Automated Vehicle Delay Estimation and Motorist Information at the U.S./Canadian Border

A Summary

WA-RD 258.2

Final Report
July 1992

Washington State Department of Transportation
Washington State Transportation Commission
in cooperation with
U.S. Department of Transportation
Federal Highway Administration

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. WA-RD 258.2	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE AUTOMATED VEHICLE DELAY ESTIMATION AND MOTORIST INFORMATION AT THE U.S./CANADIAN BORDER		5. REPORT DATE July 1992
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Ted Paselk and Fred Mannering		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Washington State Transportation Center (TRAC) University of Washington, JE-10 The Corbet Building, Suite 204; 4507 University Way N.E. Seattle, Washington 98105		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO. GC 8719, Task 41
12. SPONSORING AGENCY NAME AND ADDRESS Washington State Department of Transportation Transportation Building, KF-01 Olympia, Washington 98504		13. TYPE OF REPORT AND PERIOD COVERED Final report
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT

Congestion related delays at the U.S./Canadian border crossing between Washington state and British Columbia have underscored the need for some sort of intervention. One obvious congestion-mitigation measure is to estimate delay and relay this information to motorists so they may select among alternative, less-congested border crossing sites or delay their trip. This study defines an automated motorist information system that provides border delay estimate to motorists.

The report begins by providing a detailed description of the study area, characteristics of international travel, border crossing congestion-mitigation alternatives, and a physical assessment of the four border crossings beings considered; the two crossings at Blaine, Wash., and the crossings at Lynden, Wash., and Sumas, Wash. On the basis of a study of travel on northbound I-5 at Blaine, and the resultant statistical analysis, a model capable of predicting delay based primarily on queue length was developed. This model can be used as an integral part of a motorist information that will include 1) detectors to estimate queue length; 2) software to predict delay using the statistical model; and 3) methods of disseminating delay information to the public, including highway advisory radio (HAR) and variable message signs (VMS). The report concludes by discussing the implementation of this system and estimating costs.

17. KEY WORDS Vehicle delay, border crossings, international travel, customs delay	18. DISTRIBUTION STATEMENT No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22616

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
None	None	36	

Final Report

Research Project GC 8719, Task 41
Automated Motorist Information Detection System

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A SUMMARY

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July 1992

DISCLAIMER

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SUMMARY

Concern over congestion and the resulting long delays at the U.S./Canadian border crossings between Washington state and British Columbia has generated considerable interest in producing implementable congestion mitigation measures. The recently implemented PACE program (designed to speed border declarations and custom service) has provided some relief, but with border crossing queues occasionally delaying vehicles for more than an hour, additional congestion mitigation is clearly warranted. One suggestion has been to make border delay estimates available to the public so that they can delay their trips or select the crossing with the least delay. This idea is the focus of this study.

The technical report of this study, "Automated Vehicle Delay Estimation and Motorist Information at the U.S./Canadian Border," provides a highly detailed description of the study, including:

- background on the study area and international travel,
- a description of various proposed solutions to the border congestion problem,
- a physical description of the four border crossings considered in this study: the two crossings at Blaine and the crossings at Lynden and Sumas,
- a discussion of the travel study conducted during this project,
- a presentation of the statistical analysis of the travel data, and
- a proposal for application of a delay estimation algorithm and motorist information system requirements.

The primary findings of this study focused around a two-day collection of data at the northbound I-5 border crossing at Blaine. Through license plate matching, data were collected on individual vehicle delay, length of the queue at the time of vehicle arrival, the number of border crossing lanes open, and the service time of individual vehicles. A

statistical analysis of these data indicated that vehicle delay could be accurately predicted from the length of the queue, and additional factors, such as the number of lanes open at the time of vehicle arrival, time of day, and average border crossing processing times, further enhanced the accuracy of the delay predictions. On the basis of these important findings, the researchers recommend the implementation of a loop detection system to determine queue length and a software package to process this information into delay predictions that can then be provided to travelers. The study investigated the costs of implementing the loop detection system, as well as the costs for providing delay information to the motorist via highway advisory radio (HAR) and variable message signs (VMS). It also included the creation of an outline for system evaluation and a framework for future system enhancements.

CONCLUSIONS AND RECOMMENDATIONS

With increasing delay and congestion at the U.S./Canadian border, the state must act now to provide relief to motorists, border agents, and business owners. With a traveler information system, motorists could choose alternative routes or departure times for their trips. Their choices would distribute the traffic and help to reduce delay and congestion at the border. The use of loop detection and the analytic model described in the technical report would accurately predict expected delay, if they were maintained properly, and as additional data were gathered, the accuracy of the analytic model would improve. Providing information to motorists through media such as HAR, VMS, and computer terminals would give a wide audience border information in ways that would best suit their needs. In addition, public radio and TV would have access to accurate and frequent information.

To implement this system and evaluate its effectiveness, several events would have to take place. First, detectors would have to be installed to gather data and provide congestion/delay information to motorists crossing the border. Second, these data would have to be analyzed to determine the time advantages that would result from the choice of one route over another at any given time. If there was a significant time advantage, then the motorist information system could be enhanced to produce further improvements. If the delay could be greatly reduced, then more costs could be justified. Finally, once the detectors had been placed and the range of delay across the border had become available, the information could be tailored to motorists' needs. The information system could be implemented in a fully automatic manner, with the exception of regular evaluations and credibility checks.

INTRODUCTION AND BACKGROUND

PROJECT MOTIVATION

The United States/Canada border in Whatcom County, Washington, has lately been the topic of much concern because of a steady increase in traffic volumes. Since 1986, automobile and commercial traffic crossing the border has increased dramatically. In fact, since 1985, border crossing traffic has increased over 126 percent at just the two crossings in Blaine (Peace Arch and Truck Crossing), with similar increases at Lynden and Sumas (see Figure 1). This increase is due in part to attractive shopping, changing tax structures, increased mobility, and a general increase in population. Canada has increased the number of border agents to accommodate the increase in northbound traffic, but unfortunately, the traffic peaks are less predictable than those of urban traffic. Therefore, adequately staffing the facilities has become a difficult task.

Providing congestion/delay information to motorists might help to redistribute trips, either by time or route. Redistributing trips would lower peak volumes, which would result in reduced delays, smoother traffic flow, and fewer accidents. In addition, motorists generally experience less stress, even if they can not modify their trips, when they have advance knowledge of congestion and the reasons for the congestion. Motorists would not be the only beneficiaries. Border agents would see a change in their work load as the traffic was distributed throughout the system; air quality would be enhanced by the reduced delay; and business owners would see mobility increased along the streets near their stores. Although providing information to motorists would not be a cure-all for the congestion, it would be perhaps the least expensive, implementable alternative.

