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Prediction and Display of Delay at Road Border Crossings

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Abstract: Land border crossings in North America that serve high volumes of automobile and truck traffic experience congestion and delay, resulting in adverse effects on level of service, transportation costs, commerce, tourism, and the environment. Although efforts have been underway to expedite the customs inspection process (without compromising security), improving the reliability of delay estimates and real time dissemination of information remains a challenge. This paper reports research on intelligent technologies and methodological advances that can be used to automatically predict private and commercial vehicle queues and delays and display information to motorists, border crossing authorities, and other decision makers on a real time basis. The availability of such traveler information can be useful for making pre-trip and enroute travel decisions by private motorists as well as commercial vehicle operators regarding departure time and choice of border crossing location (if applicable). Such a system would enable motorists and carriers to avoid severe delays and commercial vehicle fleet efficiency gains can be achieved. Border crossing authorities can use the results to better match the processing capacity with demand for service. Research steps include the use of a calibrated microsimulation model of the Windsor-Detroit Ambassador Bridge crossing, development of artificial neural network (ANN) models for predicting queues and delay, imbedding these models in a traveler information system that uses sensor data as input and produces delay predictions for dissemination on dynamic message signs and other media on a real time basis. This system is tailored for border crossings with high volumes of private and commercial vehicle traffic.

Keywords: Delay, queues, border crossing, neural networks, model, traveler information system, ITS.

1. INTRODUCTION

A number of land border crossings in North America, including major Canada-U.S. border crossings, serve very high automobile and truck traffic volumes. Available information suggests that delays at border crossings have increased dramatically in recent years, particularly for commercial vehicles. According to the websites of the Canada Border Services Agency (CBSA) and the U.S. Customs and Border Protection (CBP), delay is encountered during peak periods by commercial vehicles as well as persons travelling by automobile and bus [1, 2]. Delay is time over and above the actual processing time. Customs inspection times, also called the processing times, for passenger and freight vehicles are discussed in section 5 of this paper.

Delays at border crossings are costly to bordering countries such as Canada and the United States. According to the Ontario Chamber of Commerce, the cost of Canada-U.S. border delays is very high and the U.S. economy absorbs 40 percent of this cost. Specifically, the U.S. share of this cost amounts to approximately $4.13 billion per year [3]. Border delays have a negative impact on the ability of economies to attract investors and the cost of goods to consumers is increased to cover losses. The tourism industry is also affected negatively and there are environmental impacts of congestion on border communities that cannot be overlooked.

During the periods of peak demand and given that customs inspection times are already affected by security concerns, the imbalance of demand and capacity results in increased congestion and travel time delays to crossing users [4]. Looking ahead, public and private sector interest groups are concerned that delays will become more pronounced due to future growth in automobile and truck traffic coupled with the requirements of a secure border. It is indeed a challenge to facilitate the efficient movement of people and goods while accommodating increasing travel demand and preserving national security in a post 9/11 2001 era. Therefore, measures are required to maintain an acceptable level of service and throughput at major land border crossings in the future.

Federal and provincial/state governments and border crossing authorities are very keen on improving transportation infrastructure, operations and management in order to make border crossing effective, efficient, and safe [5]. Programs have been underway prior to and since 9/11 2001 to define and apply physical and technological solutions including intelligent technologies to facilitate the secure movement of goods and people [5, 6]. To ensure that investments in border crossing infrastructure continue to be effective, Canadian and U.S. governments intend to analyze border congestion on an on-going basis. At high traffic crossings between Canada and U.S.A., capacity enhancements have been underway. But, these are not able to keep pace with crossing traffic demand. Consequently, congestion and delays continue to occur during peak periods [1, 2].

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Attempting to correct the imbalance of crossing traffic demand and processing capability is a major step ahead, but the problem of predicting queues and delay and informing stake holders such as crossing users on a real time basis still remains. For this purpose, technological and methodological innovations are required, particularly for application in a high traffic environment that includes commercial vehicles. The availability of such information on a real-time basis is useful for making pre-trip and enroute travel decisions including choice of border crossing location (if applicable). Such a system would enable motorists to avoid delays. In the case of commercial vehicles, fleet efficiency gains are possible, which in turn can alter their logistics plans. Border crossing authorities can use the information to better match the capacity of customs inspection and toll collection parts of the crossing system with demand for service.

The following parts of the paper are organized as noted next. The function of various components (i.e., processors) of the land border crossing system and the potential for queues and delays are explained in Section 2. This section serves as the problem definition part of the paper. Section 3 is devoted to a description of research need and therefore it describes the motivation for this research. The research approach and methodology are presented in Section 4. In Section 5, the simulation of the crossing traffic is described, followed by an explanation of the development of ANN models in Section 6. Example results of ANN models are presented in Section 7. In Section 8, the automated border traveler information system is explained and Section 9 is dedicated to a discussion of the approach and results. Conclusions are presented in Section 10.

2. BORDER CROSSING PROCESSORS: QUEUES AND DELAYS

For a better appreciation of the problem to be solved, a land border crossing system and its components are described briefly. A land border crossing system consists of the following main processors: access roads, bridge, primary inspection for cars, primary inspection for trucks, secondary inspection (mainly for trucks), toll collection and exit roads. A number of land border crossings span water and others function solely over land. Fig. (**1**) conveys the concept of the integrated nature of processors of a typical land border crossing between Canada and the U.S.A. In this figure, only one direction of travel (i.e. Canada to U.S.A.) is shown, given that the two directions of crossing traffic are independent and do not effect each other's operation.

The approach roads provide the necessary access to the next processor, which at many sites is the bridge. The bridge is a major component of the crossing system and its capacity is the most expensive and time consuming item to upgrade for border crossings. At busier crossings, bi-directional traffic flow on the bridge is served by multiple lanes. On bridges where there is multilane travel in any direction, the right lane is usually occupied by trucks, thus allowing cars to bypass slower moving trucks. Major crossings have either already built or considering the construction of a twin bridge in order to expand capacity.

As shown in Fig. (**1**), following the bridge crossing, vehicles go through the customs inspection step. The primary inspection process is operated by the customs and immigration officials of the country entered and is

