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

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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.

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

AUTOMATED VEHICLE DELAY ESTIMATION AND MOTORIST INFORMATION AT THE U.S./CANADIAN BORDER

by

Theodore Alan Paselk
Research Assistant

Fred Mannering
Associate Professor

Washington State Transportation Center (TRAC)
University of Washington, JE-10
The Corbet Building, Suite 204
4507 University Way N.E.
Seattle, Washington 98105

Washington State Department of Transportation
Technical Monitor
Les Jacobson
Urban Systems Manager

Prepared for

Washington State Transportation Commission
Department of Transportation
and in cooperation with
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Federal Highway Administration

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The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Washington State Transportation Commission, Department of Transportation, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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INTRODUCTION

The United States/Canada border in Whatcom County, Washington, has lately been the topic of much concern because of a continual increase in traffic volumes. Since 1986, automobile and commercial traffic crossing the border has increased dramatically. In fact, since 1985, the border crossing traffic has increased over 126 percent at just the two crossings in Blaine (Peace Arch and Truck Crossing). This increase is due in part to attractive shopping, changing tax structures, increased mobility, and a general increase in population. The number of Canadian Border Agents has been increased 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.

There are many ways to view this topic: economists predict losses in Canadian investment and patronage; air quality officials see reduced air quality; border agents feel rises in work load; communities are faced with congestion at their store fronts; travelers face higher levels of stress and longer and more frequent delays; and traffic engineers face a challenge. To the Canadian government, however, the delay may be perceived as an advantageous deterrent to shoppers that helps keep revenue at home.

The objective of this study was to determine an accurate method by which the Washington State Department of Transportation (WSDOT) can provide border crossing travel information to northbound motorists in Whatcom County, Washington, and thereby reduce potential vehicle delay. Reaching this objective involved two areas of study. The first was the collection and analysis of traffic data; the second was the dissemination of the information to the public.

Providing information to motorists might cause a redistribution of 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. The motorist would not be the only beneficiary. 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.

This report begins by describing the geography of both Whatcom County, Washington, U.S.A., and the Lower Fraser River Valley in British Columbia, Canada. From there it discusses several solutions that have been proposed, such as the PACE lane, advanced signing, new facilities, pre- and continental clearance, and others. Then several elements of advanced traveler information systems (ATIS) that are pertinent to the border situation (i.e., motorist behavior, vehicle detection, and information dissemination) are discussed. The site specific characteristics for each of the four crossings in Whatcom County are discussed, followed by the location and methodology of the traffic study that determined parameters for predicting delay at the border. Finally, the results of the study are described and requirements for a feasible automated traveler information system (ATIS) are provided.

BACKGROUND

The purpose of this section is to provide the reader with general information on the geography of the border crossing area in Whatcom County, Washington, and the Lower Fraser River Valley, British Columbia, Canada. This will include general information about the area's economic base and traffic and travel information.

Whatcom County

Whatcom County is the northwestern-most county in Washington state. To the north lies British Columbia, Canada, to the East Okanogan County, to the south Skagit

County, and to the West Island County and the Straights of Juan De Fuca. In 1990, Whatcom County had a population of almost 127,000 people, who were dispersed throughout several communities. Bellingham is the largest city and had a 1990 population of 51,875. Blaine, Lynden, and Sumas are the three border towns in the U.S. within Whatcom County, Washington. Blaine has a population of 2,650, Lynden 5,709, and Sumas 744. Lynden is approximately 3.5 miles south of the border on the Guide Meridian Highway (SR 539) but is the nearest town to the border along that route.

The main route through the area is Interstate 5 (I-5), which runs north from the southern border of California through Oregon and Washington to British Columbia. I-5 travels through Seattle, Washington, about 110 miles south of the Canadian border. Bellingham lies north from Seattle along I-5 and about 20 miles south of the Canadian border. At the Canadian border, I-5 becomes Highway 99 and continues north to Vancouver, B.C.

Whatcom County contains 2,126.2 square miles, which include the Mt. Baker Wilderness area and other rugged, mountainous areas mostly in the eastern portion, and a variety of farmland, rolling hills, and mountain foothills in the west. The elevation ranges from sea level to the top of Mt. Baker at 10,778 ft.

Whatcom County, like other Pacific Northwest counties, is known for its agriculture, fishing, forestry, and oil refineries. However, unlike most other Pacific Northwest counties, it is also becoming known as a retail employment area, especially to Canadian shoppers. According to the U.S. Bureau of Census and the Greater Vancouver Regional District, within a 50-mile radius of Bellingham is a population of 2,288,238 people. Of this population, 70 percent, or 1,615,261, are from British Columbia (metropolitan Vancouver, Abbotsford, Mission, and Matsqui). Besides shopping, several other points of interest attract, both locals and visitors to Whatcom County. These include six museums and 40 historical sites, four performing arts centers, eight community centers, 48 urban and 12 rural parks, six lakes, three rivers, five inlets, eight beaches, seven golf courses, 24 tennis courts, and at least 19 maintained hiking trails. Whatcom County is the home of Western Washington University. It also contains Whatcom Community College, Bellingham Vocational Technical Institute, McDonald's School of Cosmetology, City University, and the Northwest Indian College. Western Washington University is the largest single employer in Whatcom County, but if the 120 stores in the Bellis Fair Mall were aggregated as an employment center, it would rank number one with approximately 1,500 employees.

British Columbia

British Columbia is Canada's western-most province. To the south lies Washington state's Whatcom County, to the east Alberta, Canada, to the north the Yukon Territory, and to the west Alaska and the inland passage. The southern districts of British Columbia along the border, Delta, Surrey, Langley, and Matsquiall, are bordered on the north by the Fraser River (see Figure 1).

In 1986 the Central Fraser Valley had a population of 136,892, and it is projected to top 166,906 by 1991. In 1986 the Greater Vancouver area had 1,266,152 people, and it is projected to have 1,426,446 by 1991. White Rock, Aldergrove, Huntingdon, and Abbotsford are all towns along border crossing routes. White Rock is just north from Blaine in the district of Surrey and had a population of 14,121 in 1985, while the Surrey District had a total population in 1985 of 174,083. Just east of Surrey is the Langley District. Langley City and Langley District had 1985 populations of 16,540, and 50,618, respectively. Farther east is the Matsqui District, which had a population in 1985 of 49,623, while Abbotsford (including Huntingdon) had a population of 14,434 (1, 2).

Northbound, I-5 becomes Canadian Highway 99 and makes its way through Surrey, Burnaby, and Vancouver. U.S. Highway 543, the truck crossing, becomes Canadian Highway 15 and leads through Cloverdale to Canadian Highway 1A in the Langley District. U.S. Highway 539, the Guide Meridien, becomes Canadian Highway 13 and ends at the intersection of Canadian Highway 1A at Aldergrove. Northbound

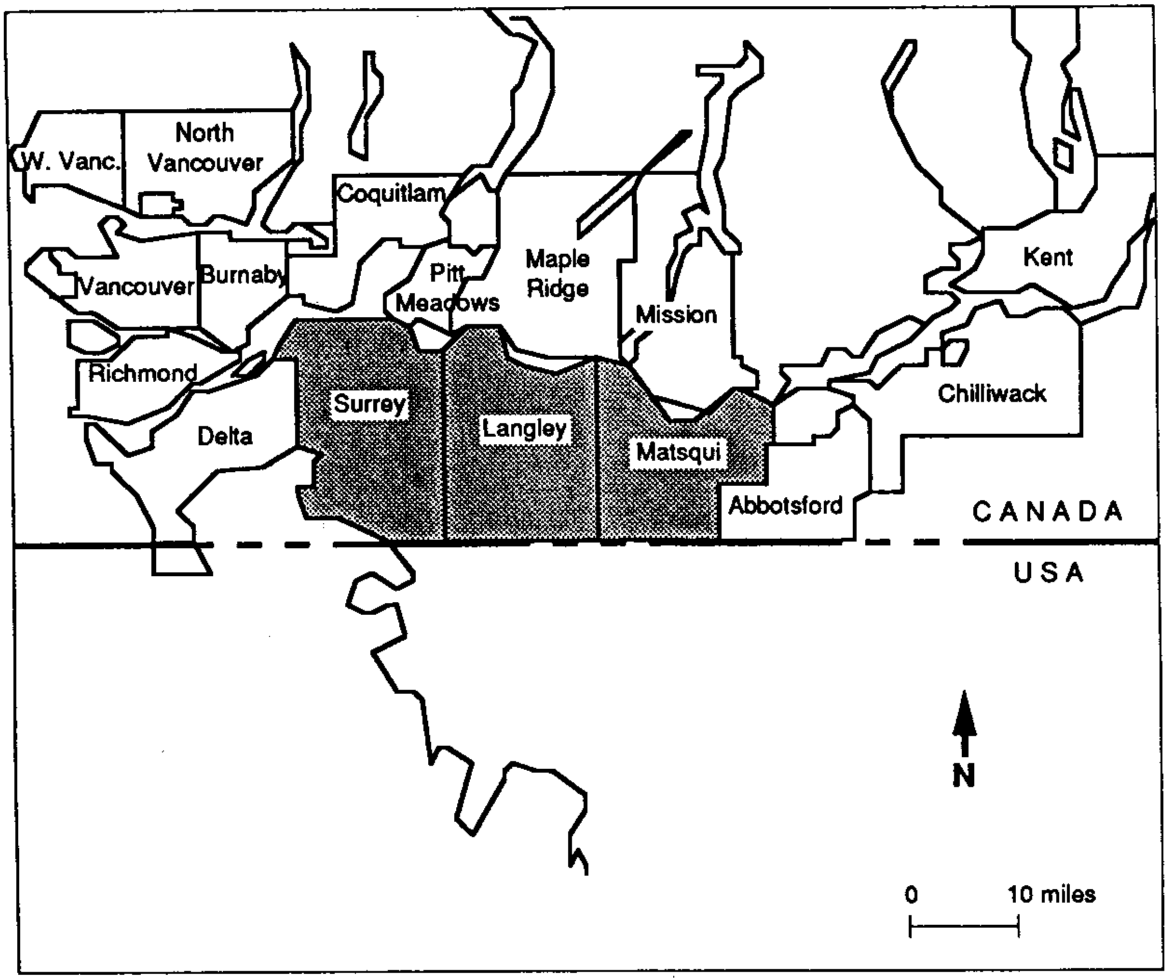

Figure 1. B.C. District Map

motorists crossing at Sumas turn from U.S. Highway 9 onto Cherry Street, which becomes Canadian Highway 11 north of Sumas and travels through Huntingdon, Abbotsford, and Clearbrook in the Mission District, Canadian Highway 11 crosses Canadian Highway 1 and 7 (see Figure 2).