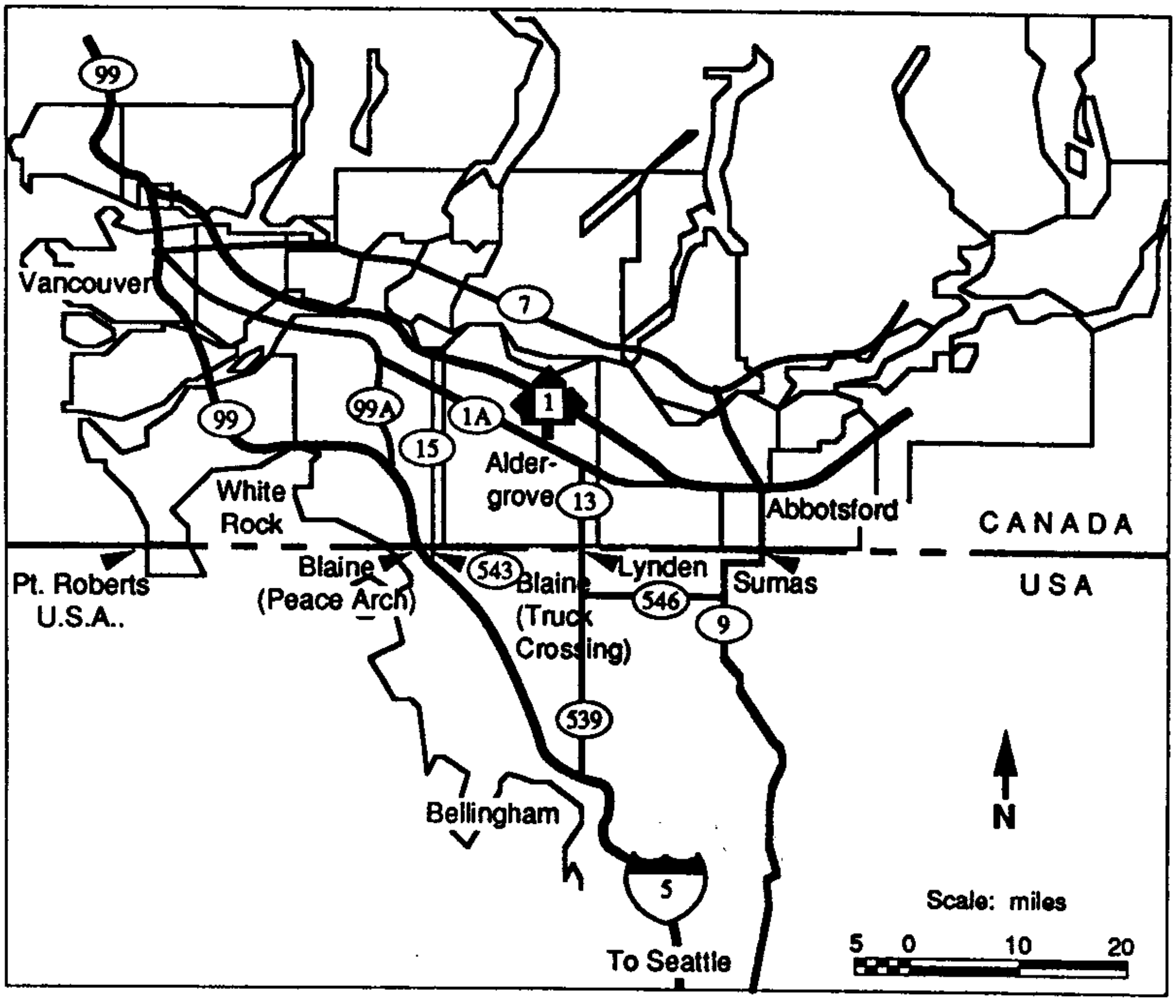

Figure 1. Highway Map

RESEARCH OBJECTIVES

The objectives of this study were to evaluate technologies for obtaining and providing automated traffic and delay information to the motoring public at critical locations. This evaluation was based on congestion/delay data collected at the Blaine I-5 border crossing.

A further evaluation of the most promising technologies will be conducted near the USA/Canada border. It will cover the conceptual evaluation of available technologies and address the relative usefulness of alternative systems. These evaluations will aid future consideration of advanced technologies for automatically obtaining congestion and delay information and disseminating it to the motoring public.

RESEARCH APPROACH

A literature review revealed that the provision of congestion/delay information to motorists had the potential to substantially decrease total vehicle delay. However, the credibility of the information was found to be very important to the eventual success of any motorist information system. Therefore, the researchers first focused on the collection and statistical evaluation of congestion/delay data (i.e., a traffic study). This traffic study was the primary research approach and was supplemented with material from a review of related literature.

This traffic study yielded recommendations regarding the following issues:

- the best ways to collect the required data for estimating congestion delay,
- procedures for implementing the real-time data collection congestion/delay estimation process,
- congestion/delay information dissemination options, and
- system cost estimates.

PROCEDURES AND DISCUSSION

TRAVEL STUDY

Objective

The purpose of the traffic study was to determine a method for estimating the time delay that a motorist could expect to encounter when crossing the border. The researchers were not interested in knowing how long a person had waited in line but how long they could expect to wait upon arriving at the back of queue.

Possible Predictors

There are many predictors for delay at the border. Some of these can be automatically observed and reported in real time, such as volume, queue length, number of lanes open, time of day, service time, and vehicle classification. Other predictors can be observed and reported manually, such as the number of staff on board, the number of motorists who need to make declarations or stop at immigrations, and the number of open lanes.

For credibility, it is important that the traffic operation observations are accurate. Without credibility, the system will be of little value to motorists or traffic operations personnel. A ±10-minute level of accuracy is desirable.

Site Location

Each of the four crossings (see Figure 1) is unique and offers different challenges. The crossing at Sumas is a three-lane system that can be accessed from Cherry Street in the heart of Sumas. Several side streets and stores near the crossing allow for mid-queue entry into the system. Also, the traffic contains both trucks and cars. The mid-queue entries and vehicle mix make analysis of the traffic difficult.

Lynden is a small facility, with only two lanes and a separate truck facility. The traffic volumes are lighter at this location than at the other crossings and offer little value for comparison.

The truck crossing in Blaine has many problems, most of them related to the geometrics of the access road. Autos and trucks must wait in the same line if the queue is long, and if the truck holding area is full, trucks must wait in line with the autos, blocking auto access. There are also mid-queue entry problems, which hamper determination of volumes and travel times.

The I-5 crossing in Blaine has the least complex traffic type and geometric design. There are no truck facilities and no mid-queue entry problems. Technically, the on-ramp is a type of mid-queue entry, in that vehicles can enter the queue at a place other than at the back. However, unlike the other crossings, these on-ramp entries can be accurately counted, as all vehicles that use the ramp have no other choice than to proceed north. The on-ramp is the only area that requires special consideration and can be a point of congestion. When queues are longer than the ramp, PACE motorists sometimes drive on the shoulder or the park lawn to gain access to "their" lane. This disrupts the flow of the on-ramp traffic, as well as the right-hand general purpose traffic.

For the reasons mentioned above, the I-5 crossing was chosen for the study site. The researchers hoped that the results of this study would also provide a good basis for future consideration of mid-queue entries and truck traffic at the other crossings.

Methodology

Equipment. Because no traffic detection instruments were located near the border, portable, cost effective equipment was needed. Pneumatic road tube counters were chosen for detecting volumes, and a license plate matching technique helped determine the time in system and service times for individual vehicles. Laptop computers were used at the service end of the queue to record service times, exit times, and license plate identification. At the back of the queue, license plate identification, arrival times, and queue lengths were recorded on paper and later coded into a database for analysis.

Volumes. WSDOT placed pneumatic road tube counter stations at the exit of the U.S. customs area for the southbound traffic and north of the last on-ramp for the northbound traffic (see Figure 2). Southbound total traffic volumes were recorded at 5-minute intervals. The northbound volumes and the PACE lane volumes were separated and recorded at 5-minute intervals.

In future studies, the northbound volume detectors should be placed farther south on the mainline, and an additional tube should be placed on the on-ramp, as well as in the PACE lane. This arrangement will more accurately detect volumes when the queues are longer than the on-ramp.

Service Time. As mentioned above, laptop computers were used to determine the service times of vehicles. These computers were located under the eaves of the customs building and out of the flow of traffic (see Figure 2). From there, all six lanes were visible to the PC operator. The program allowed the operator to press "enter" on the PC when a vehicle began to leave the service booth. This action would record the time when the following vehicle began to enter the transaction area. Then the first four digits of the vehicle license were entered as they came into view, and finally, the operator pressed "enter" to record the exit time of the vehicle when it began to exit the system. To avoid monitoring only one lane, the operator would wait for the next vehicle in the system to exit and repeat the process — usually in another lane.

Time in System/Wait Time. To record the time that a vehicle was in the system, records were matched with the use of database commands. These records were matched against three criteria. First, the license plate had to match; second, the exit time had to be after the entry time; and third, the speed of travel through the system among the matches had to be consistent. Total time in the system and wait time were calculated for each matched record. Total time was calculated by subtracting the entry time from the exit time, while wait time was calculated by subtracting service time from total time.