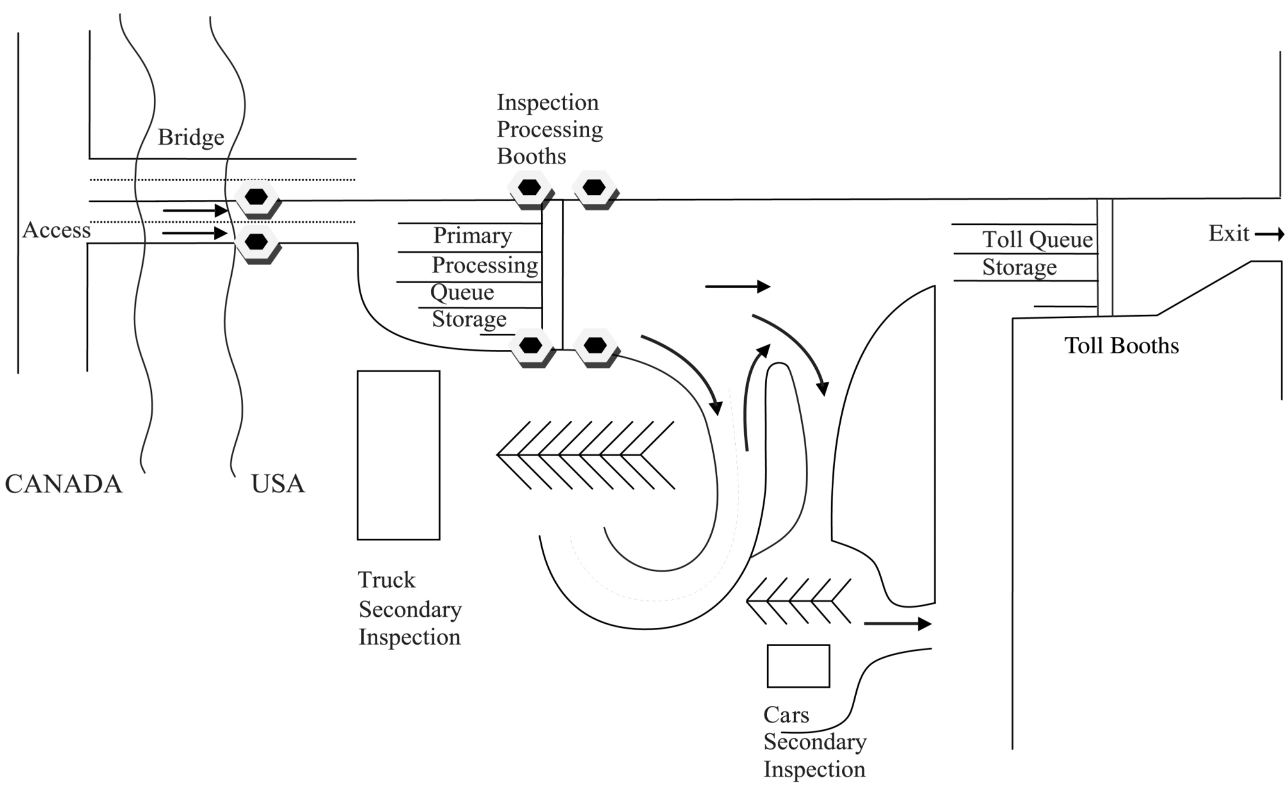

Fig. (1). Border crossing system (for one direction of travel). Note: see Fig. (**3**) and section 5 for additional information on location and function of sensors .

mandatory for all vehicles crossing the border. Passenger vehicles (i.e., cars and buses but frequently referred to as cars) and trucks go to designated separate parts of the overall primary inspection plaza. Further, vehicles registered in a priority crossing program are guided to booths that provide expedited service to these vehicles in accordance with the intelligent border initiative that pledges to facilitate movement across the border.

At major crossings, due to high demand, the customs primary inspection processor is responsible for delays. Although a queue storage area is provided immediately before the primary customs inspection booths, queues are frequently encountered on the lanes leading to this processor. Over the years, the U.S. and Canadian governments have implemented programs to expedite the crossing process, particularly the customs inspection step [7-11]. Pre-registered "low-risk" travelers, who are allowed to use a designated lane, experience lower processing times. These are pre-screened crossing users who have obtained a certain level of clearance so that they are not subjected to the full customs examination at the crossing. This enables resources to be directed to the relatively more detailed inspection of non-registered users. Although the pre-clearance program is viewed with interest, there are hurdles to be overcome in order to receive the full benefit of the expedited crossing initiative. For example, both registered and non-registered vehicles use a bridge with a limited number of lanes and there are concerns that during high traffic surges, the operating speed of traffic may fall below the normal operating speed. A more frequent phenomenon is that queues spill over beyond the primary inspection queue storage area to such an extent that the path of pre-cleared vehicles becomes blocked.

Secondary inspection follows the primary inspection in situations when there is a problem with the crossing user in the form of incomplete/incorrect paperwork. Also, vehicles are selected on a random basis for secondary inspection. This phase of inspection is very time consuming and pre-cleared vehicles are rarely sent. The secondary inspection facilities are usually separate for cars and trucks and a small fraction of trucks that are sent to secondary inspection undergo physical inspection of cargo as well. Following the customs inspection, the toll is collected manually or in electronic form. Finally exit lanes lead to the regional road network.

Various processors of a land border crossing system have their individual capacities and in theory, queues form when demand for service approaches or exceeds processing capacity. In order to reduce the overall crossing time, attempts are being made to go beyond the priority crossing programs. The Government of Canada has announced projects on new or improved highway access for border crossing and processing centers for commercial vehicles. Additionally, the intent to provide an advanced system for traveler information is noted in the Transport Canada's long term Strategic Highway Infrastructure Program [12].

Owing to long range plans, most components of high traffic border crossings already have or will have sufficient capacity to avoid significant queues, but the customs primary processor is an exception. For all practical purposes, queues and delays are now experienced at the primary customs inspection area and this trend is expected to continue in the future. For this reason, the provision of priority processing inspection booths and queue storage lanes in front of all inspection booths is a step in the right direction. If an advanced traveler information system such as the one that is visualized in Transport Canada's strategic plan can be implemented, it is expected that the motorists will be able to avoid crossing the border at a congested time/location. Another important positive impact of the information system will be to enable the crossing authorities to adapt services to match demand and therefore help in preventing an already congested border crossing system to become severely congested.

3. RESEARCH NEED

The reduction of border delay time is of much interest to a wide range of stakeholders who benefit from the efficient flow of goods and persons between Canada, the U.S.A. and Mexico. There are two facets of this challenge. (i) The first facet is to find ways to reduce the processing times in each part of the border crossing system. As noted earlier, the priority crossing programs and other parts of the intelligent border crossing initiative of governments are attempting to address this issue. (ii) The second facet, which is the subject of this paper, is to predict delays and inform key stakeholders (i.e., motorists and border crossing authorities) in a timely manner so that they can make informed decisions.

Traffic flow theory suggests that delays occur as demand approaches or exceeds the capacity of a processor. In the case of a border crossing system, in addition to the stochastic nature of demand, there are contributing factors that could potentially impact service capacity. As a result, in addition to random demand, the processing capacity becomes stochastic as well [13]. For this reason past researchers concluded that macroscopic methods are not suitable for the investigation of the dynamic aspect of traffic flow in a system since these cannot handle stochastic demand and stochastic processing capacity [14]. Therefore, a different approach is needed to study the performance of a processor and to predict queues and delays. Associated requirements are that motorists as well as managers of the crossing system should be informed about the absence or presence of queues and delays on a real time basis so that they can make timely decisions.

At present, a wide variety of stake holders, including motorists and carriers, are interested in the implementation of an automated wait time information system that can reliably capture the data with limited human intervention, predict delays, and disseminate the information to users on a real basis. As noted earlier, the provision of such information will enable motorists to decide when, where and if they wish to cross the border and the border crossing agencies need such information to better operate and manage the border crossing system [15].

The first documented attempt in automated vehicle estimation and informing motorists at a border crossing was made by Paselk and Mannering [16]. Their detailed studies at the U.S./British Columbia (Canadian) border showed that static queuing models do not hold, given mid-queue entries and the diverse nature of the checking channels at the border. They relied primarily on large-scale field data collection for the calibration of a statistical model of queue duration for the surveyed border crossing.

Other research has been reported on the development of the duration model for estimating the duration of congestion on a road section. This model can provide the probability that given its onset, congestion will end during the following period. It was found that the loglogistical functional form best describes congestion duration [17]. For the development of the duration model applicable to locations of interest, major on-site surveys are required. For security and cost reasons, this approach was not pursued. Also, research studies have highlighted the problem of multi-colinearity in the calibration of statistical models. Given that the duration model is one such method, it is not immune to the multi-colinearity problem [18]. As noted later in this paper, to overcome the multi-colinearity problem, the use of Artificial Neural Network (ANN) models has been advanced [19].

Another advance was in the direction of using technology-assisted methods of tracking queues. Chan *et al.* [20] found that it is feasible to track queues on a real time basis by using average link speed rather just the spot speeds (at detector locations), and by using pre-set threshold speeds as an indicator of queued condition. However, these approaches require the installations of sensors to obtain speed data on various sections of the queue storage and roads leading to these areas.

According to the Northern Border Noteworthy Practices References Guide, trailers can be installed that detect queued vehicles at border crossings. When queues are detected, the system automatically activates message signs to alert motorists that they should expect delays [21]. This method appears to be expensive, given that it would require relocating trailers to keep track of a dynamic queue-end or the use of many trailers. In order to overcome this and other deficiencies noted in this section, a recent study assessed technology to measure truck border delay and crossing time and proposed further research to define a border crossing time and delay information system [22].

The Canadian and U.S. customs agencies and some provincial/state transportation departments post border wait time/delay on their websites. However, this information is not collected on a real time basis and the web site is updated approximately once per hour. The U.S. and Canada border agencies use one or more of the following methods to estimate wait time [15]: (i) Unaided visual observation, (ii) Cameras, (iii) Driver surveys, (iv) Time stamped cards, (v) Licence plate readers.