The southwest part of British Columbia is not different from the northwest part of Washington state. There are ocean inlets, harbors, and rivers along the sound. Inland are flat farm lands, rolling hills, and mountainous regions. Perhaps the only real difference between the people along the border is their government system.

International Travel

Motorists who travel from Canada to the US and vice versa do so for a variety of reasons, of which shopping is perhaps primary. According to U.S. border crossing personnel, approximately 80 percent of the crossing traffic is Canadian. This is not surprising, since over 70 percent of the population that lies within a 50-mile radius of Bellingham is from north of the border. With the relatively attractive shopping facilities throughout Whatcom County; the large, relatively close population to draw from; and the strict tax structure that Canadians face, it is possible to see why a large number of Canadians cross the border to shop. Approximately 40 percent of the merchandise trade in Whatcom County is generated by Canadians, whereas upwards of 60 percent of the retail sales at Bellis Fair Mall is generated by Canadians (3). Tables 1a and 1b show how the prices of some general commodities that consumers might buy would vary depending on where they were purchased.

Political issues may also affect the travel behavior of motorists. Tariff reductions have been phased in over the past few years, prompted by the U.S.-Canada Free Trade Agreement. These, along with the stronger Canadian dollar and the new Goods and Services Tax (GST), may be reasons for many Canadians to continue to shop in the U.S. The fact that shoppers returning to Canada must declare the value of their goods and pay duty does not seem to deter many shoppers.

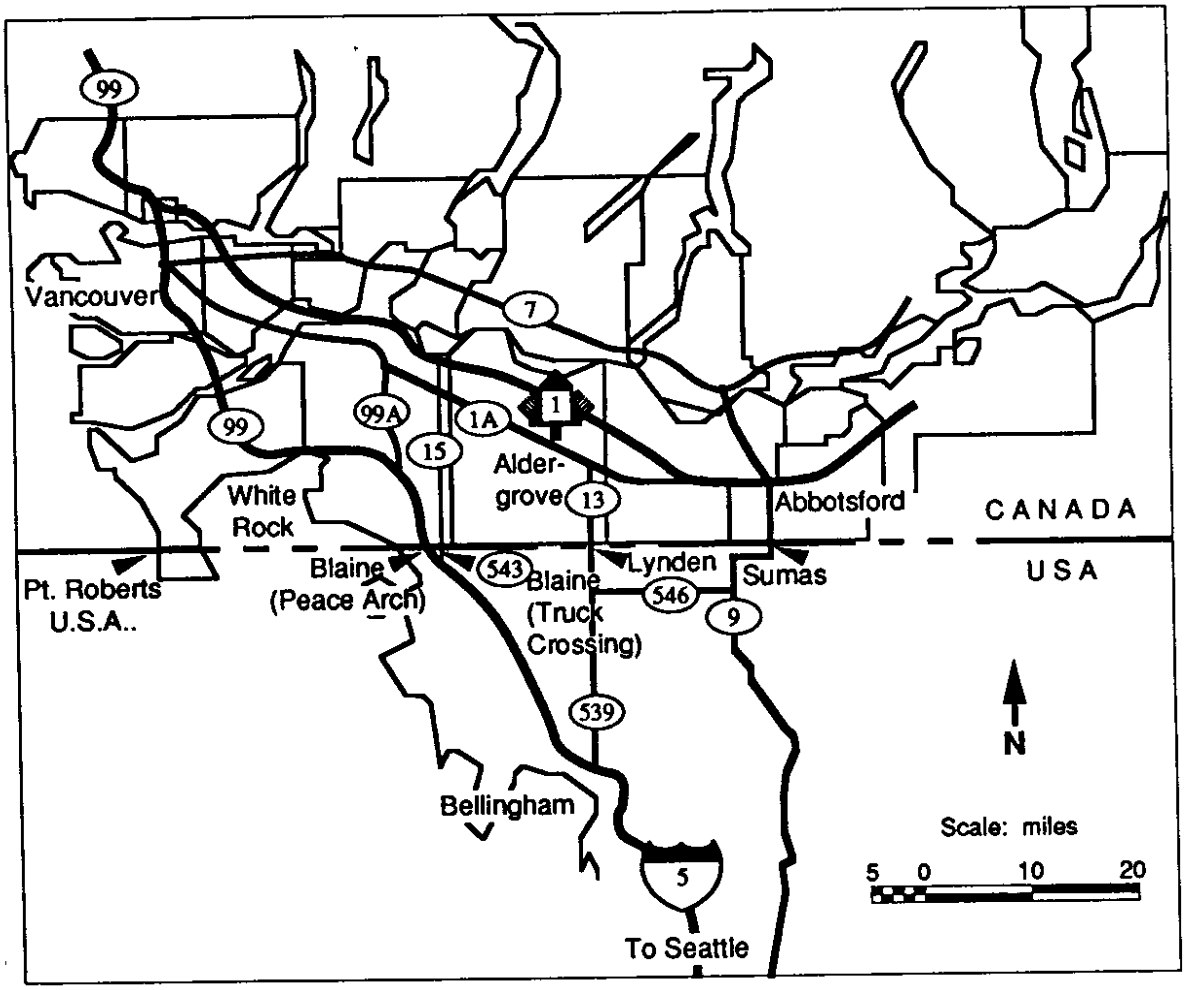

Figure 2. Highway Map

Table 1a. Prices Found While Shopping in U.S.

Commodity	Cost If Bought in the U.S.	Tariff Due at Border *	GST Due at Border*	Canadian Cost (U.S. Dollar)
N.L. Gas‡	1.19/gal 1.34/gal	0 0	0 0	1.19/gal 1.34/gal
Cheese	3.99/2 lb	12%	0	2.23/lb
Milk	1.79/gal	12%	0	2.00/gal
Beer (Budweiser)	4.25/6 pac 8.29/12 pac 9.77/24	1.79 3.58 7.16	0 0 0	1.01/each .99/each .71/each
Cigarettes	18.49/carton	2.16/pac	0	40.09/carton

Table 1b. Prices Found While Shopping in Canada

Commodity	Cost If Bought in B.C.	Quantity Equivalent (Canada Dollar)	Canadian Cost (U.S. Dollar)
N.L. Gas	.559/l .589/l	2.12/gal 2.23/gal	1.93/gal 2.03/gal
Cheese	1.17/100g 12.65/2 lb	5.29/lb 6.33/lb	4.81/lb 5.75/lb
Milk	3.59/l 4.59/l	3.40/gal 4.34/gal	3.09/gal 3.95/gal
Beer (Budweiser)	7.90/6 pac	1.32/each	1.20/each
Cigarettes	23.09/1/2 carton 43.99/carton	46.18/carton 43.99/carton	41.98/carton 39.99/carton

* See Appendix A for tariff and GST requirements for goods being brought into Canada.

‡ Allowed capacity of vehicle duty free.

Exchange Rate: $1.10 Canadian = $1.00 US

Automobile traffic at each border crossing has risen more than 86 percent since 1985. At the Lynden crossing, automobile traffic increased 148 percent from 1985 to 1991, 124 percent at Blaine, and 86 percent at Sumas.

Furthermore, the 1989 southbound crossing figures for automobiles ranks the combination of Blaine/Lynden/Sumas/Point Roberts (8,947,432) as the highest volume border crossing, surpassing Buffalo/Niagara Falls (7,633,239) and Detroit/Pt. Huron (5,582,527) (4) (see Figure 2 for location of Point Roberts).

Unlike urban traffic congestion, which has known peak and off peak periods, traffic peaks at the border are not predictable. This makes it difficult to determine appropriate staffing needs and thus increases the potential for delay. In addition, motorists about to cross the border have no way to know how much delay to expect, nor do they have any way to compare alternative routes to avoid the congestion. This report will outline a method to provide delay information to motorists, while individual motorists will have to make route choice and departure time decisions.

PROPOSED SOLUTIONS

The purpose of this section is to discuss possible solutions to current border crossing congestion and delay problems proposed by the border crossing task force and compiled by Don Jackson of the Washington State Department of Trade and Economic Development (4).

Some solutions would require little capital investment to implement, while others would be expensive and would consume large amounts of capital. The extensive list of potential solutions includes increasing the number of border agents, implementing an information system, undertaking highway improvements, providing automated border passage, developing a red door/green door concept, adopting pre-clearance policies, constructing new border facilities, and adopting continental clearance policies to provide free travel between Canada and the U.S. A discussion of each of these alternatives, as well as a description of the newly implemented PACE lane, and how they might provide relief to both motorists and border operation personnel follows. Table 2 provides a comparison of each of these solutions in relation to cost, short-term and long-term benefit, and the effort required to implement these solutions.

Table 2. Proposed Solutions

SOLUTION	COST	BENEFIT		EFFORT TO IMPLEMENT	COMMENTS
		SHORT TERM	LONG TERM		
Increase Border Personnel	⊕	Θ	Θ	Θ	Cost per agent
Implement Information System	⊕	Θ	Θ	Θ	Trip and work load distribution, some installation costs required.
Capital HWY improvements	⊗	Θ	⊕	⊗	Subject to budget and priority. Required for most other proposed solutions.
Automated border passage	⊕	Θ	Θ	⊗	PACE program combines these ideas.
Red door / Green door lanes	⊕	⊗	⊗	Θ	Requires geometric improvements and is not likely to reduce congestion or delay in either long or short term period.
Preclearance	⊗	Θ	⊕	⊗	Requires Canadian implementation, cost to include facility and geometric improvements.
Construct A New Crossing	⊗	Θ	Θ	⊗	Must meet long term planning goals and budget plan. Without information system which route will motorists take.
Continental Clearance	Θ	Θ	Θ	⊗	Not likely to happen.
PACE program	⊕	Θ	Θ	⊕	Requires geometric improvements, reduces delay, improves border efficiency.

Θ = Least expensive and or easiest to implement

⊕ = Moderately expensive and or moderate to implement

⊗ = Most expensive and or hardest to implement

Increased Border Personnel

Additional border agents would allow the existing border crossing facilities to be used more efficiently. Opening lanes before excessive delay occurred would reduce the total delay on any given crossing and minimize individual motorist delay. However, border managers would run the risk of being overstaffed when the crossing volumes were not excessive. Additionally, as the traffic demand continues to rise, it is evident that the need for more service capacity will continue to grow; therefore, increasing the number of agents could be considered an ongoing solution.

Implementation of a Signing System

The implementation of a motorist information system that would indicate the length of delay at each crossing a few miles ahead of the border and before alternative route intersection points would allow drivers to make route choice decisions. In fact, this project was a direct result of this proposed solution.

Capital Highway Improvements

To alleviate some of the highway congestion leading to the border, state and federal funding was sought to widen SR 546 approaching Sumas from two to four lanes and add a dedicated truck lane. Canada has agreed to widen the lanes from the border to the Trans-Canada Highway 1 if and when the Washington expansion begins.