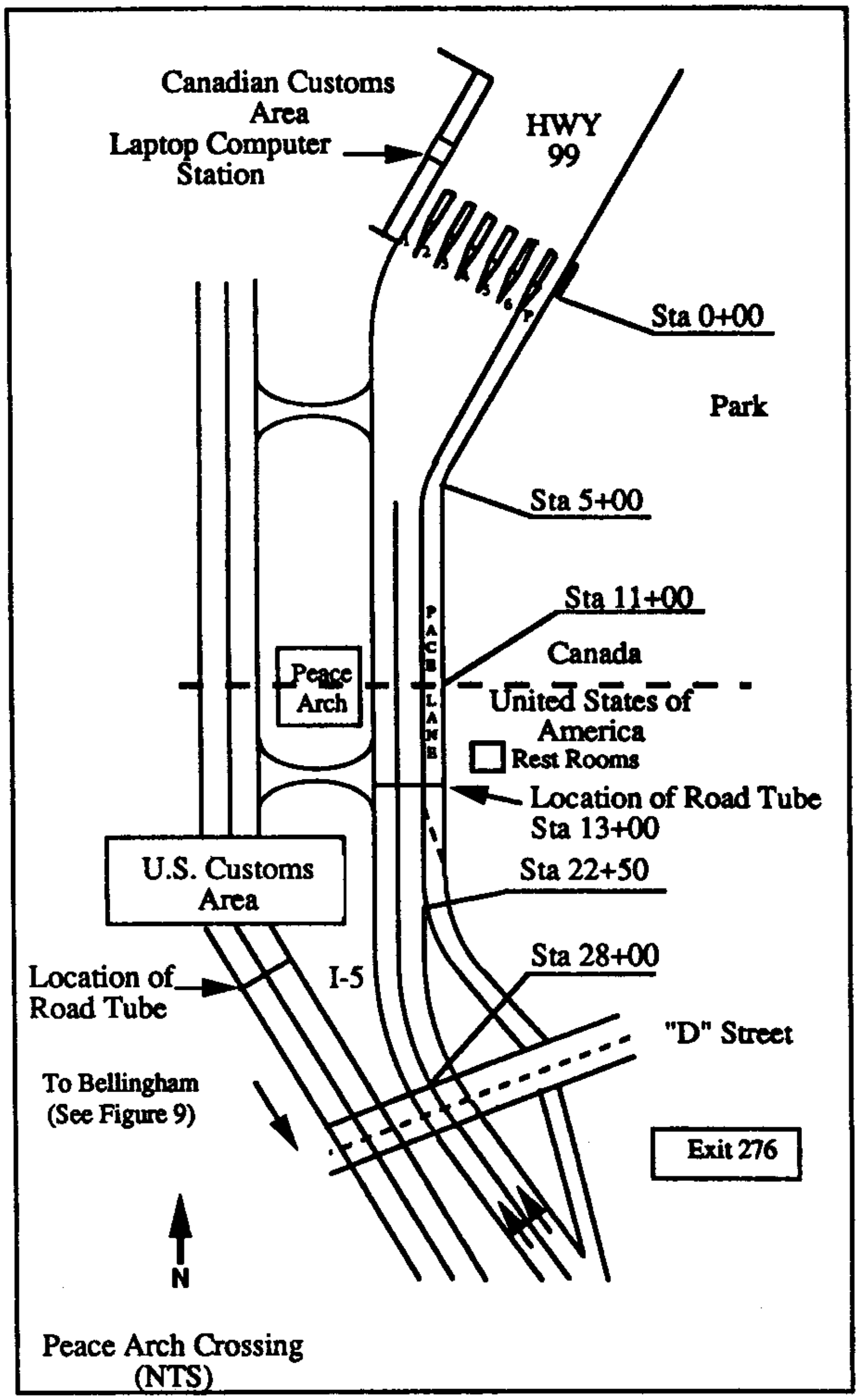

Figure 2. Peace Arch Crossing With Study Features

TRAVEL STUDY ASSESSMENT

Database Configuration

The study period covered nearly 18 hours, 10:00 AM to 8:00 PM on Wednesday, September 4, 1991, and 8:00 AM to 4:00 PM on Thursday, September 5, 1991, at the I-5 crossing north of Blaine. During the study period, 8,085 northbound vehicles crossed the border at Blaine. Of those vehicles, 50 percent were recorded on one database as they arrived at the back of the queue, and 20 percent were recorded on a separate database as they exited the system. These two databases were combined into a final database for analysis with license plate matching techniques. This procedure provided complete information on 11 percent of the traffic that crossed the border during the study period. In other words, of the 8,085 vehicles that crossed the border during that period, information concerning the time of day, length of queue upon arrival, individual vehicle service time, total time in the system, and wait time were recorded for 910 vehicles (see Table 1). Other information that was added to the database included the number of lanes that were open at the time of a vehicle's arrival and the north and south volumes at 5-, 15-, 30- and 60-minute intervals before the vehicle's arrival. Another variable was calculated to provide information on the effect of lanes opening and closing. Although operations did not permit lanes to be closed during heavy traffic, many lane openings were observed. Three similar variables were calculated on the basis of a lane opening during some prespecified time immediately before a vehicle's arrival. The three

Table 1. Travel Study Count Data

Location	Wednesday		Thursday		Combined	
	Count	Percent	Count	Percent	Count	Percent
Back of Queue	2325	70.8	1726	35.9	4051	50.11
Front of Queue	707	21.5	950	19.8	1657	20.49
Matches	334	10.18	580	12.08	910	11.3
Total Volume	3282	100	4803	100	8085	100

prespecified time intervals were 5, 15, and 30 minutes. The best of these three variables was always the 15-minute interval. The value of the variable was assigned a 1 if a lane was opened within the specified time period and a 0 otherwise.

General Results

Wait Time. Of the 910 vehicles that were tracked through the system, the average wait time in the system was 20.19 minutes, with a standard deviation of 11.76 minutes. Border policy makers have set the desirable maximum time a vehicle should be kept in a queue at 20 minutes, but because of increased traffic volumes, this policy has been relaxed. The maximum time that a vehicle was in the system was 59 minutes. Fifty percent of the vehicles had to wait less than 18 minutes, 75 percent less than 28 minutes, and 90 percent less than 38 minutes (see Figure 3).

Length of Queue. The average queue length was 1,190 ft. Fifty percent of the vehicles faced a queue of 1,050 ft. or less, 75 percent faced a queue of 1,840 ft. or less, and 90 percent faced a queue of less than 2,380 ft. (see Figure 4). The transition from two lanes to six occurred between 300 and 500 feet from the border. Of course, all six lanes were not always open.

Northbound Volumes. North- and southbound volumes were collected at 5-minute intervals. During the study, an average of 42 northbound vehicles crossed the counter every 5 minutes (standard deviation = 13), or 502 every hour. For queue lengths longer than 1,300 feet (where the counter was located) the counter would read a delayed volume. This was not detrimental to the study, however, since the 15-minute interval worked best. As many as 5 to 6 minutes may have passed from arrival time to the time a vehicle crossed the counter when the length of queue was longer than 1,300 feet.