The manual acquisition of wait time by customs staff is time consuming and subject to error. By the time the compiled information is disseminated to border crossing users, it is outdated [15]. Also, concerns have been raised by users of the information (notably private motorists, carriers) about the reliability and timeliness of the distributed wait time information. It has also been reported that some agencies calculate delay by taking into account the time spent in the primary inspection lane only, while ignoring queues on roads approaching the primary inspection lanes [23].

4. RESEARCH APPROACH AND METHODOLOGY

A number of approaches exist for measuring queues and estimation of delay. These include: queue length measurement, fixed point vehicle re-identification, and dynamic vehicle tracking [15, 24]. Queue length can be estimated by using technology to measure arrival and departure rates of vehicles and a calibrated model to estimate queue-end. Fixed point vehicle re-identification enables the calculation of time spent by a vehicle at a fixed point and between two fixed points. From these readings, waiting times can be found, but only for archival purposes since such data are of little use for a real-time information system. Likewise, the dynamic vehicle tracking based on the use of a wireless signal emitted by a device placed in the vehicle can generate data on time spent at a given spot or between various locations. However, the resulting information has archival value only.

In the research reported here, the objective is to develop an efficient, reliable and cost-effective method for automatically estimating the extent of queuing and delay at border crossings and alerting road users and border crossing authorities on a real time basis. In order to achieve this objective, it was decided to work with a combination of advanced technologies and predictive models. Major methodological steps followed are shown in Fig. (**2**).

For the development of the border traveler information system, an off-line modeling and simulation approach was used that incorporates intelligent transportation system (ITS) technology components. This approach consists of (i) microsimulation of traffic in the border crossing system (including access roads), (ii) development of ANN Models for the prediction of queue formation/dissipation and delay from the inputs and outputs of the microsimulator, and (iii) the development of an algorithm and software that encompass the developed models for automatically predicting queues and delay and deciding on the message to be conveyed to the road users (on changeable message signs and other media).

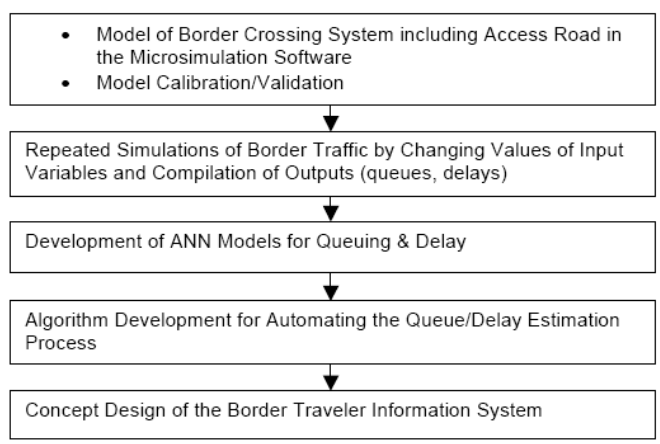

Fig. (2). Major methodological steps.

5. SIMULATION OF CROSSING TRAFFIC

5.1. Choice of Border Crossing

The Ambassador Bridge (U.S. bound) border crossing system, linking Windsor (Ontario) and Detroit (Michigan), was selected due to high traffic levels and frequent queues and delays experienced by users. Additionally, useful data were available for methodology development. At present, the maximum number of lanes for inspecting trucks is 13 and for passenger vehicles it is 19. According to consulting studies, the 2002 capacity for toll collection was 5400 passenger car equivalents/h and 611 trucks/h. The customs processing capacity in 2002 was 1440 passenger vehicles/h and 611 trucks/h. The bridge capacity in 2002 was 3500 passenger car equivalents/h [9, 10]. These features of the Ambassador Bridge border crossing suggest that it has much potential as a site for the development of a system for automated prediction of queues and delay and real time dissemination of information.

5.2. Choice and Calibration of a Simulator

Off-line microscopic simulation is a relatively inexpensive and useful tool that is employed to help analyze a real system when direct field experimentation is impossible, too costly, or unsafe. The microsimulation of traffic flow provides a basis for the detection of queues, and estimation of queue-end and delay. Queues are detected (by noting stopped or slow moving vehicles) through simulated detector action in the software. The number of simulations to be carried out is established on the basis of statistical reliability analysis. The minimum number of simulation runs was arrived at by using the desired confidence level as a guide. That is, the variables that were used to find the number of simulations to be carried out are the standard normal deviate, standard deviation, and the maximum tolerable error in our estimate of the population mean.

Microscopic simulators of traffic are well established and are widely accepted tools for assessing the impacts of planned measures such as changes to infrastructure, equipment and operating rules. For testing the effectiveness of intelligent transportation systems, the use of a microscopic simulation model is necessary. The stochastic nature of vehicle arrivals, vehicle following, lane changing, service times and routing within the border crossing system can be handled by a stochastic microscopic simulator.

A review of literature on border crossing simulators led to Border Wizard and CANSIM. Border Wizard was developed for the U.S. Federal Highway Administration (FHWA) and the Border Station Partnership Council [21, 25]. CANSIM is the Canadian version of this model. According to the developers of the software, it is a discrete event simulation model of border station operations and can be used for planning infrastructure and workforce. However, no literature references were found that could provide details on these tools or their applications. Also, this tool has not been made available to the public.

Published information on previous microsimulation studies of land border crossings is scarce. Past attempts focused mainly on the use of microsimulation as a tool to evaluate technology applications at land border crossings and references have been found on the use of WESTA for this purpose. This model was developed by Mitretek for Truck Weigh Stations on highways or vehicle inspection or toll collection stations [26]. WESTA has the capability of modeling the various physical infrastructure components of a border crossing such as access roads, toll facilities, bridge crossing, inspection facilities, parking, egress, fixed cycle and actuated traffic signals. Additionally WESTA is programmed to take into account various behavioral aspects of drivers and vehicle operation characteristics such as vehicle following, lane changing and merging of traffic.

WESTA is suitable for modeling border crossings in all aspects, including the ability to route vehicles to inspection booths, depending on queue length pending for each booth. For this reason, in a 1999 research project, a model of the Ambassador Bridge was implemented in WESTA in support of the North American Trade Automation Prototype (NATAP) field operational test and this software was calibrated with data collected specifically for this purpose [26]. Although WESTA could be used in this research, on the basis of a comparative assessment, another software, namely VISSIM was selected. However, it was decided to use WESTA database in VISSIM calibration.

Verkehr In Stadten – SIMulation (VISSIM) was developed by the European firm ITC and in North America it is marketed and maintained by PTV America [27]. It is a microscopic, time step and behavior-based simulator. It uses the psycho-physical driver behavior model to simulate traffic flow by moving "driver-vehicle-units" through a network. This software has the capability to loop-in intelligent technologies, including sensors and dynamic message signs (DMS). Strategies on incidence diversion can be modeled as well. It has all the features of interest to this research that are found in WESTA and additionally it is relatively easier to code a major border crossing including intelligent technologies. Further, user support is available.

Probability distributions are used by the microsimulator for treating the stochastic nature of the traffic demand, speed, diversion decisions, and processor service rates. VISSIM has enough capacity to accommodate a large number of links and its processing capability enables computations at relatively quick speeds [27]. It is suitable for simulating traffic flow through a border crossing system of a specified configuration. Travel time and queue formation are obtained for given traffic (i.e., volume, composition) and processor specifications.

The base configuration of the Ambassador Bridge (U.S. bound traffic) was coded in VISSIM, including access road. In the case of primary inspection processor, the processing time used in this research took into account the proportion of booths that were dedicated to serving the priority crossing traffic. As noted earlier, the delay time encountered by vehicles while waiting for service is the time that is over and above the inspection time.

VISSIM was calibrated by using available travel time database for this crossing. It consisted of WESTA database, data compiled by surveys of commercial vehicles, and border crossing authority data on passenger vehicle flow through the system. The freight vehicle survey involved the use of automated tractor log device and geo-coding of vehicle position [28]. Following VISSIM's calibration, it was validated against a part of the data that were not used for calibration.