Automated Border Passage

Another consideration is the use of automated vehicle identification (AVI) technology that would allow automated entry. At the time of its proposal, it was considered an expensive option to secure and maintain and would only serve those who did not have to make declarations. However, the PACE lane is a modification of this suggestion and seems to be working well. See the discussion of the PACE lane program later in this section.

Red Door/Green Door Lanes

The implementation of "red doors" for those who wished to declare something and "green doors" for those who did not would not be very practical because approximately 70 percent of those entering Canada would line up at the "red door." However, one could argue that if only 30 percent of the motorists used an approach like this, delay would be significantly reduced all along the border.

Pre-Clearance

Because the majority of northbound traffic consists of returning Canadian shoppers, one suggestion is to provide Canadians with alternative points of customs clearance, such as at the Bellis Fair Mall. Because of its political implications, this issue is solely a Canadian one and would have to be implemented by the Canadian government.

Construction of a New Crossing

As traffic volumes continue to rise, the time will come when the existing facilities will no longer be adequate, even if enough border agents are hired to keep all lanes open. New facilities are being planned for both the Sumas and Lynden northbound crossings. Obviously, the construction of new facilities is considered a long-term, high capital solution.

A new facility is being designed for the Sumas crossing; construction should begin in June of 1992. The facility will have six service lanes with a separate truck facility. Efforts to move the facility to locations that would reduce congestion in the Sumas business area have apparently been ignored. Moving the facility only one-half mile to the north would allow an increase of up to three lane-miles of storage if all six service lanes were open and one lane-mile of storage if only two service lanes were open. This added storage would help reduce the congestion at Sumas store fronts.

Continental Clearance

This proposal is the most radical. It calls for free travel between Canada and the U.S. Of course, such a concept requires substantial changes in both federal law and foreign policy and is a long-term solution at best.

The Pace Program

One solution that was not directly suggested by the task force but is perhaps a combination of many of its suggestions is the PACE lane. This concept is already in its infancy at the I-5 crossing in Blaine. The PACE program, which began in May of 1991, is a joint U.S.-Canada project that entitles preauthorized travellers to use a separate lane for quicker border crossing processing. The requirements and privileges under each country's PACE program vary slightly, and separate applications are required (see Appendix A).

After arrival at the back of the queue, motorists without the PACE lane privileges, must move slowly in the queue until they have arrived at the front of the line. Once they have arrived at the front of the line, they are questioned about the nature of their trip, their citizenship, and whether they need to declare any goods. If no declarations are necessary, they proceed, provided their citizenship has not been challenged. However, if declarations are necessary, they must park their vehicle and walk inside to face yet another line. At the front of that line they pay their declarations as necessary. In contrast, PACE lane users fill out the necessary paperwork and include any declarations in advance of their arrival at the border, and payment is made by credit card. Upon arrival at the border they proceed unimpeded to the booth and drop their envelope in a box for agents to process. Approximately 10 percent of the PACE vehicles are checked for compliance. If motorists are found to be in violation, their PACE stickers are scrapped, and their PACE privileges are forever denied. The potential exists for the PACE lane program to more efficiently use the border crossing personnel and facilities. As awareness increases, PACE lane use and its associated mobility are expected to rise.

Currently the northbound PACE lane operates from 6 - 8 AM and from 12 noon to 8 PM on weekdays and 6 to 8 AM and 12 noon to 10 PM on Saturday, Sunday, and Canadian and U.S. holidays. The southbound PACE lane operates from 7 AM to 7 PM.

Backers of the PACE program will evaluate its performance after 20,000 users have signed up. As of November 11, 1991, 17,429 vehicles were registered for the northbound PACE program. This project's traffic study, described later in this report, revealed an average of 50 users per hour, which was only about 10 percent of the total hourly crossing traffic during that period. The month of October saw 25,549 vehicles use the PACE lane, or a daily average of 824 vehicles.

One can envision the potential advantage the PACE lane offers to both motorists and border agents. The cost savings to the motorist is evident. Less pollutants are emitted into the air, vehicles are not subjected to the abuse of idling engines, and stress levels are greatly reduced. The cost savings to the border agents are not as high because they still have to process the envelopes and conduct compliance checks. However, the border agents may find their stress levels lowered because of the reduced interaction with the public. As the PACE lane program continues to provide more efficient use of the facilities, the number of vehicles served can be greatly increased, and as PACE lane use rises, the number of lanes dedicated to the PACE lane program may be increased to better serve motorists.

RESEARCH APPROACH

SITE DESCRIPTION

This section will provide the reader with more specific information about the towns and four northbound crossing facilities at the border in Whatcom County, Washington. Each of these crossings have unique histories and characteristics that provide challenges to solving the congestion problem.

The four primary routes motorists use to travel to Canada from western Washington are I-5 in Blaine; SR 543 (Pacific Highway or truck route), also in Blaine; SR 539 (Guide Meridian), which crosses the border 3.5 miles north of Lynden; and Highway 9 approaching Sumas (see Figure 2). Point Roberts is also a border crossing, but the land mass that makes up Point Roberts in the U.S. is not connected to the U.S. mainland. People wishing to travel to Point Roberts from the U.S. mainland must travel north through parts of British Columbia and then southwest to Point Roberts. Therefore, the Point Roberts crossing was not included in this study.

Blaine

Peace Arch. Private motorists travelling north on I-5 can either continue on I-5 or exit to SR 543; commercial trucks are not allowed to cross at the I-5 crossing. Motorists who travel on I-5 and enter Canada at the Peace Arch find a four-lane freeway (two northbound lanes and two southbound lanes) leading to the border. The I-5 crossing is approximately 20 miles north of Bellingham and 100 miles north of Seattle, Washington. The last exit from I-5 is approximately one mile south of the Canadian customs facilities, while the on-ramp merge point is located about 1,500 feet south of the customs facilities. This on-ramp is a point of congestion when the queues are longer than 1,500 feet. In addition, when the PACE lane is open and vehicle queues interfere with the on-ramp, motorists have difficulty accessing the PACE lane. Parks department personnel have pointed out that many PACE motorists drive on the shoulder and the park lawn. These parks department people keep the park area well groomed, and driving on the lawn should be discouraged. Local Blaine police sometimes set up barriers on the on-ramp and only allow PACE vehicles to enter the freeway from that on-ramp. Vehicle queue capacity at the Peace Arch consists of six 300±-ft service lanes near the border, which are supplied by two lanes of interstate freeway, and one 1,500-ft PACE lane (see Figures 3 and 4). Currently, there are no plans to modify either the geometrics or the capacity of the facilities at this crossing when the PACE lane is in operation.

Canadian Customs has seen volumes at the Peace Arch increase from 1,431,716 vehicles during the 1985-86 fiscal year to 2,671,391 during the 1990-91 fiscal year. This is an 86.6 percent increase since 1985 and ranks number one in total volume out of the four crossings in Whatcom County, Washington. In addition, the Peace Arch recorded 32.1 percent of the total crossing traffic in Whatcom County in 1990-91, excluding Point Roberts (see Table 3).

Truck Crossing. Contrary to popular notion, this crossing was never built for, nor restricted to, truck traffic. Supporters of the trucking industry sometimes offer the idea that this crossing should be "returned" to trucks to alleviate trucking woes at this crossing.

Motorists traveling the SR 543 route find a fairly new customs facility that serves trucks and passenger vehicles separately. In addition to the seven general purpose service

Table 3. Border Volumes

Crossing	Lanes	Pace Lanes	Trucks Permitted	Annual Traffic 1990-91	% of Total Traffic	% Rise Since 1985
I-5	6	1	No	2,671,391	32.1	86.6
SR 543	7	No	Yes	2,371,615	28.5	187.7
SR 539	2	No	Yes	1,190,101	14.3	148.2
SR 9	3	No	Yes	2,094,572	25.1	186.4
Total	17	1		8,327,679	100	115.8