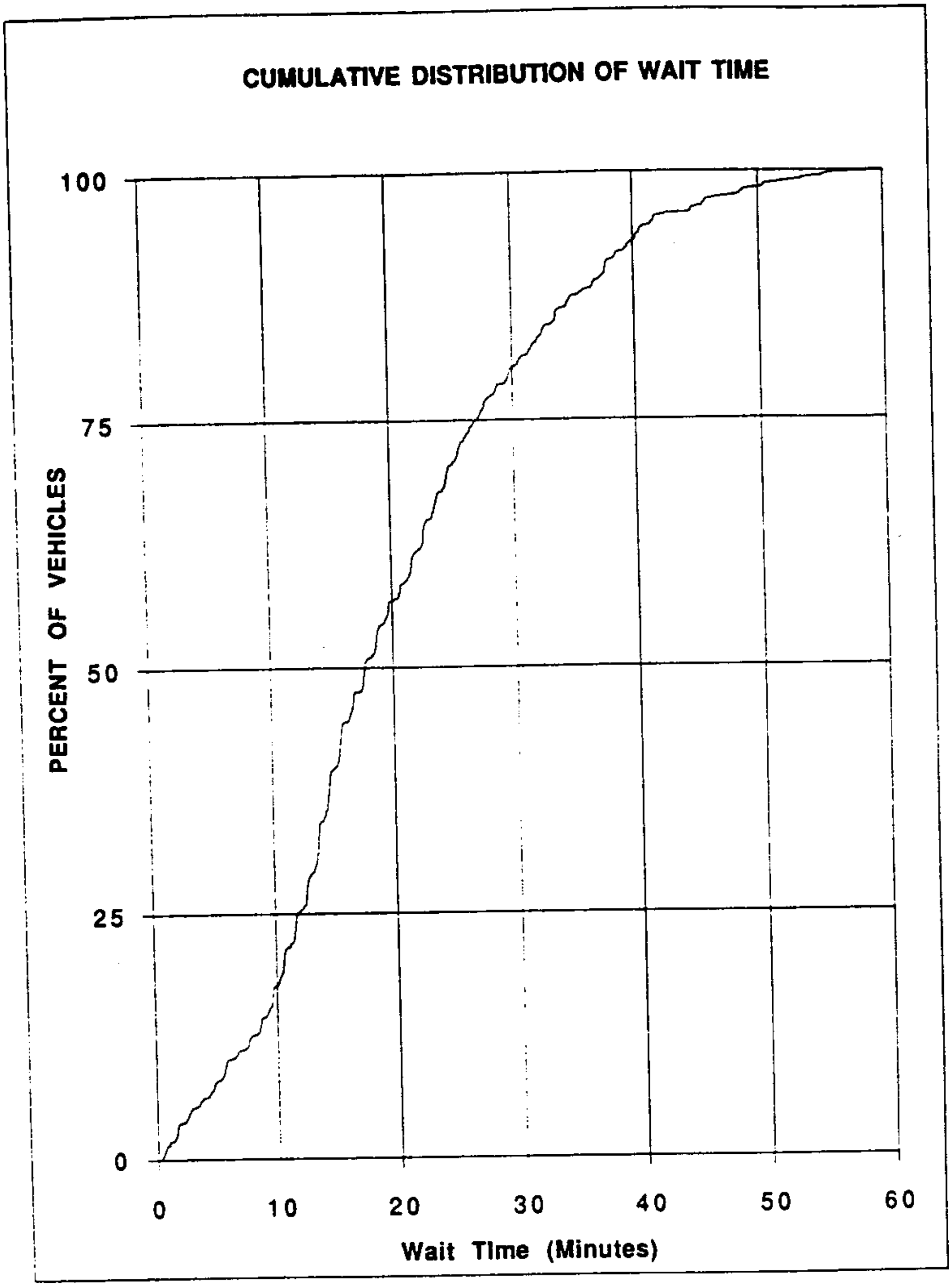

Figure 3. Cumulative Distribution of Wait Time

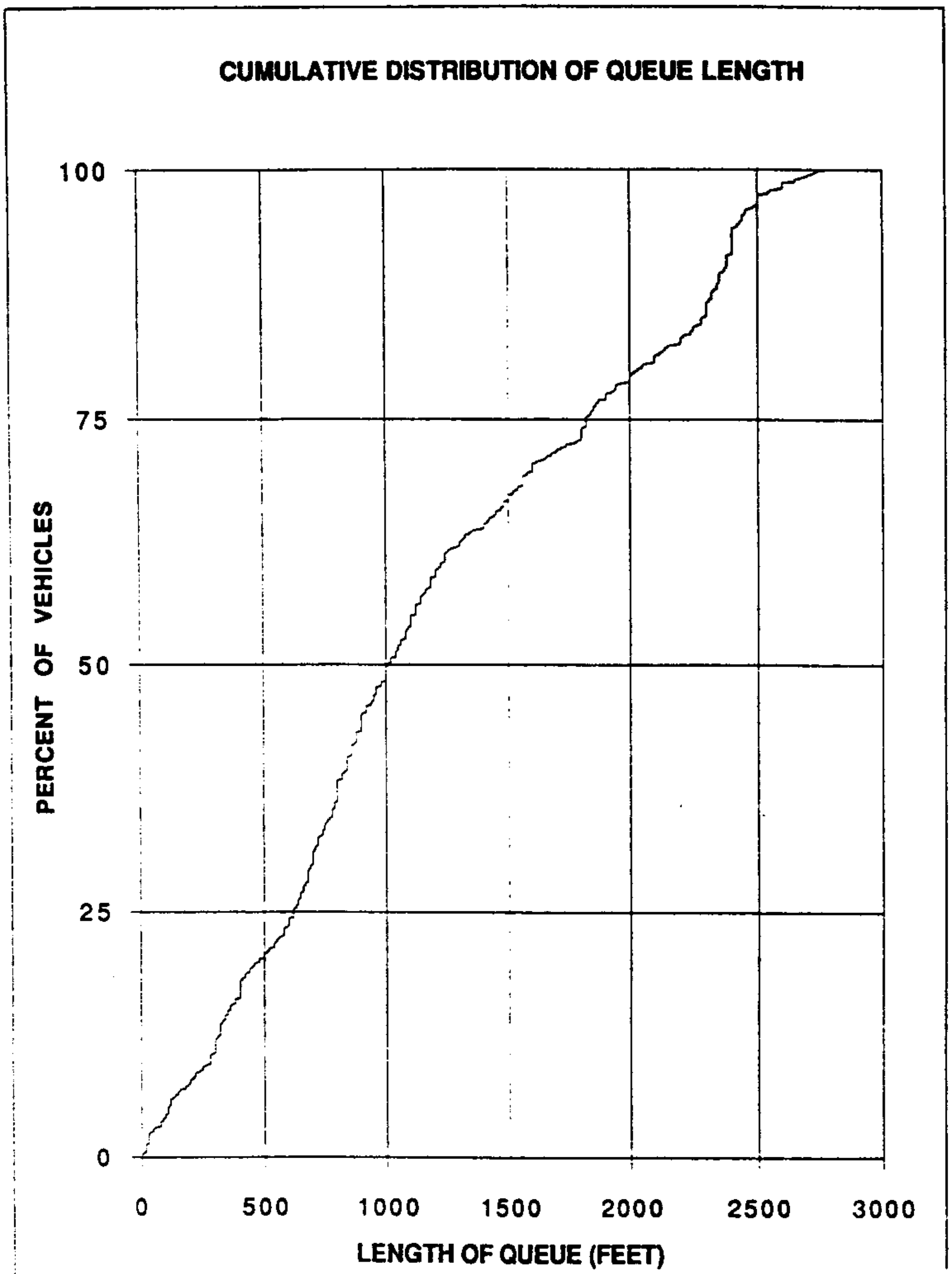

Figure 4. Cumulative Distribution of Queue Length

The number of vehicles using the PACE lane during the study was 857, or an hourly average of nearly 50, and the 5-minute interval average was nearly four (see Figure 5). According to Canadian PACE officials, total October PACE use was 25,549, or a daily average of 824.

Southbound Volumes. The southbound volumes were recorded to find a link or significant time lag between the southbound and northbound volumes. However, after the researchers considered the actual effects, the southbound volumes were not used. The southbound traffic totalled 9,980 vehicles, which were also counted at 5-minute intervals. This total equated to an hourly average of 576 vehicles and an average of 48 vehicles for each 5 minutes.

MODELING RESULTS

Duration Modeling Theory

Duration models have been used in accident risk analysis and for understanding commuter activity. One promising approach is to use duration models that consider the conditional probability of ending the wait, instead of the traditional direct probability approach. This study used duration models to analyze queue wait times. See the technical report of this study for details.

Variables Used to Predict Queue Wait Times

The best duration model was found to include several predictive variables. The following is a description of each of the predictive variables used in the model.

- Natural log of the length of queue (LDIST)

  The natural log of the queue length upon a vehicle's arrival was found to be much more significant than just the distance itself. The implication was that a change in queue length when queues were excessive would have a smaller effect than that same change would have on a shorter queue length.

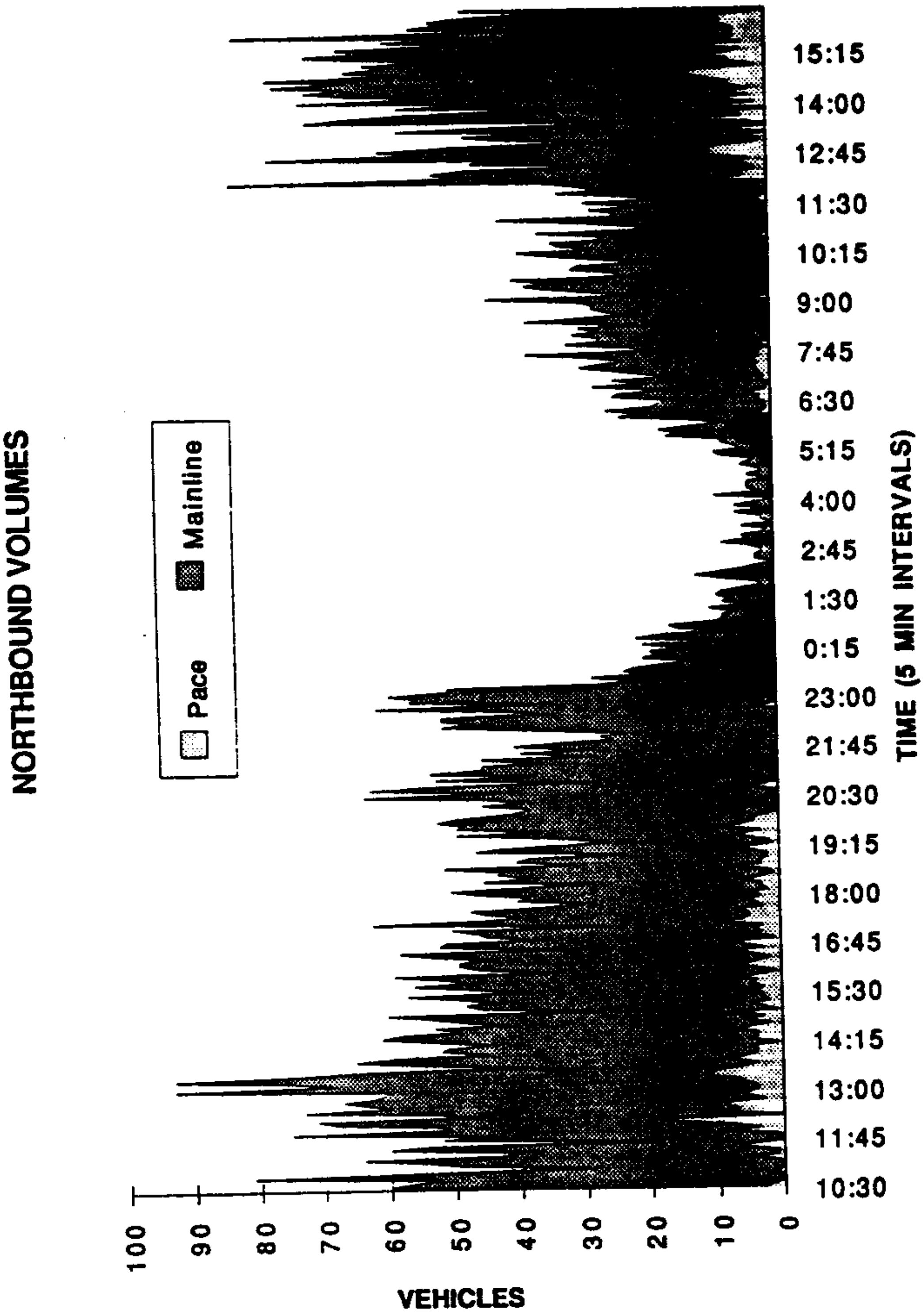

Figure 5. Northbound Volumes

- Time factor (TF)

  A binary indicator variable was used to model the effects of time of day. A 1 was coded into the database if a vehicle arrived between 10:00 AM and 2:00 PM, and a 0 was coded otherwise.