In the calibration step, the difference between the actual and simulated average travel time was about 15% for trucks and about 14% for passenger vehicles for peak hours (Table **1**). The validation step produced generally similar results.

Table 1. Comparison of VISSIM Model Output and Survey Data

Vehicle Type and Service Item	Survey Data (Minutes)*	Model Output (Minutes)*	Percent Difference
Freight Vehicles			
Average truck travel time (across all categories) (peak period)	25.0	21.2	15.2
Passenger Vehicles			
Average passenger vehicle travel time (peak period)	9.8	8.4	14.3

*Time taken from the location of crossing into the USA to the primary inspection booth.

The simulation runs for other hours showed an expected variation of travel time for passenger vehicles and trucks in response to changes in traffic demand. This was further indication that the simulator was calibrated, given that this phenomenon was consistent with the real world experience of capacity-constrained processors in which service will deteriorate as demand approaches or exceeds capacity and during hours of low demand, motorists do not experience delay.

5.3. Application for Data Generation

Following the calibration and validation of the Ambassador Bridge simulator, traffic sensors were looped in the software as shown in Figs. (**1**, **3**). In the simulator, sensor 1 captures the arrivals and sensor 3 records departures and open booths. The purpose of sensor 2 is to note the number of queues in front of inspection booths, service rates, and the number of vehicles in moving or stopped queues. In the software, queues are detected by noting stopped or slow moving vehicles through simulated detector action.

The customs inspection personnel open processing booths in response to demand. Beyond the base number, additional booths are opened to serve increasing traffic. For passenger vehicles and trucks, a limited number of booths serve priority crossing traffic. As traffic demand increases containing a relatively higher proportion of priority clearance category of vehicles, more booths are dedicated to serve priority traffic. Table **2** provides available information on weighted average processing rates, taking into account the conventional checking method as well as intelligent technology applications for priority crossing vehicles [10]. In order to account for variability of processing rates in simulations, a standard deviation of 10% of the mean value was used.

The number of simulation runs made for each configuration of the crossing model (i.e., traffic volume, number of open booths) was guided by the statistical design of the simulation study. The minimum number of samples (i.e., simulation runs) required for every simulated case was arrived at by using the desired confidence level as a guide. Specifically, the variables that affect the choice of sample size are: the standard normal deviate, standard deviation, and the maximum tolerable error in our estimate of the population mean.

6. DEVELOPMENT OF ARTIFICIAL NEURAL NETWORK (ANN) MODELS

ANN Models have gained acceptance in the transportation field due to a number of their favorable features vis-à-vis statistical methods. These have been successfully applied to transportation problems involving queuing and delay, in which the input/output relationships are non-linear, and/or involve high-order correlations among the input variables [29, 30]. For these reasons, it was decided to use the ANN modeling approach. Another reason for developing ANN models is the ease with which these can be imbedded in predictive algorithms used for real time applications.

Although ANN models are essentially "black boxes" due to their inability to display the relative effect of independent variables on the output (e.g., travel time and delay in this research), these are recognized to be efficient models in terms of calibration/validation and predictive ability. Very complex ANN models that incorporate many variables and must process vast amounts of data in their real time development require more time to complete calculations than corresponding statistical models. However, as noted below, in this research, the ANN models were developed and tested off-line and then these were imbedded in an algorithm for the real time computation of queues and delays. Therefore, in their application, these take very little time to produce results.

The MATLAB Neural Network Toolbox was used for training and testing ANN models [31]. Fig. (**4**) shows the methodological framework followed for ANN model development. Two steps were followed in the development of the ANN Models. These are the training (calibration) process and the testing (validation) process. A large number of data sets (over 5000) were used for ANN model training. Data were pre-processed according to the requirements of the neural computation algorithm, including the scaling of input variables through data transformations.

As previously noted, the inputs to the calibrated microsimulation model and its outputs were used to train the ANN models. From repeated simulations of each configuration of the crossing system, data were generated for the development of the ANN models of queue propagation and delay. Since data for ANN model development were obtained from the repeated runs of the stochastic microsimulator, the stochastic nature of traffic in border crossing is addressed.

In the selection of the ANN structure, a two-layer neural network model with a feed-forward structure was selected for queue and delay prediction purposes. Variables for inclusion in the ANN models were identified in VISSIM inputs (i.e., traffic characteristics and volume, number of booths, processing rates/capacity) and its outputs, namely

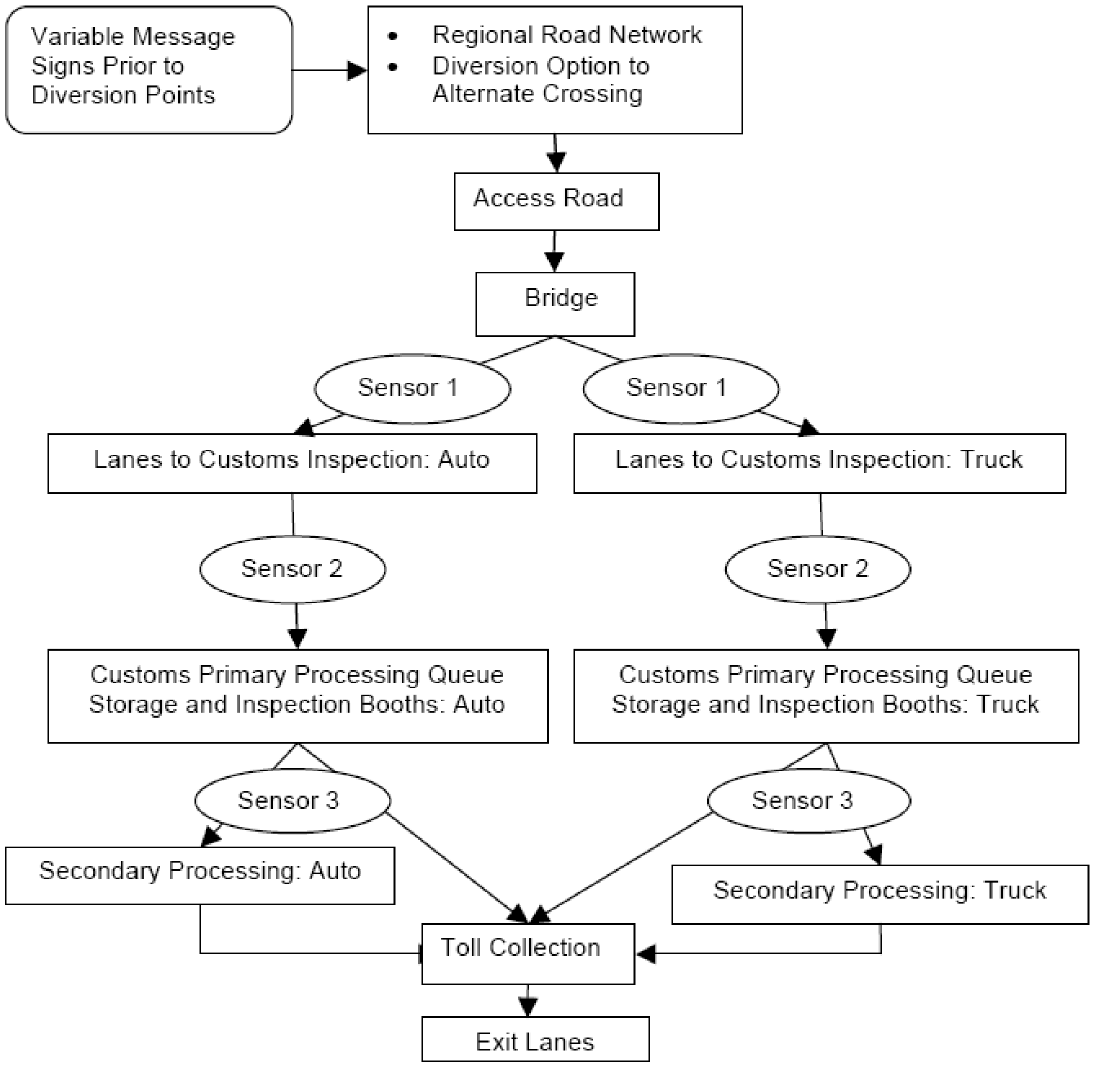

Fig. (3). Location of sensors and variable message signs.