** Volumes provided by Canadian Customs and are fiscal year data.

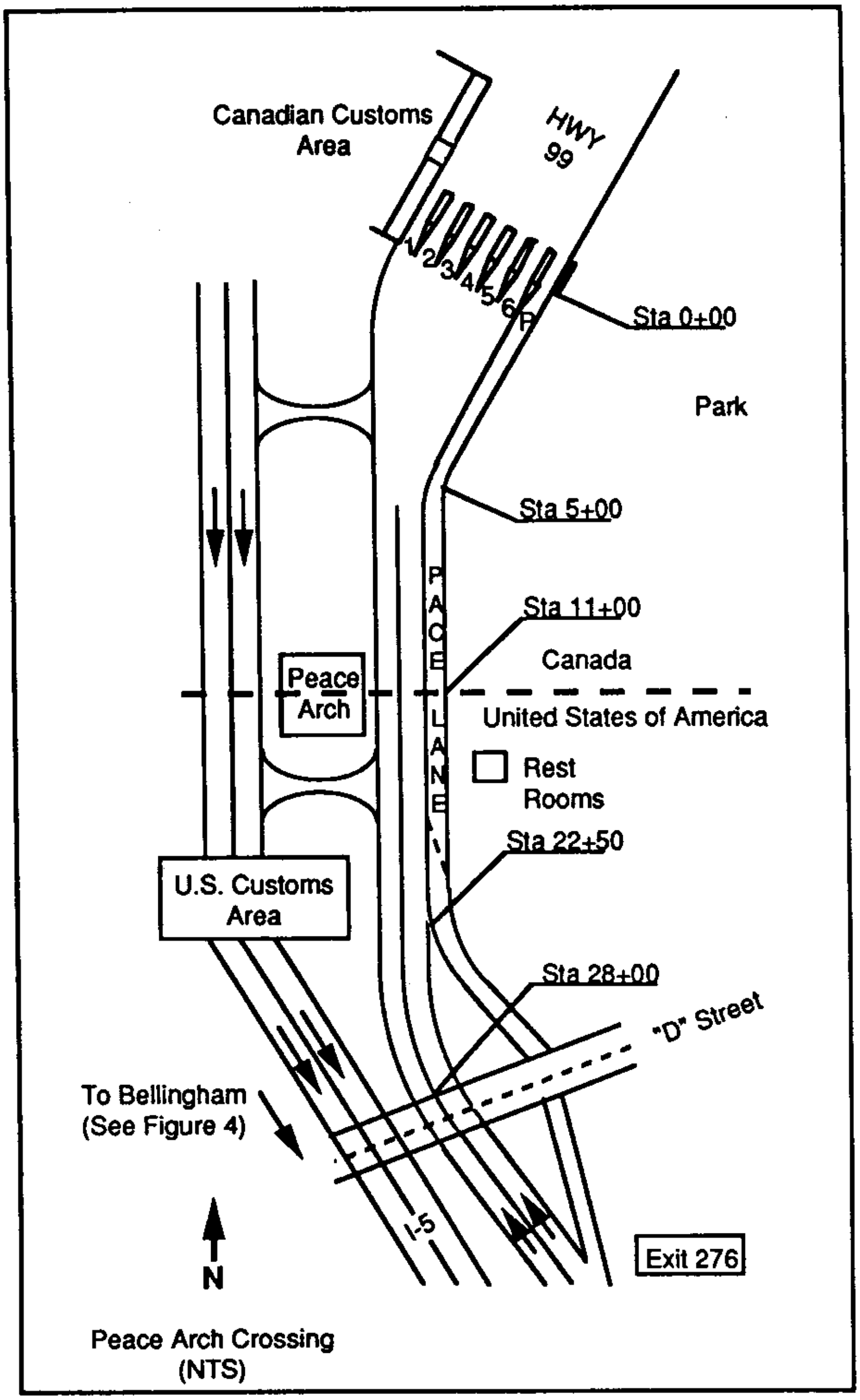

Figure 3. Peace Arch Crossing Geometric Configuration

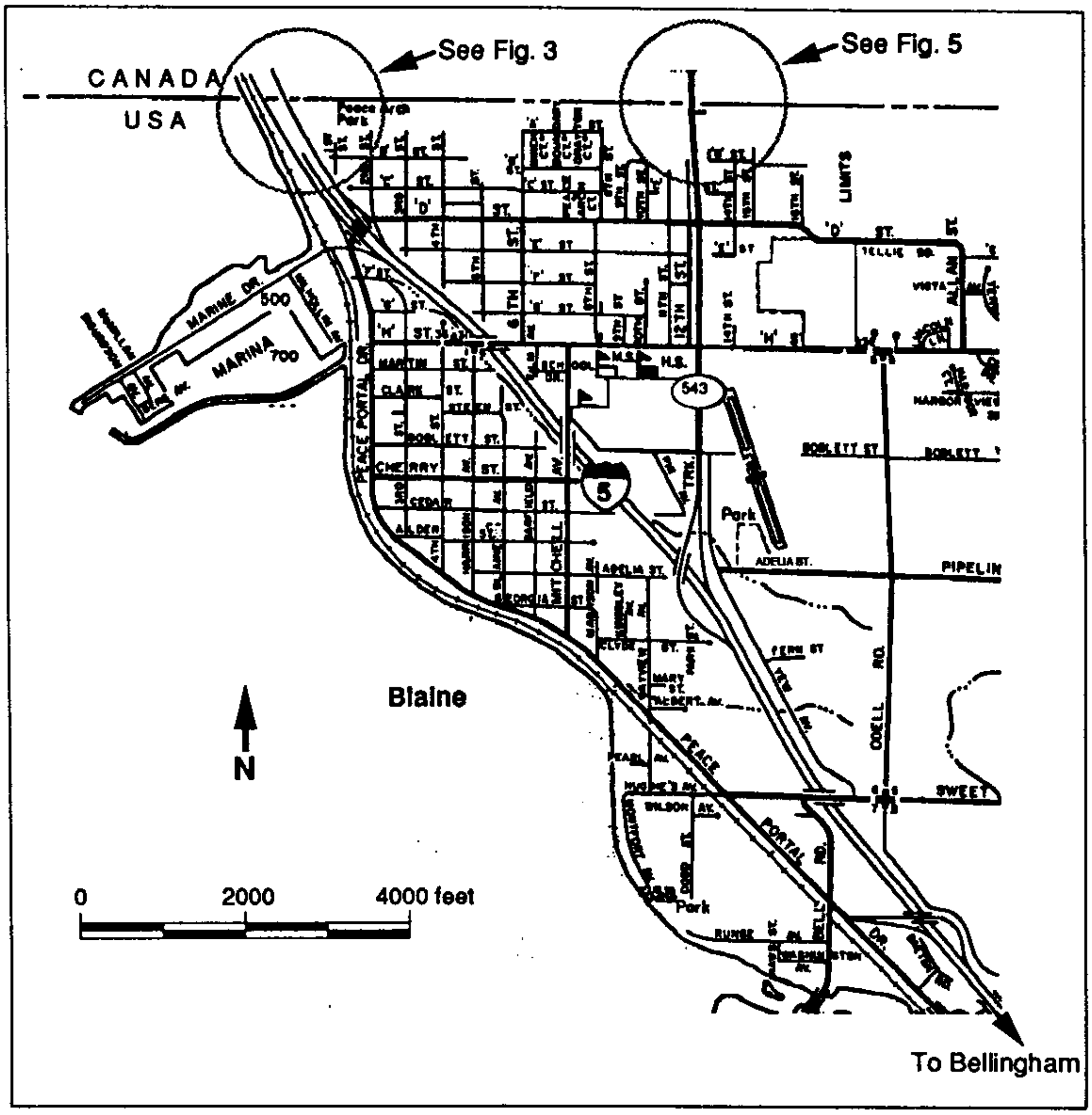

Figure 4. Map of Blaine, Washington

bays, there are separate facilities for Customs officials to conduct routine searches and investigate other matters of interest (see Figure 5). The Customs service area is approximately 2 miles north of I-5 on highway 543 and is also 20 miles north of Bellingham. Highway 543 is a two-lane roadway with a flashing yellow signal at the intersection of H Street and SR 543, and non-signalized intersections at D and B streets.

Truck access to this facility is about 600 feet south of the Customs service area. When the queues are excessive enough to block trucks from accessing their facility, or when the truck facility is full, trucks must wait in the general purpose lane until they can access the truck facilities. Often these waiting trucks unintentionally block northbound auto traffic from proceeding north to the auto facility. Recently, Canadian customs personnel have provided a traffic control official to manage the traffic congestion when long queues have formed. Each of the cross streets, B, D and H, allow vehicles to enter the stream of traffic; when the queues are beyond the intersection, a mid-queue entry condition exists, causing further delay for up-stream motorists. Because of the variety of vehicles served at this crossing, the single supply lane, and businesses near the crossing, there are several points of conflict. In fact, this crossing has produced reports of fights, car nudgings, and even people drawing fire arms (4). Immediately after clearing U.S. Customs, southbound vehicles can cross the queue at B street and buy gas, milk, and other supplies at the duty free store and then return to the front of the queue. Even northbound vehicles can take a side road up to the front of the queue and enter. This is hardly acceptable to motorists and truck drivers who have been waiting for some time from the back of the queue.

There may be some relief for the truck driver. Business owners, together with WSDOT, are working out a plan whereby truck traffic can be separated from general purpose traffic. This plan is an attempt to more efficiently use the customs facility and staff and reduce the delay that truckers face on a regular basis. The trucks will still encounter delay, but the customs officials can keep the flow of truck traffic constant

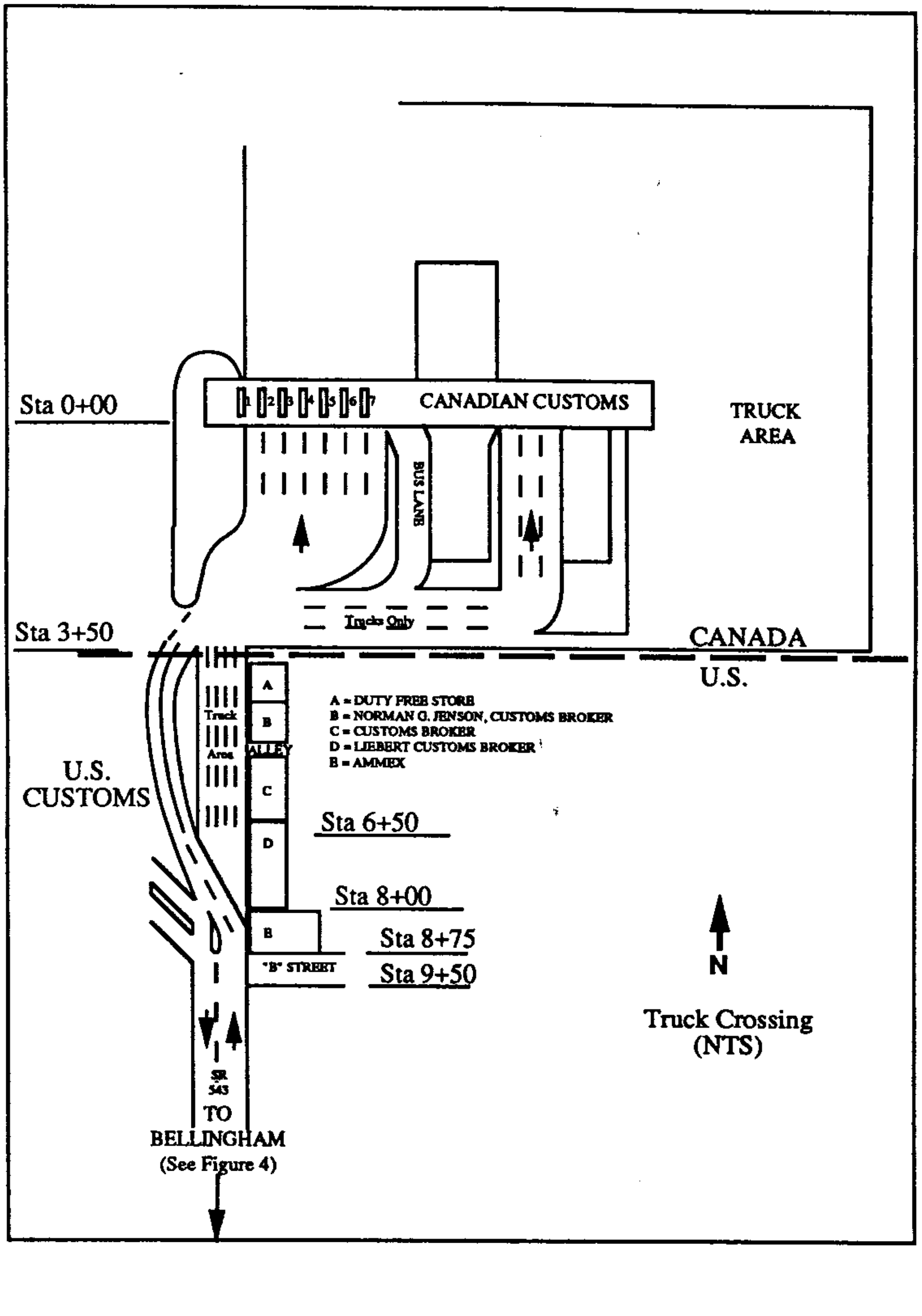

Figure 5. Truck Crossing Geometric Configuration

instead of taking whatever can get through the general purpose access lane. Part of this solution might include an approach area for general purpose traffic similar to those at ferry terminals. If the delay was longer than 20 minutes, vehicles would park in rows, and an attendant would dismiss the rows when space became available. When delays were less than the 20 minutes, vehicles could pass on through to the gates. This scheme would remedy the excess emissions caused by idling vehicles, reduce stress levels, and better use existing facilities (3).