- Natural log of the number of lanes open (LLNOP)

  A third variable was the natural log of the number of lanes that were open upon a vehicle's arrival at the back of the queue. Its use also suggested that a change from one open lane to two open lanes would have a larger effect than a change from five open lanes to six.

- Lane open factor (LOF)

  A fourth variable was used to calculate the change that would occur when a lane was opened. A binary indicator variable was used to model this effect, i.e., a 1 was coded into the database if a lane opened within 15 minutes before a vehicle's arrival at the back of queue, and a 0 was coded otherwise. Actually, several variations of this indicator variable were tried, but the variable with the 15-minute time period always produced a better model.

- Average service time up to 30 minutes before arrival at the back of the queue (ST30)

  A fifth variable was the average service time up to 30 minutes before a vehicle's arrival at the back of queue. The value of this variable was produced from the larger database, in which service times were recorded for 1,657 vehicles.

Note: This analysis procedure can be viewed as a mixture of traditional queueing analysis inputs and outputs. Where queueing analysis uses arrival rates and exit rates to calculate the length of queue and system delay, this method used service times, length of queue, and others, to estimate the wait time.

Several other variables that were tried included various time slices of volumes, system exit rate (vehicles per minute), linear rather than the natural log of distance, and number of lanes open, as well as a binary indicator variable for closing a lane. Efforts were made to explain more of the distance variable by splitting it into two sections (i.e., one variable for length of queue less than 350 feet and another for queue length greater than 350 feet), but the statistical results were disappointing. Splitting the distances was intuitive, especially at the 350 foot level, because of the geometric transition from two to six lanes. Many combinations of the above variables were modeled together. Initially, the variables that were expected to produce a good model were those traditionally used in queueing analysis: arrival rate, service time, and the number of channels open. However, the length of queue variable was statistically so strong that it always dominated the model. Volumes, for example, should have been a solid independent variable. However, almost exclusively, when volumes were used in any combination with other variables, the sign was negative, indicating that an increase in volume would result in less wait time.

EVALUATION

To evaluate the model, the wait time was estimated for each record in the database using the duration model and was then compared to the measured wait time. Model estimated wait times were calculated and are shown graphically in Figure 6. (Figure 6 has an example of Model 1. See the technical report for details). However, overall, the duration model developed in this report predicted delay with remarkable accuracy, given the length of the vehicle queue.

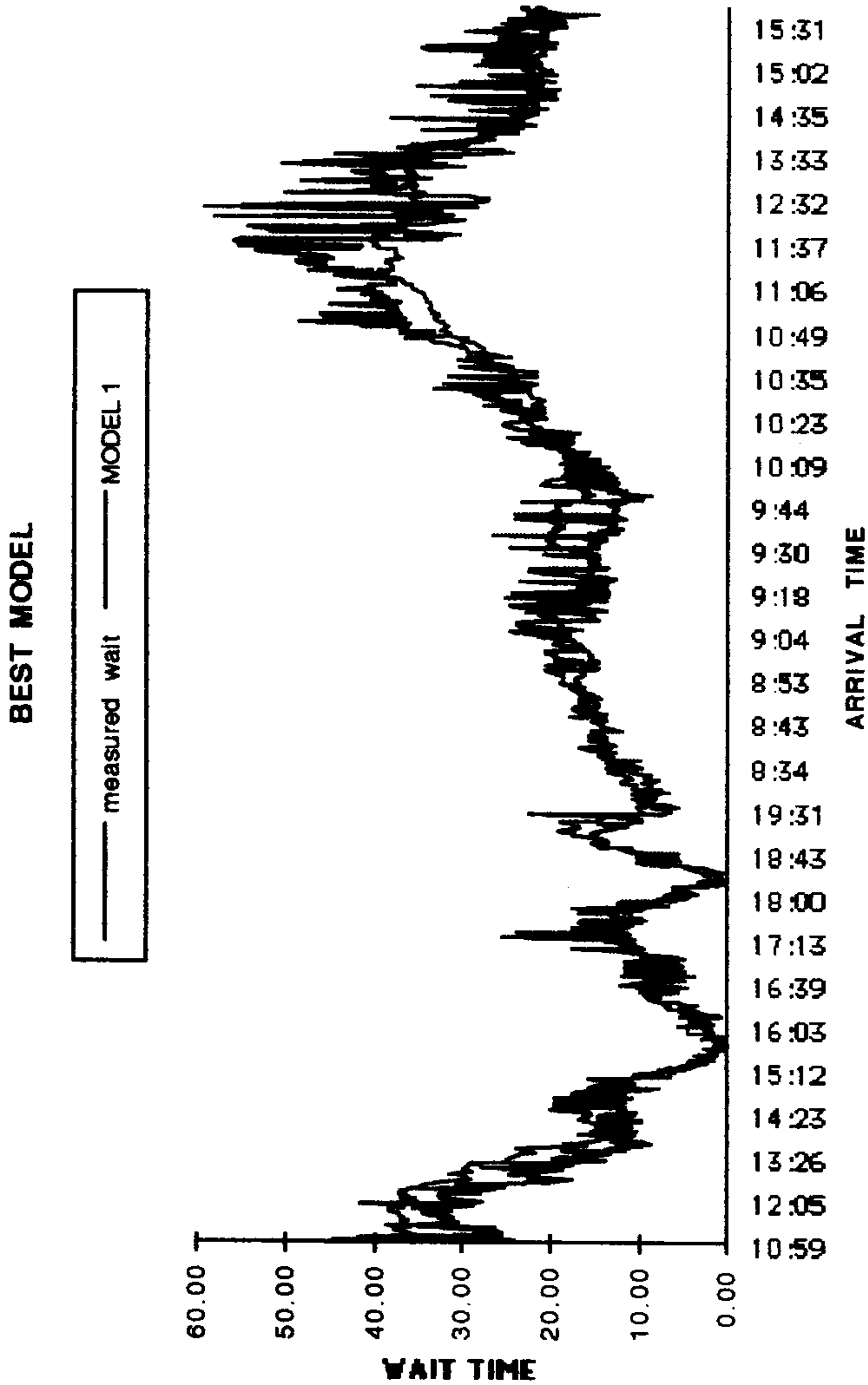

Figure 6. Estimated Wait vs. Measured Wait

APPLICATION AND IMPLEMENTATION

TRAVELER INFORMATION SYSTEM GOAL

Given the duration model and its capability to accurately predict vehicle delay, we can now focus on the goal of the traveler information system, which is to aid customs and transportation officials in more efficiently moving travelers through the border crossing facilities while reducing their delay and travel related stress.

ISSUES

To accomplish the task of implementing a traveler information system, several issues must be addressed. To reach the goal stated above, the system must be accurate and perceived to be credible. Both accuracy and credibility can be achieved through effective design, installation, and maintenance of the system. The design of the system must allow the system to be installed and operated with minimum amounts of redesign. This is especially important in light of the number of technologies currently being developed. The installation of existing and proven technologies where applicable will maximize the use of a maintenance department's knowledge and expertise, whereas the use of new and unproven technologies would not only require extra work to fit the technology to the application but would also require additional training for maintenance personnel.

Consistency is also important in maintaining the credibility of a traveler information system. Route signing must be consistent with other signing conventions adopted throughout the roadway network. The purpose of traveler information systems is to divert motorists to alternative routes, therefore, the signing of these alternative routes must accommodate all travelers.

SYSTEM IMPLEMENTATION

The following is a list of the steps needed to implement the total system effectively.

1. Install detectors at each border as required.
2. Place the order for the sign systems to be installed.
3. Gather data.
4. Determine the model variables and their ß using in-place detector systems for each crossing.
5. Determine the range of the dependent variable (wait time) to determine message content.
6. Program and install the computer system.
7. Implement the system without broadcasting information to test for accuracy.
8. Install the signing system.
9. Broadcast the information.

Once these steps have been completed, an evaluation process should be conducted to determine how travelers are using the system and to see whether the goal of the system has been met.

COMPONENTS OF AN AUTOMATED TRAVELER INFORMATION SYSTEM

The four main components of an automated traveler information system are vehicle detection, data communication, data analysis, and information dissemination. The following sections discuss each of these components and list the requirements for each type of component to be implemented.