Table 2. Primary Processing Booths and Average Processing Rates

Vehicle Type	**Passenger Vehicle**				**Truck**			
Inspection booths	8	10	12	15 and more	6	8	10	12 and more
Average processing time (sec/vehicle)	35	35	32	31	85	85	64	61

Notes: (1) Delay is not included in the average processing time. (2) Source: References 9 and 10.

queue and delay results for passenger vehicles and trucks calculated by the microsimulator.

In the ANN training process, the inputs are the accumulated number of arrivals into the processor every 5 minutes and departures. These are obtained from VISSIM's data sensors 1(at approach to the queuing area in front of customs inspection booths) and sensor 3 (after the primary inspection booth) (Figs. **1**, **3**). The outputs of VISSIM are the queue length in meters and delay in minutes. These are used for the development of the queuing model and the delay model, respectively. It should be noted that delay is the time over and above the free flow time between sensor 1 and the point of reaching the customs inspection booth (captured by sensor 2) for every period of time. That is, delay is computed between sensors 1 and 2. This is consistent with the definition of the border wait time used by the crossing authorities (i.e., the time it takes for a vehicle to travel from the end of queue to the customs primary inspection point). If traffic flows freely and there are no queues, the delay is zero.

The hidden layer is characterized by the number of vectors, the number of hidden units, the activation functions, the number of epocs, and the regularization function. In this research, the optimal number of hidden units was arrived at by using the Bayesian evidence framework. The optimal number of hidden units for the selected two-layer neural network was calculated as follows. Using the training data set, the network was trained with Bayesian regularization. The activation functions used were a hyperbolic tanget

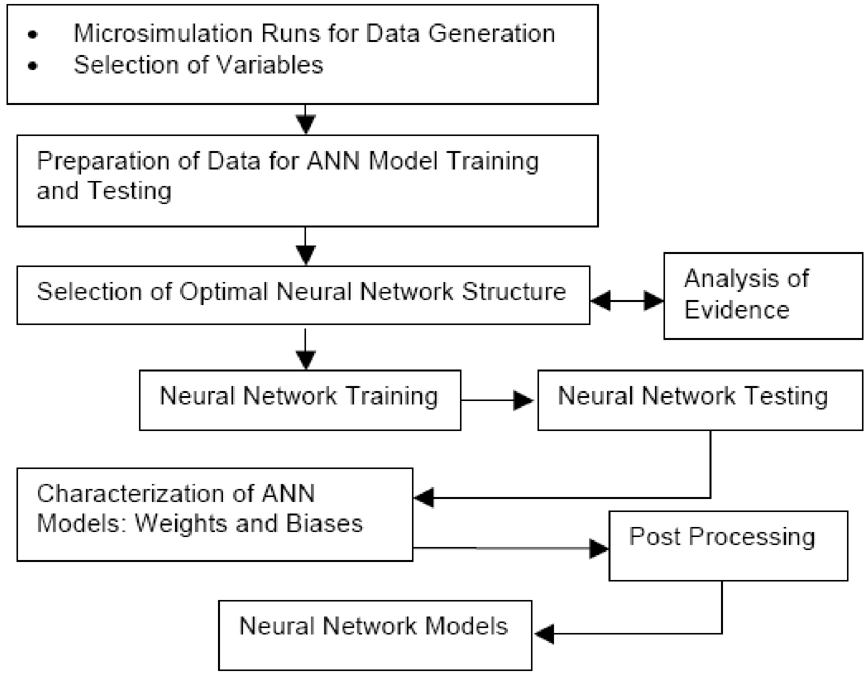

Fig. (4). Neural Network model development.

function for the neurons in the hidden layer and a linear function for the output layer. A different number of hidden units were used every time and the "evidence" was calculated. The network structure with the highest "evidence" and less hidden units was selected as optimum. The number of hidden units was found to be equal to 10.

For assessing the success of the training process, queue length was estimated by using the traffic microsimulator and the ANN models in response to an identical traffic profile. For realism, the traffic flow was expressed in terms of time. Also, the time profile of traffic was chosen so that it exhibited the traffic rise and drop over time. The queue length predictions of VISSIM and the ANN models were compared visually and statistically. Results showed that the training process was successful. The correlation (between queue length estimated by VISSIM and the ANN Model results were high (R^2 over 0.98). These suggest a highly satisfactory model. The same observation holds for the delay model with R^2 over 0.97. These results are not unexpected, given that the ANN methodology is well recognized to produce very good fits into the data.

Next, the ANN Model validation was performed. To ensure that the ANN Models are capable of predicting queue length and their dynamic changes, a new set of data generated by the microsimulator had to be selected. That is, this new set of data was not utilized for ANN Model training. Using these data, queue length and delay were estimated. The validation results are highly satisfactory. For example see Fig. (**5**).

As can be observed from results presented in Fig. (**5**), there is in general a very close correspondence between VISSIM and ANN model results. In the left part of the diagram, the ANN model appears to slightly overestimate the queue length. In the right part, first the ANN slightly overestimates and then under estimates the queue length. In the extreme right side, the ANN overestimates the queue length. The degree of closeness of the queue lengths predicted by the ANN model and VISSIM is captured by a very high statistical correlation. This indicates that the trained ANN Models are capable of estimating queue formation, queue length during any time period, termination time, and delay. A general check on the correspondence of ANN models and actual data used for VISSIM calibration was satisfactory. However, due to inability to conduct real world experiments with crossing traffic and processing booths, precise comparisons could not be made.

A post processing step was completed and finally the algorithm containing the ANN models was developed for use in the border crossing information system. According to the standard practice for coding the trained and tested ANN models in an algorithm, these were represented in terms of weights and biases so that queue length and delay calculations can be performed. As noted later in this paper, in order to apply the algorithm for estimating queues and delays, inputs obtained from sensors are used.

7. EXAMPLE RESULTS OF ANN MODELS

Figs. (**6-8**) illustrate the ANN model results. Fig. (**6**) shows queue length and delay on a real time basis for trucks in the scenario when 6 primary processing booths are open. The horizontal axis shows time in minutes and queue length (meters) is shown as the left vertical axis. The right vertical axis presents corresponding delay (minutes). This figure illustrates how the developed ANN model is used to predict queue formation and dissipation and the incidence of resulting delay on the basis of traffic input data provided by the sensors.

Additional illustrations are presented in Figs. (**7**, **8**) for passenger vehicles when 8 booths are open for customs primary service. Fig. (**7**) shows changes in traffic volume

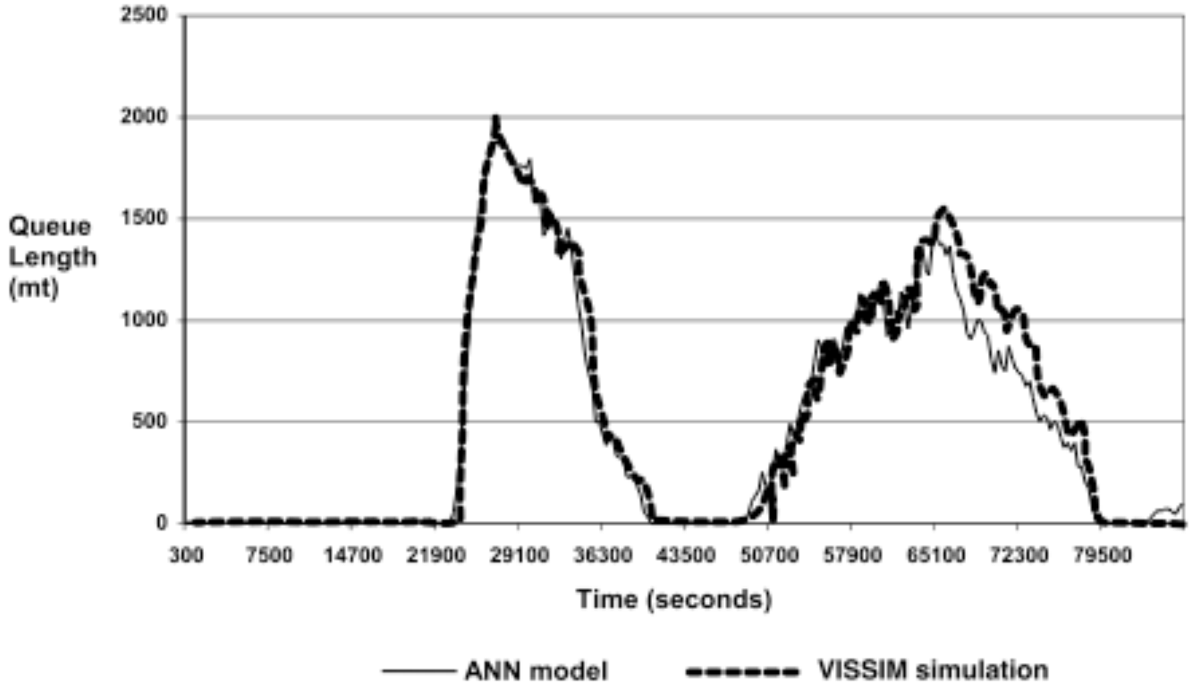

Fig. (5). ANN model validation, truck traffic queue length.