Northbound volumes at the truck crossing increased from 824,252 vehicles during the 1985-86 fiscal year to 2,371,615 during the 1990-91 fiscal year. This represents a 187.7 percent increase and ranks number two in total volume, with 28.5 percent of the total crossing traffic in Whatcom County in 1990-91 (see Table 3).

Lynden

The crossing on the Guide Meridian (SR 539) is approximately 3.5 miles north of Lynden and approximately 16 miles north of Bellingham. SR 539 is a two-lane road running north and south from Bellingham to the border. The crossing facility has two northbound service lanes and a separate truck crossing facility that can accommodate a limited number of vehicles (see Figure 6). This facility is closed from midnight to 8 AM. Motorists who would otherwise like to use this facility at those times must use one of the other crossings. Lynden services the fewest number of people each year but perhaps has the greatest potential for increased use. A new facility will be built in the next few years, but not before the proposed new facility at Sumas has been built. The Lynden crossing processed 1,190,101 vehicles in 1991, which was only 14.3 percent of the overall western Washington crossing traffic but an increase of 248.2 percent since 1985 (from 479,554 in fiscal year 1985-86 to 1,190,101 in fiscal year 1990-91 (see Table 3). It could continue to see a high growth rate because it would have the greatest potential for increased volume if capacity were increased.

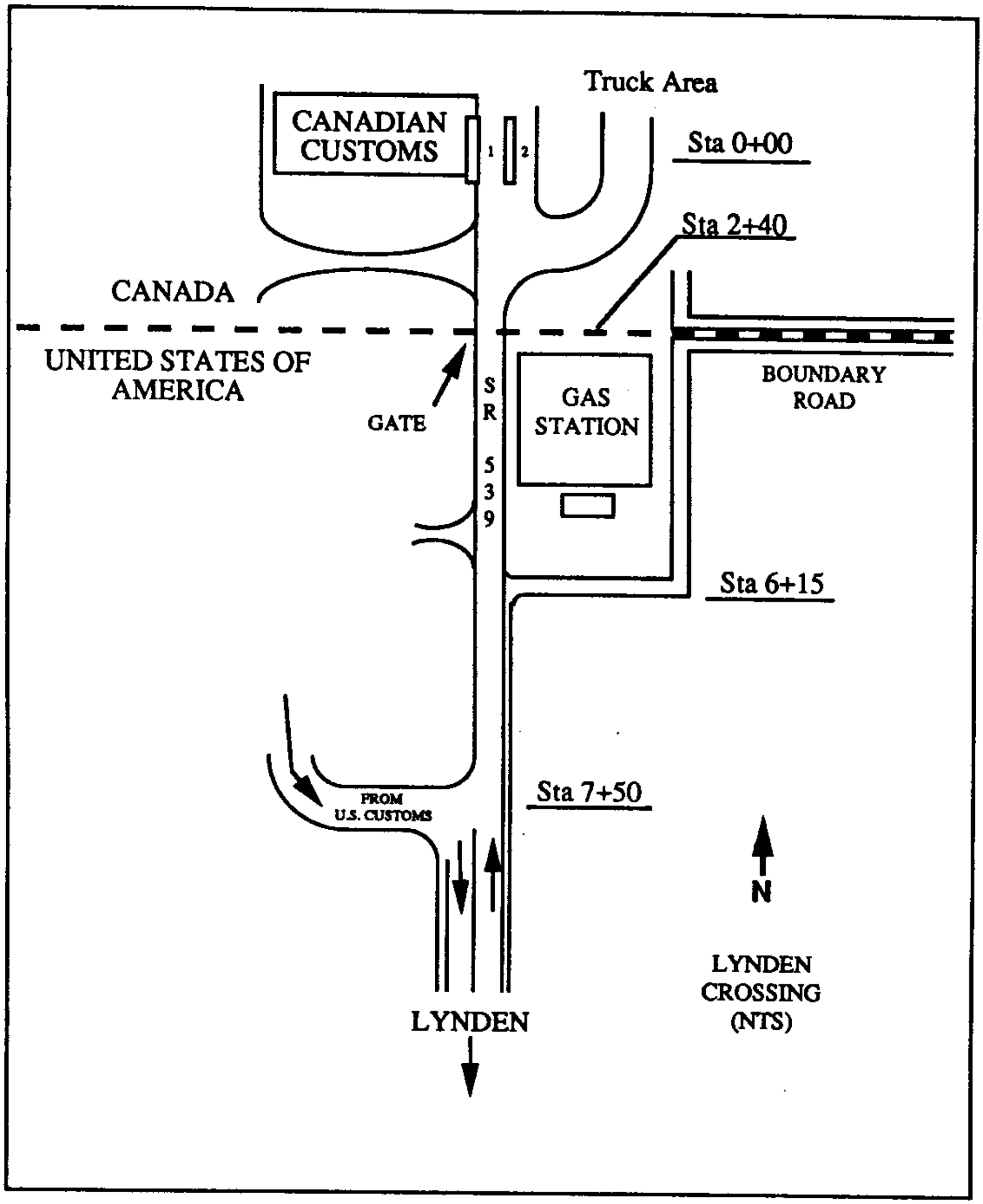

Figure 6. Lynden Crossing Geometric Configuration

A duty free convenience store near the crossing often has motorists waiting for gas along the shoulder of the highway. Although this contributes to congestion, the contribution is not considered significant. Congestion can also be attributed to a few cross streets in the area that have the potential to provide mid-queue interference when queues are excessive. The closest point is about 600 feet south of the customs facility at the duty free store. The road leading west to that point is Boundary road. Another potential mid-queue entry point is the North Prairie Road, which is an east-west road and is located about 3/4 of a mile south of the border. A third access point is the Blaine to Sumas highway (State Route 546), which is approximately 1.5 miles south of the border.

<u>Sumas</u>

Sumas is the eastern-most border crossing in Whatcom County, Washington. The crossing itself is on Cherry Street at the northern end of Sumas. Cherry Street intersects Highway 9 about 3/4 of a mile south of the border. Cherry Street and Highway 9 are two-lane, two-way roads that dissect the heart of Sumas (see Figures 7 and 8). Currently, there are three service booths, each of which have 320± feet of queue storage. In addition, a truck service area accommodates about 10 commercial vehicles at a time. Traffic at the Sumas crossing has increased from 1,123,663 vehicles in 1985 to 2,094,572 in 1991, an increase of 86.4 percent. Sumas ranks number three, as 25.1 percent of the total crossing traffic used this facility in 1990-91 (see Table 3). A new facility will be built in the summer of 1992 and is proposed to have six service lanes and a separate truck facility. With this new facility, a very large increase in traffic volume is expected. From 1990 to 1991 traffic increased only 2 percent. The reason for this small increase is most likely that Sumas is usually extremely congested. With better crossing facilities the magnitude of growth will be large.

Trucks that wish to cross at Sumas must wait in the general purpose lanes until they reach the front of the line and then divert to the truck facility. Some alternative traffic plans have been proposed. WSDOT is looking at ways for trucks to access the