Vehicle Detection

Vehicle detection is needed to collect traffic parameters such as queue length and service time data. Several types of detectors are operational today for detecting queue length and service time. These include induction loops, magnetometers, infrared sensors, ultrasonic sensors, photoelectronic sensors, and video imaging. As discussed above, use of a technology that maintenance crews are familiar with will minimize training and will make maximum use of existing knowledge at that level.

During the traffic study for this project, several variables were found to be useful. The length of the queue was the dominant variable. For actual implementation, detectors would need to be placed at intervals (or at points of conflict) that would achieve the desired level of accuracy. Figure 7 shows the accuracies achieved when the database queue lengths were modified to simulate detectors spaced at both 500- and 1,000-foot intervals. The distances used were mid-interval distances. (That is, if queues were less than 500 feet, a 250-foot interval was used for the 500-foot interval spacing. If queues were between 1,000 and 2,000 feet, a 500-foot interval was used for the 1,000-foot interval simulation.) Figure 7 supports the use of closer detector spacing. On facilities with multilane approaches, detectors should be placed in just one lane, since queues seem to form nearly evenly in adjacent lanes. The queues to be detected here are different than those found at traffic signals. While traffic is usually stopped at signals, the queues at the border are nearly always moving. Therefore, the algorithm for queue detection should evaluate occupancy percentage or travel speed to determine whether border queues exist at a specific location.

Current detection technology will allow the detection system to estimate the length of queue between detectors. This could be achieved with a detector controller that scanned two or four channels for processing different types of data. One channel might be vehicle count, another occupancy, another flow rate. By using two channels, occupancy or speed and vehicle count, an algorithm could determine that if a queue existed at detector 1 and not at detector 2, the estimated length of the queue would be the queue length up to detector 1 plus the number of vehicles between the detectors,

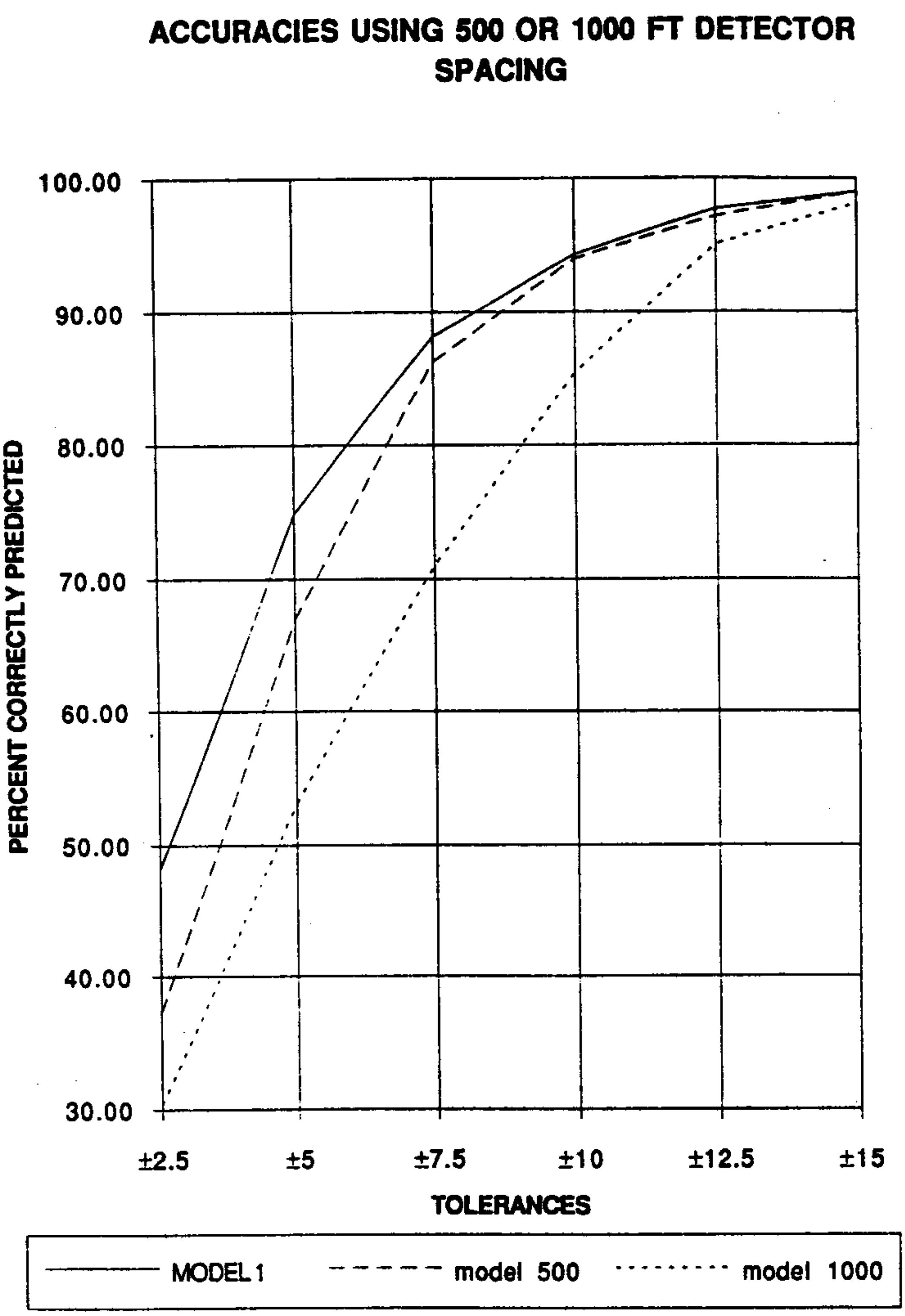

Figure 7. Detector Spacing

multiplied by some assumed vehicle and headway length. The number of vehicles between detectors could be used to estimate queue lengths between detectors for both increasing and decreasing queues. To estimate increasing queues, the detectors would simply count the number of arrivals passing detector 2 and subtract the number of departures at detector 1. Of course, some logic pertaining to minimum and maximum estimated queue length would be necessary. To estimate decreasing queues, the number of vehicles between detectors could be estimated with, first of all, an observation of the average number of vehicles that usually fit between the detectors. Then the algorithm would add the number of arrivals and subtract the number of departures to obtain a new estimate of the number of vehicles that were between the detectors. The same minimum and maximum queue length logic would apply.

Other necessary detectable variables would include service time and lane use. Note that during the study the researchers observed border agents leaving their booths to walk south into the sunshine if the temperature in the booth was cold, or north into the shade if the booth temperature was warm. Thus, the detection zone would be difficult to define. Perhaps a policy change could be suggested to keep the detection zone confined to the booth area to better facilitate the traveler information system as a whole. The researchers realize that such a policy change might never be accomplished. Therefore, a detection system that would accommodate the current detection zone must be designed. The service times could be obtained with a presence detector upstream of the border and a passage detector downstream. The presence detector would serve two functions. If the detector was occupied, the computer would recognize that the lane was open and send a lane use signal to the controller; if the lane was open, the service time would then be the time interval between the activations on the downstream passage detector.

A more desirable and cost-effective approach might be to replace the upstream presence detector with a system that connected directly to the light switch that activated the lane open arrow. When the operator switched the arrow lights on, the computer would recognize that the lane was open, and service times could be determined.

Detectors should also be placed where traffic volume data could be gathered. Although the study model found volume data to be insignificant, the data would be appropriate to gather for further analysis and statistical reference. The volume detectors should be placed in each lane of traffic and far enough upstream so that the queue would not back up over the detectors. Other volume detectors should be placed at the Peace Arch crossing on I-5 on the on-ramp at exit 276 and on the PACE lane. Volume data would be desirable for all crossings; however, because of the number of mid-queue entry points along the routes other than the Peace Arch, accurately detecting all northbound traffic might be difficult.

In addition, the proportion of trucks in the system involved in congestion at the truck crossing, Lynden, and Sumas would be desirable to know. Detectors could be used to separate the auto volumes from the truck volumes. Although this variable was not tested for significance, its significance is appropriate to assume because much of the congestion affects the truck lanes.

Data Communication

Communication, in this case, means the method by which information would be sent from the detectors to the central computer station and from the computer station to the various message components, i.e., highway advisory radio (HAR), variable message signs (VMS), or a computer terminal. Most likely, information would be sent via commercial telephone links to the central computer station. Once the variable message signs have been installed, the appropriate technology to use could be determined.

Data Analysis

Another primary component of this traveler information system would be analysis of the data to estimate the expected delay that travelers would encounter. The following section discusses applications of the study model and the elements necessary to implement a real-time model.

The Study Model. The primary purpose of the study model was to uncover relationships between the dependent variable (wait time) and possible independent variables. The exercise was successful in that several variables were found to be significant in estimating wait time. The major shortcoming of the study model was that the method in which the study data were collected was somewhat different than the way they would be collected for the implemented system. For example, service times were collected on just a portion of the crossing population in the study, but for actual implementation they would be collected for the entire population.