and queues over time. The traffic and queue information is presented in terms of 5 minute time intervals. Fig. (**8**) presents changes in traffic volume and delay for the 8 booth scenario. The traffic volume information in Fig. (**8**) is the same as in Fig. (**7**). But, Fig. (**8**) presents delay information on a 5 minute time interval basis. It is interesting to compare the queue and delay information in order to see how queues result in delay to border crossing vehicles. It should be noted that the delay time is over and above the processing time.

The queue and delay diagrams reflect the interaction of demand for service and the capacity of the primary inspection processors of the border crossing system. The traffic pattern, expressed on a five minute interval basis, is to

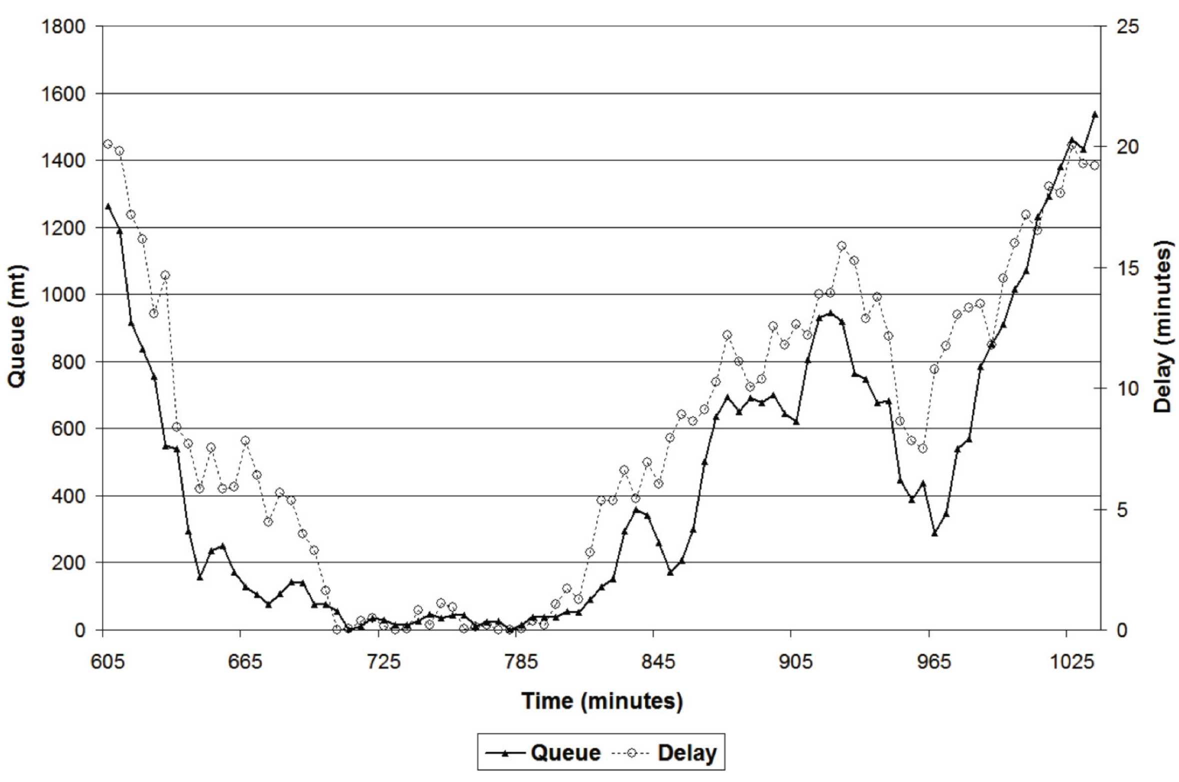

Fig. (6). Example of truck traffic queue length and delay (6 booths).

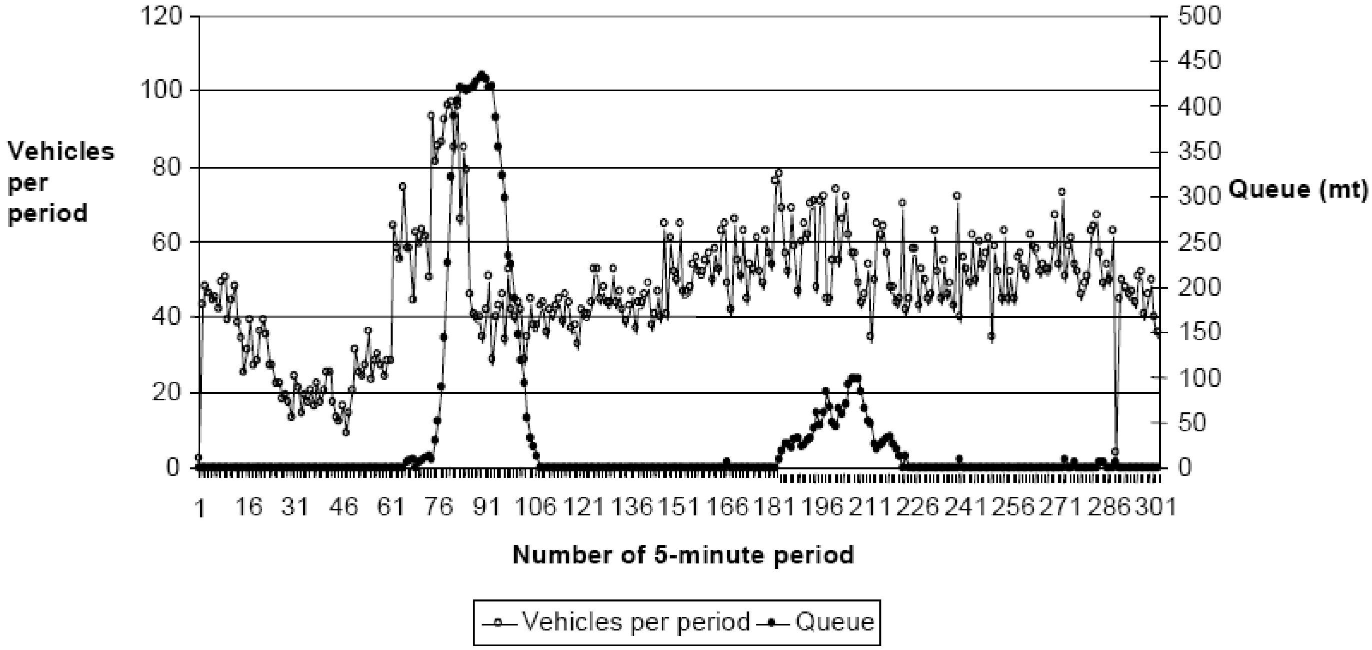

Fig. (7). Example of queue length for passenger vehicles (8 booths).