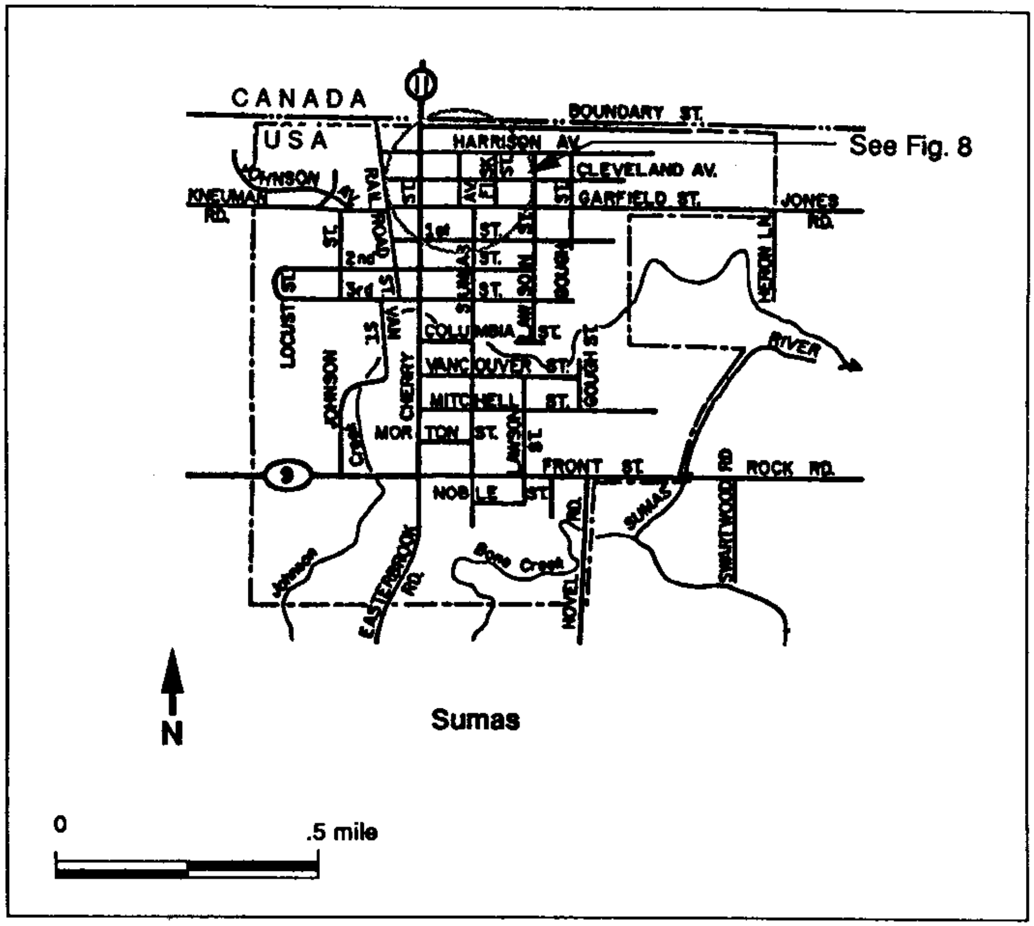

Figure 7. Map of Sumas, Washington

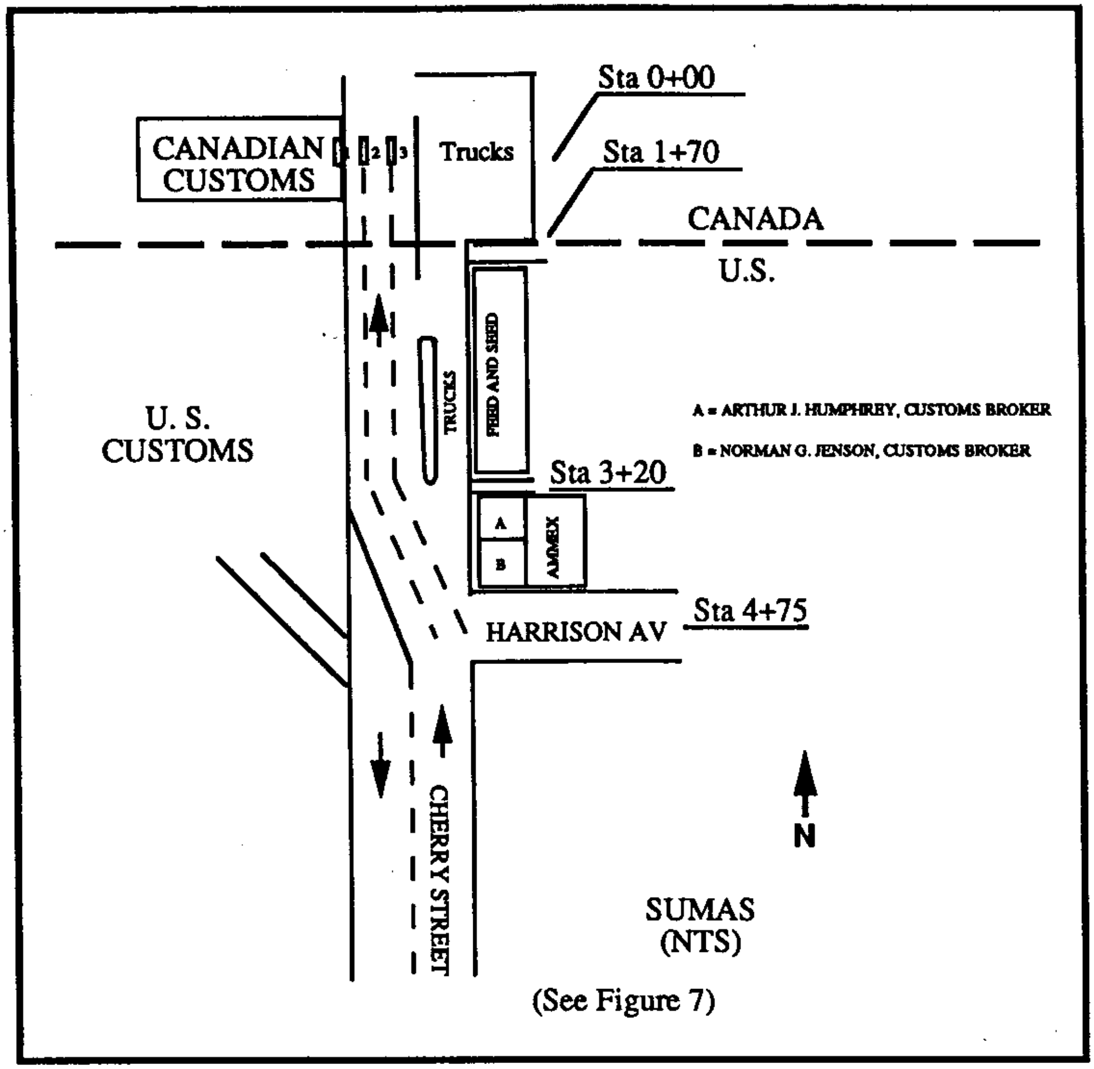

Figure 8. Sumas Crossing Geometric Configuration

crossing by way of a street that is a block to the east; however, this plan has caused some local controversy because some feel it would take away potential business. Cherry Street has many cross streets that provide mid-queue entries when the queues are excessive. Sumas businesses suffer the most from lack of traveler mobility when queues are excessive; however, they seem to balk at the idea of rerouting the traffic for fear of losing business. The congestion has finally reached the point where Sumas police attempt to blockade the side streets to reduce mid-queue entries. When asked about the criteria for blocking the side streets, one officer stated that it is done just by observation. When the back of the queue is beyond Columbia St. (see Figure 7), officers try to control traffic. Nevertheless, many vehicles still use side streets to enter near the front of the line.

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. It was not important to determine 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 to observe the traffic operations in a manner that will provide a high level of accuracy. 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 was unique and offered 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 light at this location in comparison to 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, as pointed out before, 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 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 results of this study should 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 9). 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 produce more accurately detected 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 9). 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

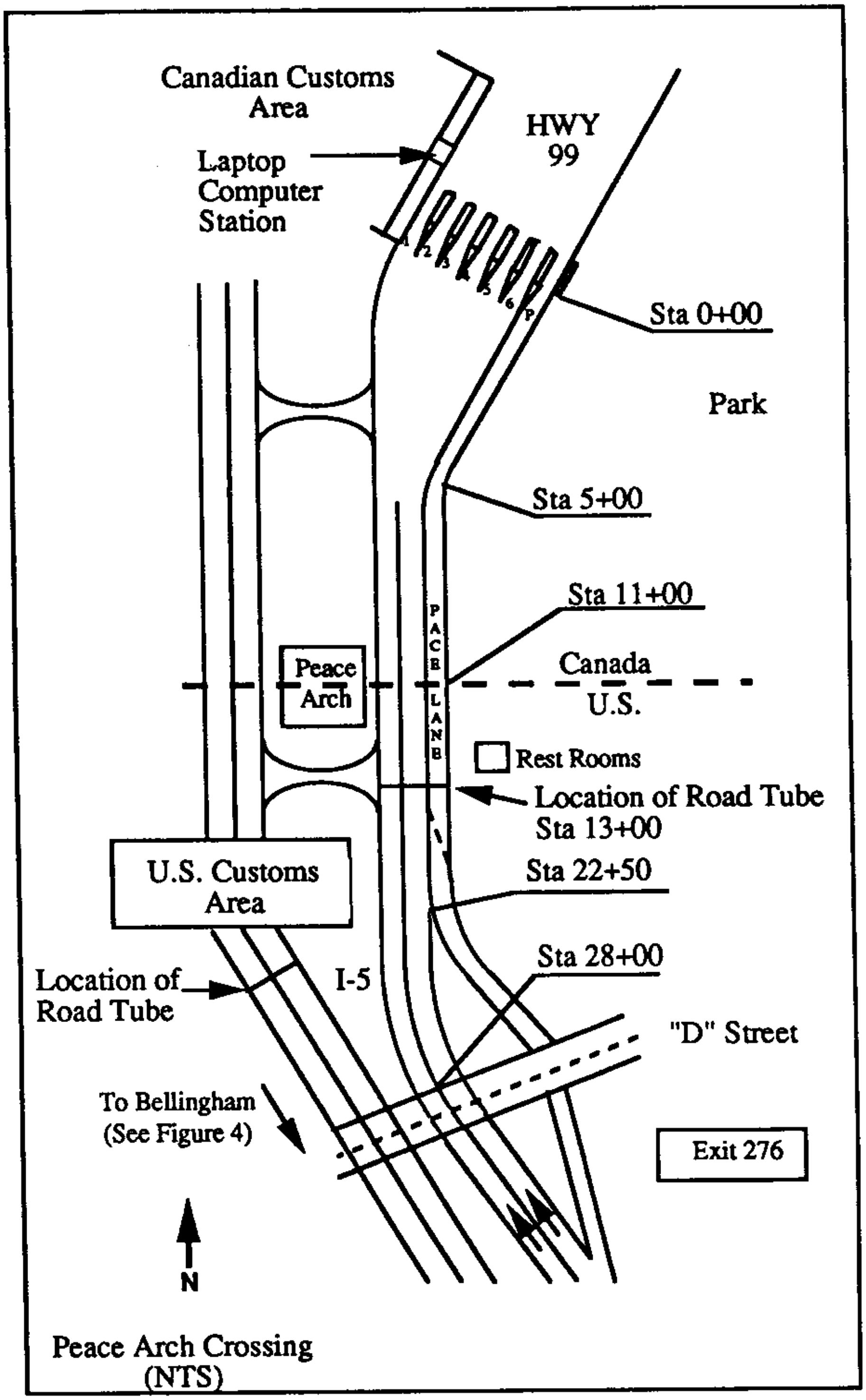

Figure 9. Peace Arch Crossing With Study Features

"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.

Validity Concerns

One validity concern was time. The survey was conducted on Wednesday and Thursday following the Labor Day holiday weekend. Further studies may be needed to determine whether the results of the survey will be good at other times of the day, week, or year.

Another validity problem concerned the testing process. Because the PC operators were in plain site of the border agents in the booth, they may have had an impact on the border agents' behavior. The border agents may have been concerned about their jobs, since they did not know why the researchers were there. They may have taken steps to work more quickly or accurately if they suspected their work habits were being observed for personnel management reasons.

A third validity problem concerned talk of a work slow down. The Monday following the survey the customs personnel went on strike. Before that rumors of a slow down were circulating; however, no one would admit to performing anything other than normal work. Some customs personnel suggested that the flow of traffic was normal, while others said their work was being conducted according to their job descriptions. Another study may be needed to validate the service times.

A final concern was the seasonal variation in the population of the motorists and the operations personnel. The summer recreation season had just ended and the fall season was beginning. In addition, the summer temporary staff were no longer working, and half of the staff was inexperienced, as they had been on the job only a short time, according to customs personnel.

Summary

Although the study left some areas uncovered, it did provide a good base to build upon. Truck traffic and mid-queue entries will need to be closely observed, as will other times of the year. Nevertheless, the methodology was good. It provided important data that can be used to study important queueing/delay features.

FINDINGS: ASSESSMENT OF TRAVEL STUDY

Two processes were considered to analyze the data obtained through the traffic study (previously described) in order to find the best parameters for estimating the time a vehicle would wait in the system at the border. Queueing analysis is perhaps the most common approach whereas, regression analysis using a family of parametric models is not as common. Both are discussed below.

DESCRIPTIVE STATISTICS

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 4). Other information 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

Table 4. 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 immediately before a vehicle's arrival. The three 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, their 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 10).