Implementation Model. After the system detectors had been placed, data would have to be gathered and the traffic conditions remodeled. Data for the dependent variable would have to be manually collected over several days, both weekdays and weekend days, to have a larger database from which to model. One way to gather the wait time data would be to have one person stand at the back of the queue and pass out cards with a date and arrival time stamp on them, while a second person collected the cards at the border booth and stamped the end of wait time on them. (A toll booth operation in France uses video image processing system (VIPS) to track random vehicles through the system to gain time-in-system information.) This information would then have to be coded into the database with information gathered with permanent detection equipment. Other information that would be useful to model includes the length of the queue, time of day, number of lanes open, service time, auto volume, truck volume, day of week, and a lane open/closed indicator variable.

Queue length should be modeled as the natural log of the distance from the border agent booth to the back of the queue. As discussed earlier, this distance can be measured at 500-feet intervals accurately and estimated in between the detectors. Further study might provide evidence that detectors could be acceptably spaced at 1,000 feet if estimation of the queue length between detectors was determined to be acceptable.

A binary variable for the time of day or peak factor might be used, as it was the second most significant variable in the study model. Along those lines, a day of week factor might be necessary if it was found to be significant (i.e., Sunday might have longer delays than Monday, and Saturday longer delays than Sunday). This could be modeled and used if significant.

Another variable that was very successful in the study model was the number of lanes that were open. However, this variable was only considered significant when the natural log of the number of open lanes was used.

The study model also used a binary variable to signify when a lane opened in relation to a vehicle's arrival. This variable was significant and should be considered, as well as a variable to indicate a closed lane. The study model found that the variable for opening a lane was most significant up to 15 minutes following the opening of the lane. While the study model did not have enough data to support the effects of closing a lane, further data collection and analysis might provide significant findings. However, lanes are not often closed when queues are long.

Modeling service time was difficult. The service time variable used in the model was calculated by averaging the service time for 30 minutes before a vehicle's arrival. This was a very cumbersome process, especially for the value it contributed to the model. However, service times are intuitively a factor in the wait time. In addition, when the detector system was in place, it could be programmed to return the data in whatever form was desired, i.e., at 10-minute, 1-minute, or 30-second time periods. Therefore, initially the system should use the service time variable on 30-minute averages, updated every minute, i.e., the controller would keep a continuous average of the service times only for the most recent 30 minutes and report this information to the computer system for analysis.

Finally, the use of volumes in the study model did not produce intuitive results. The signs were nearly always negative, indicating that an increase in volume would result in a decrease in wait time. Nevertheless, the nature of queueing problems suggest that volume should be a good variable and should be considered in further study. Keep in mind, the volumes at crossings other than the Peace Arch would not be total volumes unless a detector network was used to determine the side streets' contribution to the northbound flow. In addition, because of the number of truck related problems, it would be interesting to study the effect that the number of trucks in the stream had on the delay. Officials know that when trucks are denied access to their facilities, some truck drivers divert to side streets to enter the queue nearer the border, causing additional delay. However, they do not know whether an increase in truck volumes has an impact on auto traveler delay, although they do know that an increase in auto traffic has a significant impact on truck congestion.

Once the data had been coded into a database, a software program such as LIMDEP could be used to find the best model coefficients. During the testing phase, all data would have to be recorded and databased for modeling.

Several runs involving many combinations of variables might be necessary to determine the best model. To know whether the best model had been achieved, two outputs would have to be examined. One indicator of a good model is the log likelihood found in the output of the model. The higher this value is, the better is the model. The log likelihood should always be negative; therefore, a -172 signifies a better model than a -1,000. A second indicator of a good model is the sign and t-stat of the ß's. The sign should be negative if an increase in the value of the variable should intuitively accompany a decrease in the wait time, i.e., an increase in the number of open lanes should decrease the wait time. On the other hand, the sign of the ß should be positive if an increase in the variable should intuitively accompany an increase in wait time, i.e., an increase in volume should result in an increase in wait time. The t-statistic of the variable, which is also found in the output, should be greater than |1|. The farther the t-stat is from zero, the more significance it lends to the model.

Other Analysis Techniques

Other methods, such as queueing analysis, can be tested against the log-logistic methods described in this report to determine whether a simpler analysis approach could maintain the accuracy and credibility of the system. These tests could be accomplished once the detector system had been placed and was accurately detecting traffic parameters. Some areas to test include loop failures and re-initializing the system after it has been interrupted.

Queueing analysis uses arrival rates and exit rates to determine queueing parameters such as delay time. If the detector system was not functioning properly, the arrival rates would be unknown, and queueing analysis would not be able to provide credible information. In addition, once the system had lost count of the number of the vehicles in the system, it would be difficult to restart. One re-initialization possibility would be to manually count the number of vehicles in the system and manually enter the number to restart the process. However, the most likely possibility would be to wait until no vehicles were in the system. This is the most likely possibility, since the border is nearly 100 miles from any traffic management center. Other characteristics of the queueing analysis approach that would have to be worked out are mid-queue entries and truck volumes. Perhaps these characteristics would not be significant enough to affect queueing analysis; however, if queueing analysis was used, these variables would have to be closely observed.

Information Dissemination

Highway advisory radio (HAR) is the primary dissemination component WSDOT is considering. Variable message signs (VMS) are also being considered as a component in further developmental stages of the system. In addition, a computer screen showing delay information might also be made available in shopping malls, gas stations, radio stations, TV stations, and even the office of the border crossing management.

Highway Advisory Radio. HAR has been successfully used in many motorist information systems. WSDOT operated a HAR system from the Bellingham area during Expo 1986 when traffic levels were expected to be high. The license has since expired, but WSDOT has submitted an application to reinstate the license. Locating the HAR antenna in Bellingham would allow motorists to receive information to help them choose any of the four alternative crossings. Alternatively, they might change their trip departure time or postpone the trip. HAR would also be a tool for businesses that wished to display border information to motorists who were still in their shopping area. A business could receive the radio message and manually enter the message into its own in-store dissemination system. Caution would have to be exercised in allowing this kind of activity to occur. If a business was motivated to use the message to keep shoppers in the store longer, system credibility would be lost. Efforts should be made to display the message correctly.

Variable Message Signs. Providing information through variable message signs is also considered a good alternative and has been used successfully in many areas. WSDOT is considering two types of signs for the border area. One type is an internally illuminated rotating drum with four sides available for messages. This type is currently being used in the area for weigh station information. Another type is also a rotating drum but is externally illuminated and uses regular highway signing material for the message face. This second type allows operators to replace the sign face more easily than on the internally illuminated type if the information requirements change over time. Figure 8 shows possible sign formats. The VMS would have a static message on the left side of the display showing the route, while the right side of the display would have a rotating drum face to display different messages for each route. A three sign system would be desirable for motorists in this area. One sign located near Bellingham would display