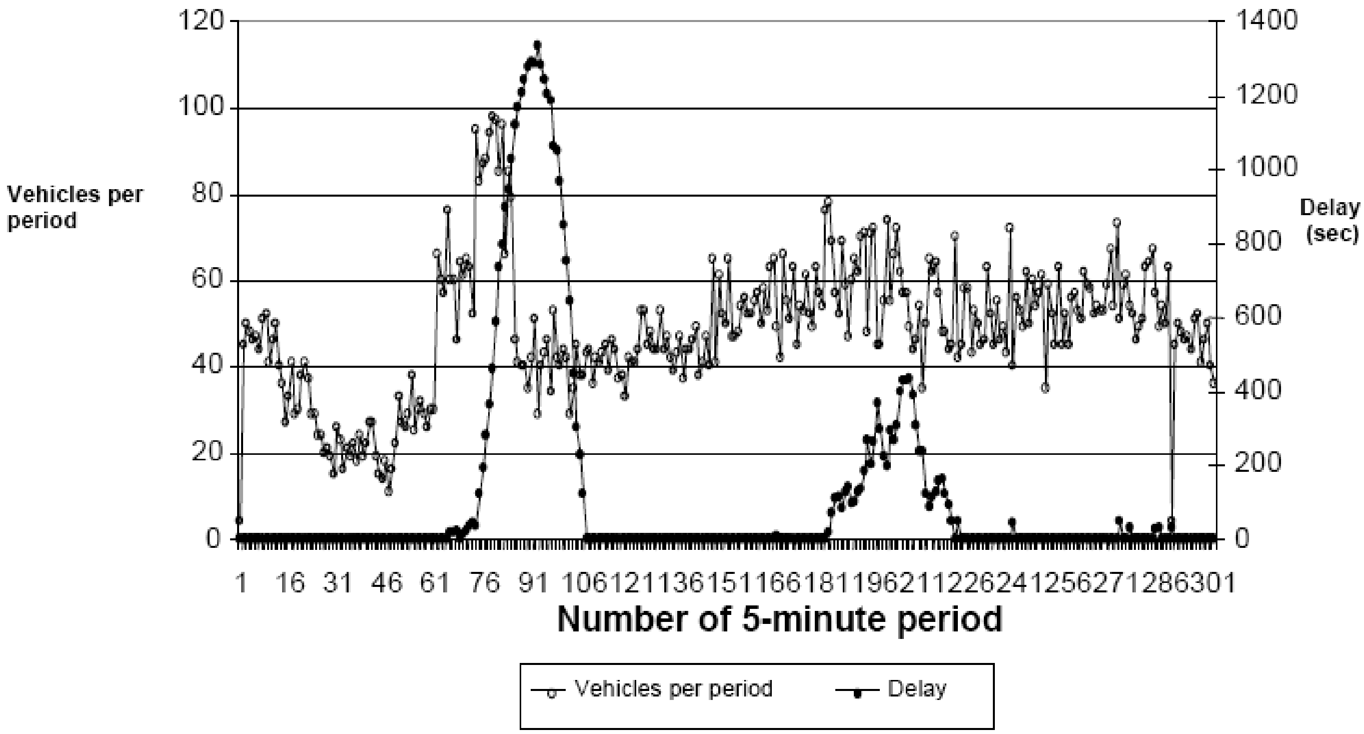

Fig. (8). Example of delay for passenger vehicles (8 booths).

be served at the primary inspection booths. Whenever demand for service approaches or exceeds capacity of these inspection stations, queues form and delays are encountered. As the demand drops, queues dissipate and no delays occur.

The prediction of queue formation and dissipation and rise and fall of corresponding delay appear logical. As expected, during low traffic periods, there are no traffic queues and no delay is encountered. When higher traffic volumes canot be served by the available capacity of the processor, queues form and delay is experienced. Queue dissipation and delay-free service follows a drop in traffic measured by sensors placed in the border crossing system shown in Figs. (**1**, **3**).

8. AUTOMATED BORDER TRAVELLER INFORMATION SYSTEM

8.1. Concept Design

The concept design of the border traveler information system shares a number of features with the work zone information system reported by the author in 2007 [19]. Prior

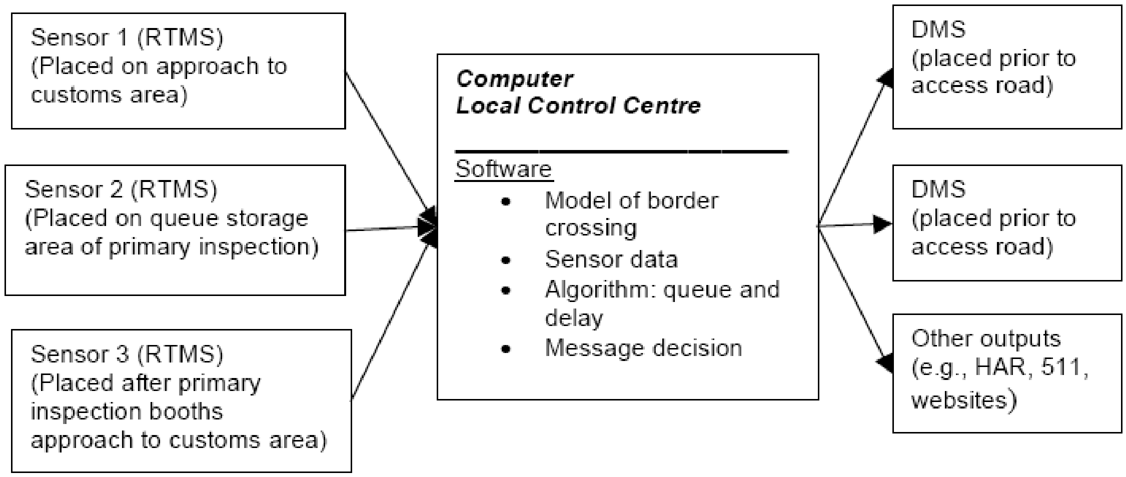

Fig. (9). Border traveler information system.

to finalizing the concept shown in Fig. (**9**), available information on the effectiveness of using dynamic message signs (DMS), in-vehicle traffic advisory system, and other methods were studied [32]. The architecture for the information system includes (i) pole-mounted non-intrusive remote traffic microwave sensors (RTMS) 1 to 3 (as shown in Figs. **1**, **3**), located on roads leading to customs inspection area, at the primary processing queue storage site and after primary inspection booths, (ii) dynamic message signs placed in the regional road network prior to diversion points, (iii) computer situated in a border crossing management office, (iv) communication links of wireless type.

According to the design, the RTMS 1 and 3 supply the main input to the algorithm, transmitted by wireless (radio) link to a file in the computer. Please note that separate RTMS are used for passenger vehicle traffic and truck traffic. The inputs to the information system provided by sensor 2 is used to establish the number of queues in front of open booths (lanes) and for archiving data for use in ANN model re-calibration, if desired. The information system relies on sensor data and the ANN Model-based algorithm to produce the outputs. The algorithm estimates queue length and delay on the basis of traffic to be served, number of open inspection booths, and processing rates/capacity of booths to handle the load. The outputs produced by the algorithm form the basis of compiling messages on delay which are transmitted by wireless (radio) link to DMS and other media (e.g. HAR—highway advisory radio). The arrows in Fig. (**9**) show wireless communications.

The functional requirements of the system are: (i) real-time operation, (ii) open architecture (so that it is compatible with any new detector/surveillance or dissemination tools that may become available in the future), (iii) information to be available to travelers on DMS, and with suitable interface design, to other media, (iv) affordable (minimum number of sensors used), (v) use of solar powered boards, and DMS components with low maintenance requirements.

Research indicated that the RTMS has the capability to handle many lanes and provides the following data: volume per lane, vehicle classification, speed and occupancy [33]. The system is suitable for any traffic pattern. Sensors provide the necessary inputs on traffic and number of booths open and the ANN models calculate queue formation and delay (if any). Should the RTMS send no data or imperfect data, the information system will not transmit messages to the DMS or other media and will display an alert message on the computer monitor used by the technical staff.

8.2. Hardware and Software Requirements

The hardware building blocks of the information system are as follows. (i) RTMS X3 with built-in digital spread spectrum modem (DSS) (900 MHZ) with Yagi antenna, (ii) DSS master controller modem with antenna (to be used for communicating to the RTMS and the computer), (iii) solar powered DMS mounted on their stands, (iv) solar power kit (containing 75W solar panel, voltage regulator, 100 AHr deep cycle batteries and enclosure), (v) computer.

