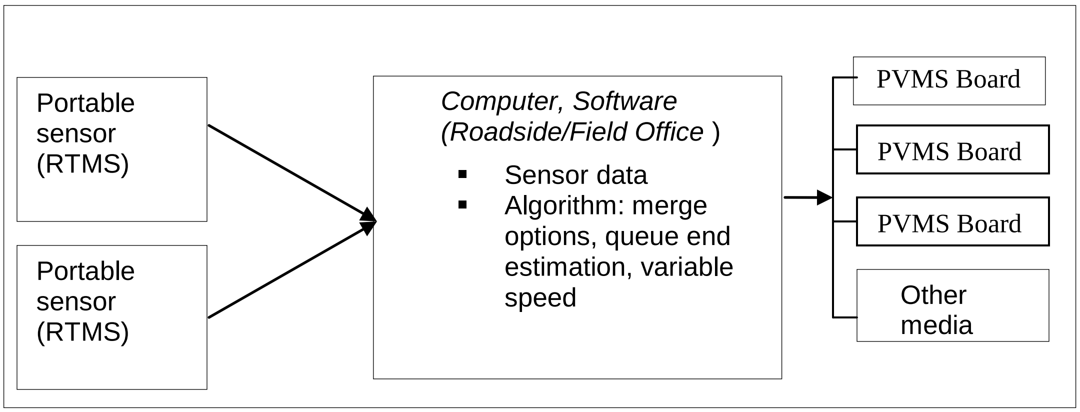

Fig.14. Automated work zone information and traffic management system

According to the design concept, the RTMS-supplied data are transmitted by wireless (radio) link to a file in the computer (EIS, 2003). An algorithm uses the input data and produces outputs, which are transmitted by wireless (radio) link to PVMS and other media (e.g., HAR –highway advisory radio). The arrows in Figure 14 show wireless communications. The location of sensors and the PVMS for a very basic AWITMS are shown in Figure 13. The upstream sensor is mounted on the PVMS stand. Since no PVMS are used at the termination area downstream, the second sensor has its own stand.

Traffic inputs required by the algorithm are received from sensors 1 and 2, and its outputs on queue length and queue-end are sent to PVMS located at a known distance from the transition area. The queue is measured from the taper part of the work zone. The messages to be sent to other media will not report queue end location but simply would inform the road users about the presence of queues.

6.0 CONCLUSIONS AND RECOMMENDATIONS

(1) There is a role for ITS technologies to improve safety and traffic flow performance of highway work zones.

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

(3) The calibration and verification steps were successful and applications of the ANN models produced logical results.

(4) The ANN modelling approach is suitable for simulating traffic operations in a construction zone, including queue length and average speed prediction. The queue-length information provides a basis to advise users about queue-end location and speed estimates are useful for establishing variable speed limits. Given the success of ANN models, on-line use of an expensive and data-intensive microsimulator is not required.

(5) On the basis of research carried out on merge options 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 merge location. This situation results in queues 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.

(6) The automated work zone information and traffic management system (AWITMS) is expected to be cost-effective. It requires a very limited number of traffic sensors and relies upon the ANN-based algorithm to perform its function.

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8.0 PUBLICATION AND`DISSEMINATION OF RESULTS

Progress has been made in publishing and dissemination of results. A scientific paper titled "Avoiding Rear Impacts Through Queue-End Warning System" was presented at the ITS World Congress (October 2006 London) and published in proceedings CD. An expanded version of the paper is accepted for publication in the IET ITS Journal (UK). The title of the paper is "Intelligent infrastructure-based queue-end warning system for avoiding rear impacts". Another paper titled "Microsimulation of Traffic in Highway Work Zones for Testing ITS-Based Traffic Management Measures" is accepted for presentation at the 2007 World Conference on Transport Research (Berkeley, California) and publication. Information dissemination in the form of research papers is in accordance with the MTO Guidelines regarding 2006 HIIFP. The papers include the MTO suggested disclaimer and acknowledgement.

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