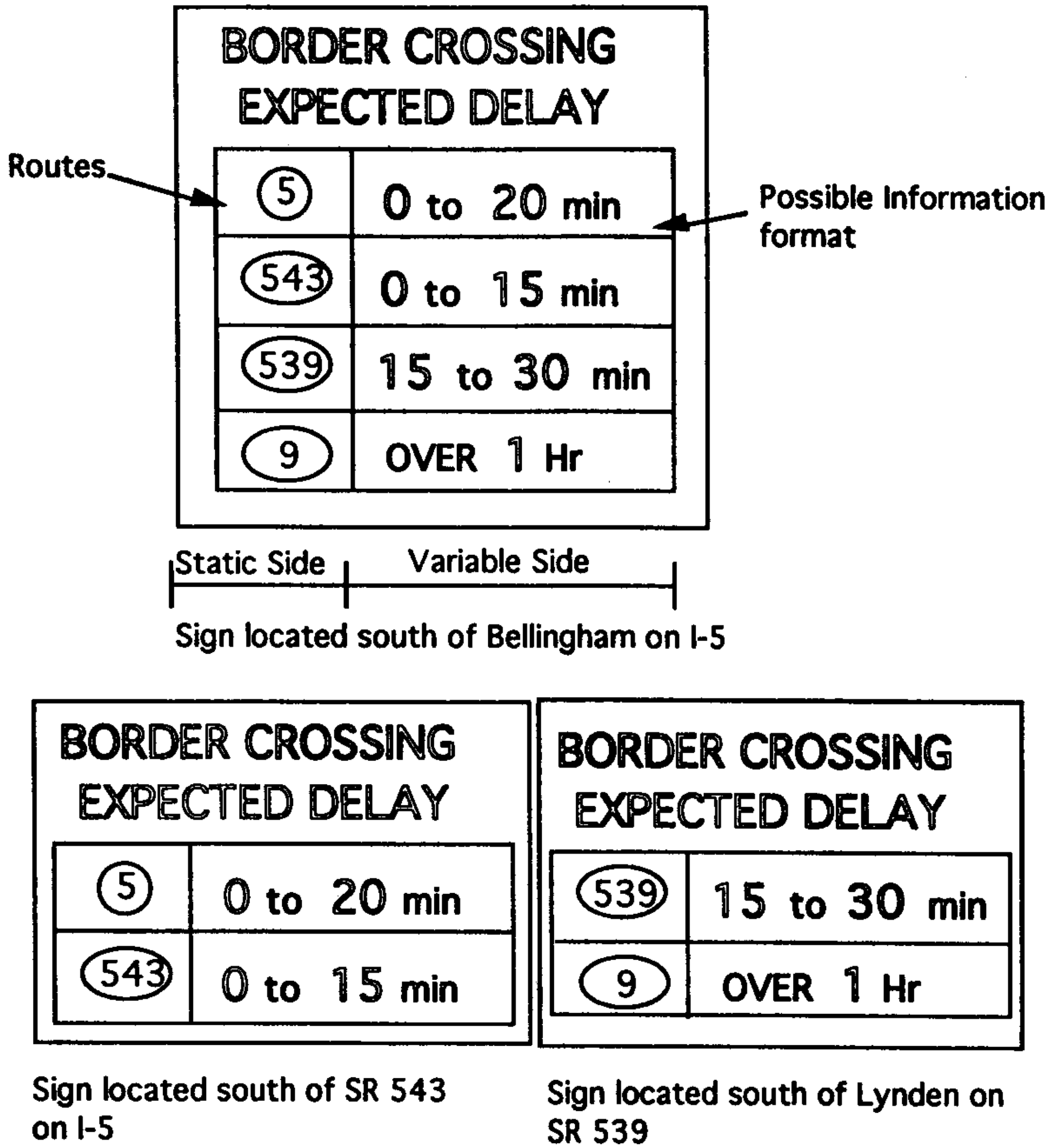

Figure 8. Possible Variable Message Sign Formats

information for all four available routes. A second sign on I-5 south of the exit to the truck crossing would display information pertaining to the I-5 and truck crossings. Athird sign near Lynden but south of the roadway leading to Sumas would display information pertinent to the Lynden and Sumas crossings (see Figure 9). This configuration would provide information to motorists who did not pass through Bellingham. In addition, stress levels have been reported to increase when motorists diverted to an alternative route did not know whether they had made the correct decision. This three sign dissemination system would reassure motorists that they had actually made the correct travel decision. An alternative to the three sign system would be to install the HAR in Bellingham and one of the two, two-route signs south of the truck crossing on I-5 and the other south of the highway to Sumas on SR 539 (Guide Meridian). This system would provide better coverage in the Bellingham area, especially for motorists who did not use I-5. The larger area of coverage would allow motorists to decide at Bellingham whether to go through Blaine or Lynden/Sumas. Minor decisions could be made on the basis of the information on the two VMSs located at the last decision points, as described above. The use of VMS without HAR would only benefit northbound motorists on I-5, whereas HAR coverage would extend beyond I-5 to the Guide Meridian Highway.

Computer Terminal. Studies have shown that a percentage of the motorists who seek travel information do so before their departure. These same travelers will alter their transportation mode, departure time, or route to better use their time. A computer terminal can effectively transfer information electronically and graphically to these pre-trip information users. The subscribers to this network would most likely not be individuals but rather companies, groups, or even businesses that desired to provide information to their employees and or customers. The electronic graphics display would show the alternative routes in map form for better recognition. Shopping malls could display this type of dissemination system, while the traffic management center could

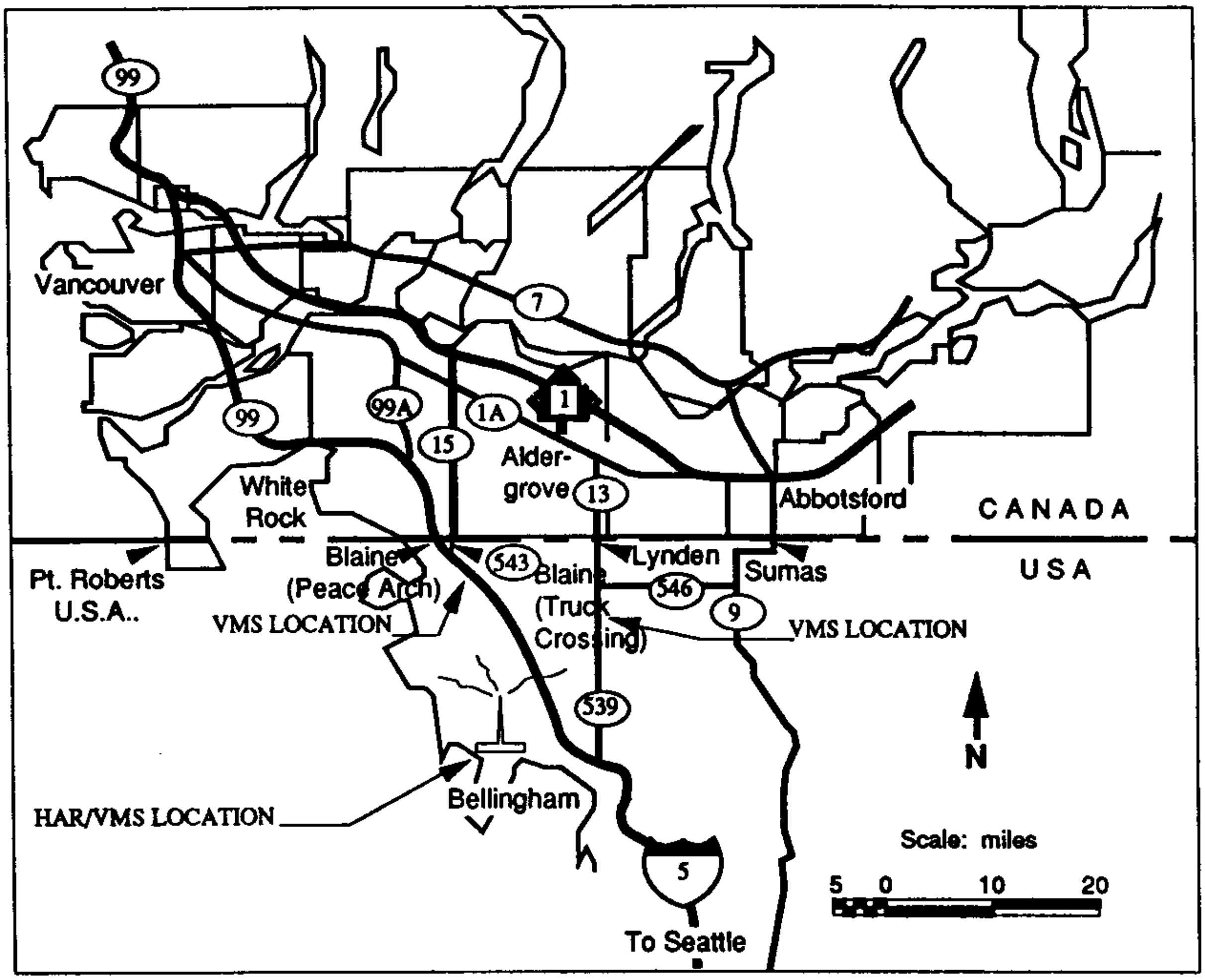

Figure 9. Vicinity Road Map Showing Location of VMS and HAR

maintain control of the message content. And because the motorists would not be in their vehicles when they received this type of information, a display of this type would provide a much greater amount of information than the in-vehicle types such as the HAR or VMS. This type of system would offer other types of advantages. Public radio and TV could access this information and broadcast it to a large body of listeners and viewers; traffic management centers at remote locations could view the conditions and make necessary adjustments; and customs management (not border agents) could achieve greater levels of efficiency by knowing the conditions across the border.

ACCURACY

The accuracy of this system would be dependent upon the care in gathering and analyzing the data. Proper matching of records would be mandatory, as would obtaining a good sized sample that was representative of the population. In addition, the model would require occasional updating to guarantee the credibility of the system. Accuracy could be tested periodically either by handing out cards stamped with date and time information to arrivals at the back of queue, collecting them at the front of the line, and stamping them with the exit time, or by driving and recording times much like in an arterial travel time study. These wait times could be validated by comparing them to the information that was broadcast to motorists before their arrival. Accuracy could be lost in the modeling process and in the information dissemination process. In addition, there could be some lane choice variance in the wait time, as pointed out in the travel study in an earlier chapter. Discussion with border officials suggested that this variance in lane choice is caused by agents who conduct both primary and secondary tasks in the booth. These officials also indicated a willingness to try to enforce an existing policy that prohibits the agents from conducting secondary duties in the booth. If this enforcement was accomplished, the accuracy of the model would greatly improve and the variation in wait time due to lane choice would decrease.