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 11). 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

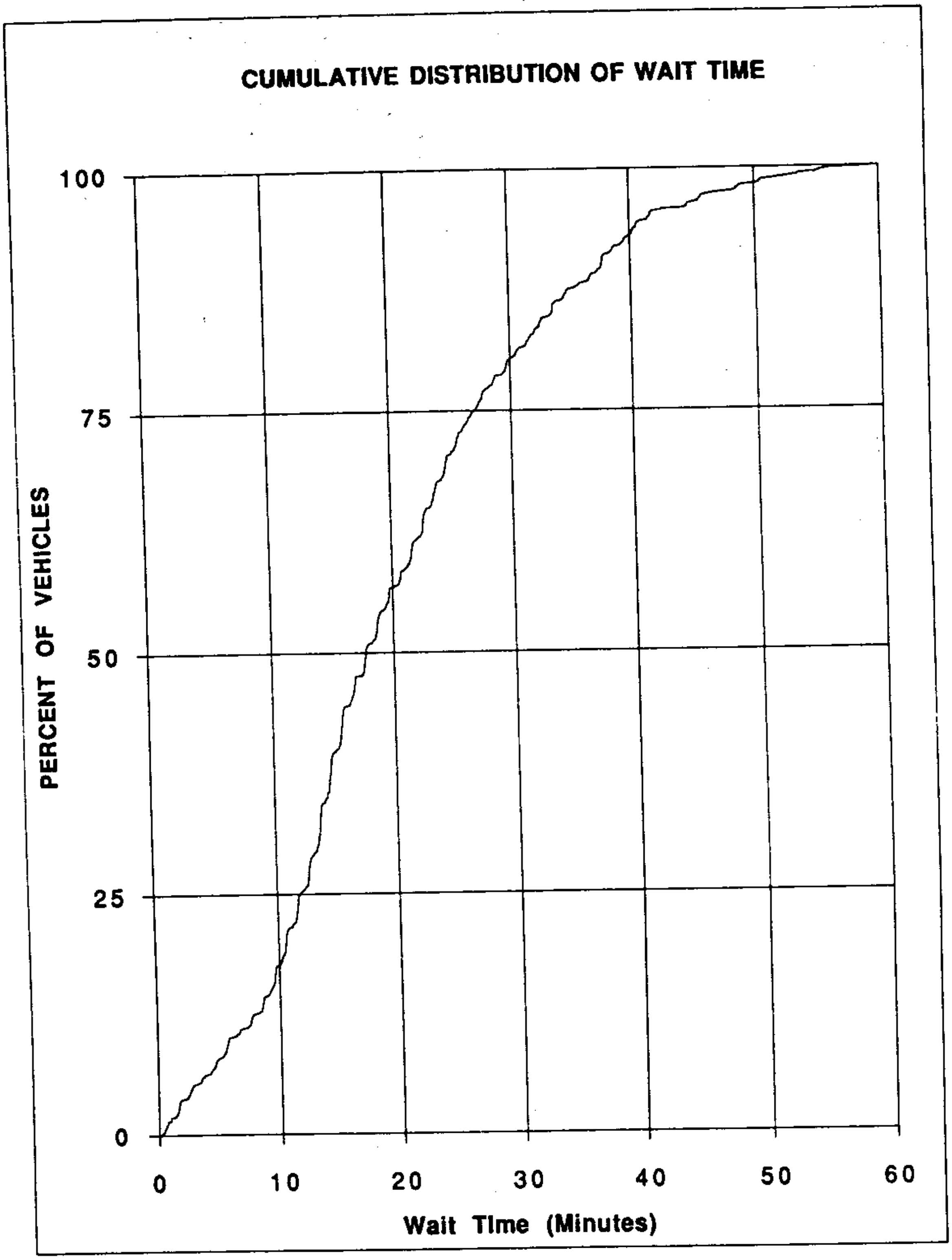

Figure 10. Cumulative Distribution of Wait Time

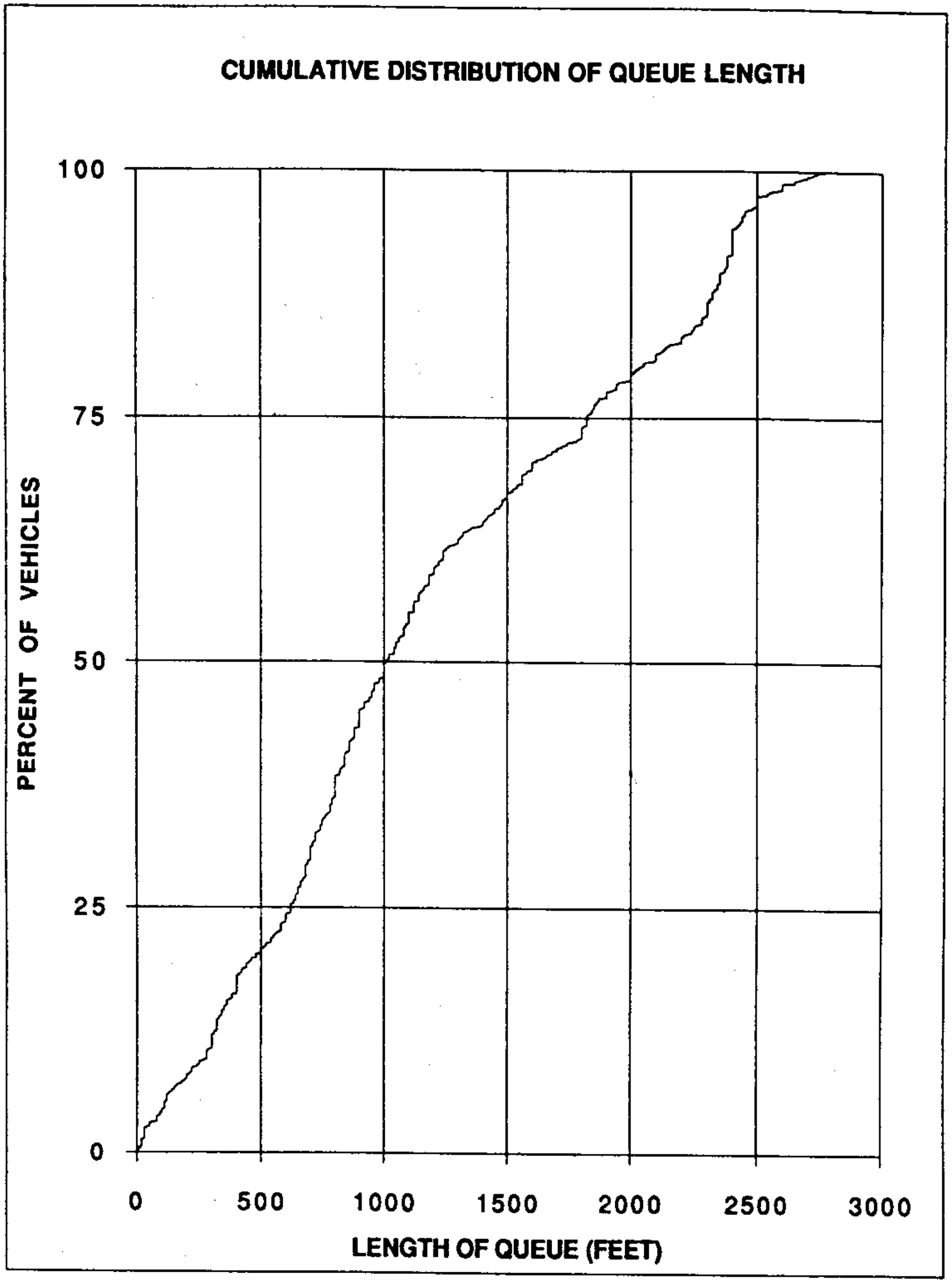

Figure 11. Cumulative Distribution of Queue Length

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.

The number of vehicles using the PACE lane during the study was 857, which is an hourly average of nearly 50, and the 5-minute interval average was nearly four. (see Figure 12). According to Canadian PACE officials, total October PACE use was 25,549, which is 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 equates to an hourly average of 576 vehicles and an average of 48 vehicles for each 5 minutes.

MODELING TECHNIQUES

Duration Modeling Theory

This section explores the use of duration models to estimate the time a person could expect to wait in a queue until being served. Duration models have been used in accident risk analysis (5) and in understanding commuter activity (6). One promising approach is to use duration models that consider the conditional probability of ending the wait, instead of the traditional direct probability approach. The intent of this portion of this chapter is to explore the application of such duration models to border crossing traffic and operational characteristics and to study alternative parametric models of duration.

The hazard function approach to analyzing these data considers the probability of a driver exiting the system, conditioned on the inability of the driver to exit up to a

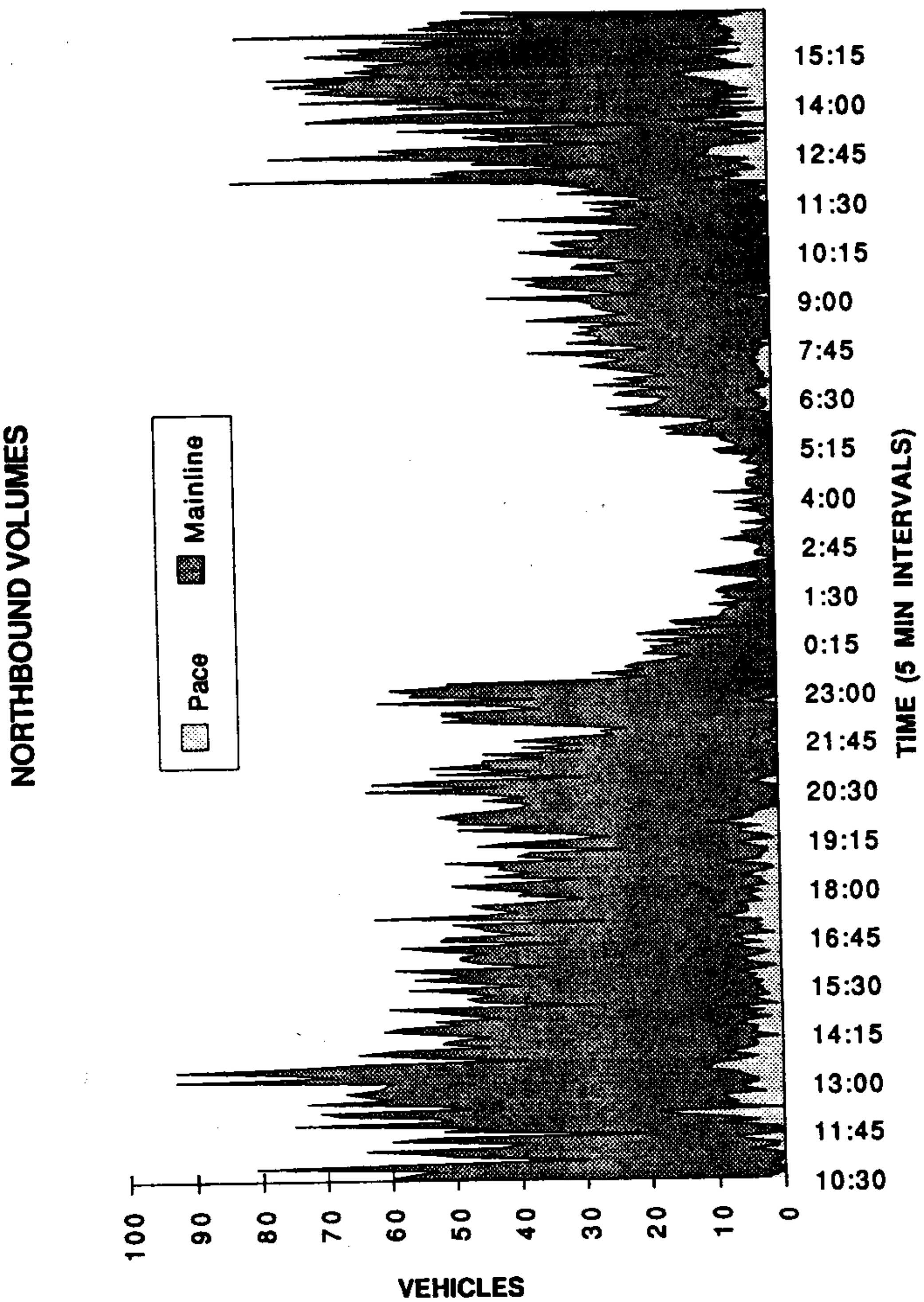

Figure 12. Northbound Volumes

certain wait time, t_W. Let $F(t_W)$ be the cumulative distribution function of the wait time, t_W, such that

$$F(t_W) = \Pr[T_W < t_W] \qquad \text{(Equation 1)}$$

where T_W = a random variable, and

t_W = some specified wait time value.