As a part of this research, software coded in Visual Basic was developed for implementing the information system. It has the following main features: ability to accommodate border crossings of various configurations, use of sensor data on a real time basis and ANN model-based algorithm. The algorithm is designed to process input data received from sensors, activate the ANN models so as to estimate queues and delays, and formulate the message on delay that is to be sent to travelers. Although information on both queues and delays can be seen on the computer monitor, only delay estimate is disseminated to travelers.

The algorithm seeks from sensors, the number of open inspection lanes (for passenger vehicles and for trucks) and corresponding traffic inputs and sends messages on delay to DMS and other media. As explained below, a demo sensor can be used for checking purposes. As for time interval for viewing results, although the neural network model is designed to work with traffic per 5-minute interval for real time field operation, for the demonstration mode based on a hypothetical demo sensor data file, the user can select a different time interval for viewing results on the screen (e.g. 1 second, 5 seconds, etc.). For actual field operation (called Sensor Real Time in this software), the user should set the time interval equal to 5 minutes.

In the software, input data sources can be specified as demonstration mode *vs* actual field operation. The user can get a feel for the algorithm by selecting the sensor demo mode. In order to view results on the screen in a tabular format, the user can select passenger vehicles or trucks and the corresponding information is displayed. The delay information is updated at five minute intervals. In case of data problems, the algorithm is designed to alert the technical staff in the form of a message displayed on the computer monitor.

If sensor demo as input data source is selected, example data are read from a file and results are displayed. On the other hand, should the "sensor real time" be selected as input data source, the program looks for input data obtained from sensors installed in the field. At the time of installation, the user should program sensors to send 5-minute traffic data to these files. The queue and delay results appear on the screen for the use of border crossing authority and delay information can be automatically transmitted to the DMS and other media. The program requires resetting since the neural network model accumulates the traffic data. That is, the program is designed to reset its accumulated traffic data to zero after 24 hours. It is important to set up the system and start it during low traffic conditions so as to avoid errors in the use of the model and before re-setting, data should be archived for future analyses.

9. DISCUSSION

Research is reported here on the combined use of methodological advances and ITS technologies for automatically predicting passenger and freight vehicle queues and delays at a land border crossing and displaying selected information to motorists, crossing authorities and other decision makers on a real time basis. The crossing authority can view queues and delays on computer monitors in the office. However, only delay information is presented to motorists and other interested parties. This study was motivated by the need for real time information for supporting crossing user, management and other stakeholder decisions. The importance of the availability of this information can be appreciated from the high cost of delay to border crossing traffic and the economies of the countries connected by the crossing system.

As noted in the paper, in spite of the need, there is no known information system of appropriate scope to serve this need. Past attempts at the development of border traveler information system had limited scope in terms of technology and methodology for model development. The current methods used by border crossing authorities for tracking queues and delays that were reviewed in this paper do not meet the challenges of a border crossing information system. The data generated by the existing methods have archival value only and these cannot serve the real time needs of motorists and other stakeholders.

Although strategic plans of governments show the intent to implement a real time information system in the future, no such system has been announced to date. In the absence of real time information on delay, the motorists are not guided to make travel decisions and it is difficult for the crossing managers to match service supply with demand. Also, the logistics of freight companies cannot be assisted due to lack of required information. Consequently, under the current and projected crossing traffic demand, costly delays are expected to continue to occur in the absence of an advanced information system such as the one reported in this paper.

The approach to the development of an information system that combines methodology with intelligent technology is a new field of inquiry. Researchers and intelligent transportation system designers have come to the realization that while data capture by sensing devices is an essential starting point, the acquired data cannot serve as a substitute for the a prediction of travel conditions in the following time period. For this reason, predictive models that use the sensor data as an input become necessary. In the case of the border crossing system reported here, reliance is placed on the joint use of sensors for traffic data capture and models for the prediction of queues and delays.

In the absence of a border crossing information system such as the one reported in this paper, other approaches can be considered, but these are very expensive and/or do not have the capability to produce the required queue and delay information. For example, numerous sensors or manual methods can be used to track queues. However, these methods are costly and do not provide a prediction of queues and delays in the next period. Even if the captured queue data are acceptable to the users, there is a need for a model to provide delay estimates that correspond to the queues. The developed methodology in association with a minimum number of sensors is capable of providing the queue and delay information on a real time basis since it is built in a simulation format.

Systematic procedures were followed in the development, calibration and validation of models. In turn, these are successfully integrated into the border crossing system framework. The state of the art in the development of information systems is advanced in this research by combining ITS technologies and predictive models of machine learning technology-based ANN. The off-line modeling and simulation approach required the use of a stochastic traffic microsimulator with the ability to loop-in ITS technology components. The traffic simulator of stochastic type is suitable and also the artificial neural networks provide a good fit into the data. Since no statistical tests are to be carried out on the role of independent variables in influencing the dependent variables of queues and delay, the "black box" characteristic of the ANN does not cause an issue. Further, the ANN can be built into a real-time information system with ease. The example applications of the developed ANN models illustrate that in association with a limited number of traffic sensors, reliance can be placed on these tools to predict queue formation/dissipation and corresponding delay.

The choice of the border crossing system was appropriate since it serves high traffic volumes and experiences queues and delay on a regular basis. Further, data availability was a favorable factor for methodology development. Also, research on the Ambassador Bridge will be useful for studies on other crossings

10. CONCLUSIONS

The approach, methodology and technologies used in this study differ from those of other researchers/agencies. First, this study recognized the need for real time information based on a hybrid of sensor-data and models capable of making prediction of queues and delays. In this respect, the approach and the product of research (i.e., the border traveller information system) are unique. Second, the predictive nature of information displayed in real time makes it useful to motorists, border crossing managers and other stakeholders.

The microsimulation and the ANN modeling approaches are suitable for simulating queuing and delay at a border crossing. The model calibration and verification processes were successful and example applications of the developed models produce logical results.

The border traveler information system is an improvement over the existing methods used by crossing authorities to estimate delay. Its strength is that the system is designed to use predictive models of queue formation and dissipation that receive data from traffic sensors. Therefore a limited number of sensors are required. The prediction of queues and delays by the ANN-based models is a more realistic approach than the use of numerous sensors or other surveillance devices to locate the end of queue on a real time basis. Besides, without the combination of sensors and the predictive tools, the data captured by sensors alone become outdated very quickly.

Although in the simulation test bed, the developed traveler information system meets its functional requirements, a field demonstration can verify the reliability of the system in terms of predicting fluctuating queues. Logically, the next step is to demonstrate the system in the field. If adjustments to the ANN models are required, the analyst can do so by using the archived sensor data and the corresponding field measurements of queues.

It is contended that the border traveler information system described in this paper meets the requirements of automation and efficiency. Also, the relatively low cost intelligent technology components in association with the ANN model-based algorithm have resulted in a useful and cost-effective system.

The developed information system has the potential to alter the pre-trip and/or enroute travel decisions of private motorists and commercial vehicle operators. That is, it enables the motorists (i.e., private and commercial vehicle operators) to decide when, where and if to cross the border at a certain time. For example, drivers could avoid delays during periods of high queues by travelling during low or no queue periods or to cross the border at another location (if applicable). In the case of commercial vehicles, fleet efficiency gains can be achieved. The border crossing management can use the information to adjust the supply of services to match the demand. In addition to a reduction of adverse economic impacts, other benefits occur in the form of emission reduction, and enhancement of commerce and tourism.

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ABBREVIATIONS

ANN	=	Artificial Neural Networks
CBP	=	Customs and Border Protection (CBP) USA
CBSA	=	Canada Border Services Agency
DMS	=	Dynamic Message Sign
DSS	=	Digital spread spectrum (modem)
HAR	=	Highway Advisory Radio
ITS	=	Intelligent Transportation Systems
RTMS	=	Remote Traffic Microwave Sensor
VISSIM	=	Verkehr In Stadten – SIMulation (a microsimulation model)
WESTA	=	Weigh Stations (a microsimulation model originally developed for truck weight stations)

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