The corresponding density function is

$$F(t_W) = dF(t_W)/dt, \qquad \text{(Equation 2)}$$

with hazard function

$$u(t_W) = f(t_W)/[1-F(t_W)] \qquad \text{(Equation 3)}$$

where $u(t_W)$ = the approximate rate at which vehicles are exiting the system after some specified wait time, t_W.

Hazard functions can be assessed by evaluating the first derivative with respect to time. If $du(t_W)/dt > 0$ at some wait time, t_W, the hazard is increasing in duration. In other words, the longer a vehicle is in the system, the more likely it is to exit soon. If $du(t_W)/dt < 0$, the hazard is decreasing in duration, meaning the longer a vehicle is in the system, the less likely it is to exit soon. Finally, if $du(t_W)/dt = 0$, the hazard is constant and the likelihood of a vehicle exiting the system is independent of the time spent in the system. In the border crossing situation, the expected equation would be $du(t_W)/dt > 0$, indicating that the longer a motorist has been waiting, the greater is the probability of the wait ending.

To estimate the effects of the covariates on this hazard function and the wait time, an accelerated lifetime model is appropriate (7). If the survivor function is defined as the

$$S(t_W) = \Pr(T_W \geq t_W) \text{ (i.e., } 1-F(t_W)) \qquad \text{(Equation 4)}$$

the accelerated lifetime approach assumes a baseline survivor function for all drivers and rescales the wait time to account for the effect of the border crossing traffic and

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the accelerated lifetime approach assumes a baseline survivor function for all drivers and rescales the wait time to account for the effect of the border crossing traffic and operational characteristics on the wait time. This can be written as,

$$S(t_w, X_n, \beta) = S_o[t_w \eta(\beta, X_n)] \qquad \text{(Equation 5)}$$

where X_n = a vector of border crossing traffic and operational characteristics for vehicle n,

β = a vector of estimable parameters,

$\eta(\beta, X_n)$ = a scaling factor, and

$S_o[.]$ = the baseline survivor function.

Thus, the hazard associated with S_o [.] is,

$$u(t_w, \beta, X_n) = u_o[t_w \eta(\beta, X_n)]\eta(\beta, X_n) \qquad \text{(Equation 6)}$$

For model estimation purposes, $\eta(\beta, X_n) = \exp(-\beta X_n)$. Given the general form of the accelerated lifetime model, all that is required to proceed with the estimation of β is a specified parametric form for the distribution of the wait time. Four alternative forms are considered below.

__Exponential Distribution__. The four most commonly used distributions in survival analysis are the exponential, Weibull, log-logistic, and log-normal (5).

With the previously discussed notation and duration defined as wait time, the exponential distribution is the most simplistic. With parameter $\lambda > 0$, its density and hazard function are

$$f(t_w) = \lambda e^{-\lambda t_w} \qquad \text{(Equation 7)}$$

$$u(t_w) = \lambda \qquad \text{(Equation 8)}$$

The fact that the exponential's hazard is not a function of t_w implies, in this case, that the probability that wait time will end is independent of the length of time a motorist has waited.

__Weibull Distribution__. The Weibull distribution is a more generalized version of the exponential distribution. With parameters $\lambda>0$ and $P>0$, the Weibull has the following density and hazard functions:

$$f(t_w) = \lambda P(\lambda t_w P)^{P-1} \exp[-(\lambda t_w)^P] \qquad \text{(Equation 9)}$$

$$u(t_w) = \lambda P(\lambda t_w)^{P-1} \qquad \text{(Equation 10)}$$

The Weibull's hazard implies that if (1) $P < 1$, the hazard is monotone decreasing (the longer a vehicle is in the queue, the less likely it is to exit); (2) $P > 1$, the hazard is monotone increasing (the longer a vehicle is in the queue, the more likely it is to exit); and (3) $P = 1$, the hazard is constant and independent of wait time (i.e., the Weibull reduces to the exponential distribution) (see Figure 13).

Log-logistic Distribution. The log-logistic distribution is an even more general distribution and is often used to approximate the more computationally cumbersome log-normal distribution. The log-logistic has the following density and hazard functions:

$$f(t_w) = \lambda P(\lambda t_w P)^{P-1} [1+(\lambda t_w)^P]^{-2} \qquad \text{(Equation 11)}$$

$$u(t_w) = [\lambda P(\lambda t_w)^{P-1}]/[1+(\lambda t_w)^P] \qquad \text{(Equation 12)}$$

This hazard function is identical to the Weibull aside from the denominator. This hazard implies that if (1) $P < 1$, the hazard is monotone decreasing from infinity; (2) $P = 1$, the hazard is monotone decreasing from λ; and (3) $P > 1$, the hazard is increasing from zero to a maximum at

$$t_w = (P-1)^{1/P}/\lambda \qquad \text{(Equation 13)}$$

and decreasing toward zero thereafter. Figure 14 shows the various relationships between hazard function and duration (wait time) for the log-logistic, Weibull, and exponential distributions.

Log-normal Distribution. Finally, the log-normal distribution has a hazard function that is not a closed form. Therefore, it is the most difficult of the four distributions to estimate. Its hazard follows the log-logistic with $P > 1$, in that it increases to some maximum and then decreases approaching zero as t_w becomes large.

For each of the four distributions discussed above, accelerated lifetime models of wait time can be estimated. Estimation of such models is accomplished with standard maximum likelihood methods and the software package LIMDEP. Unlike accident

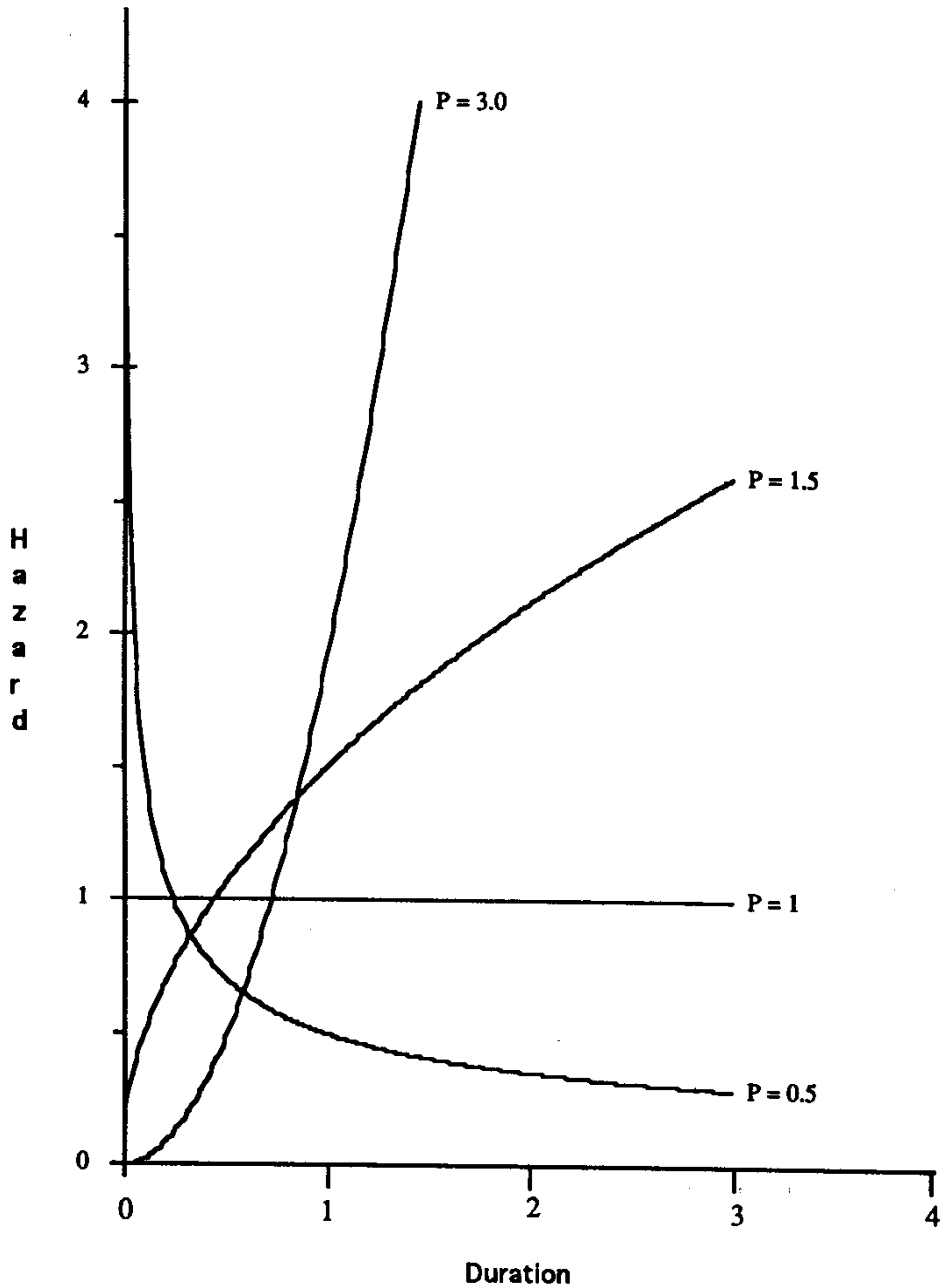

Figure 13. Weibull Hazard Functions For Different Values of P, $\lambda = 1$ (6)

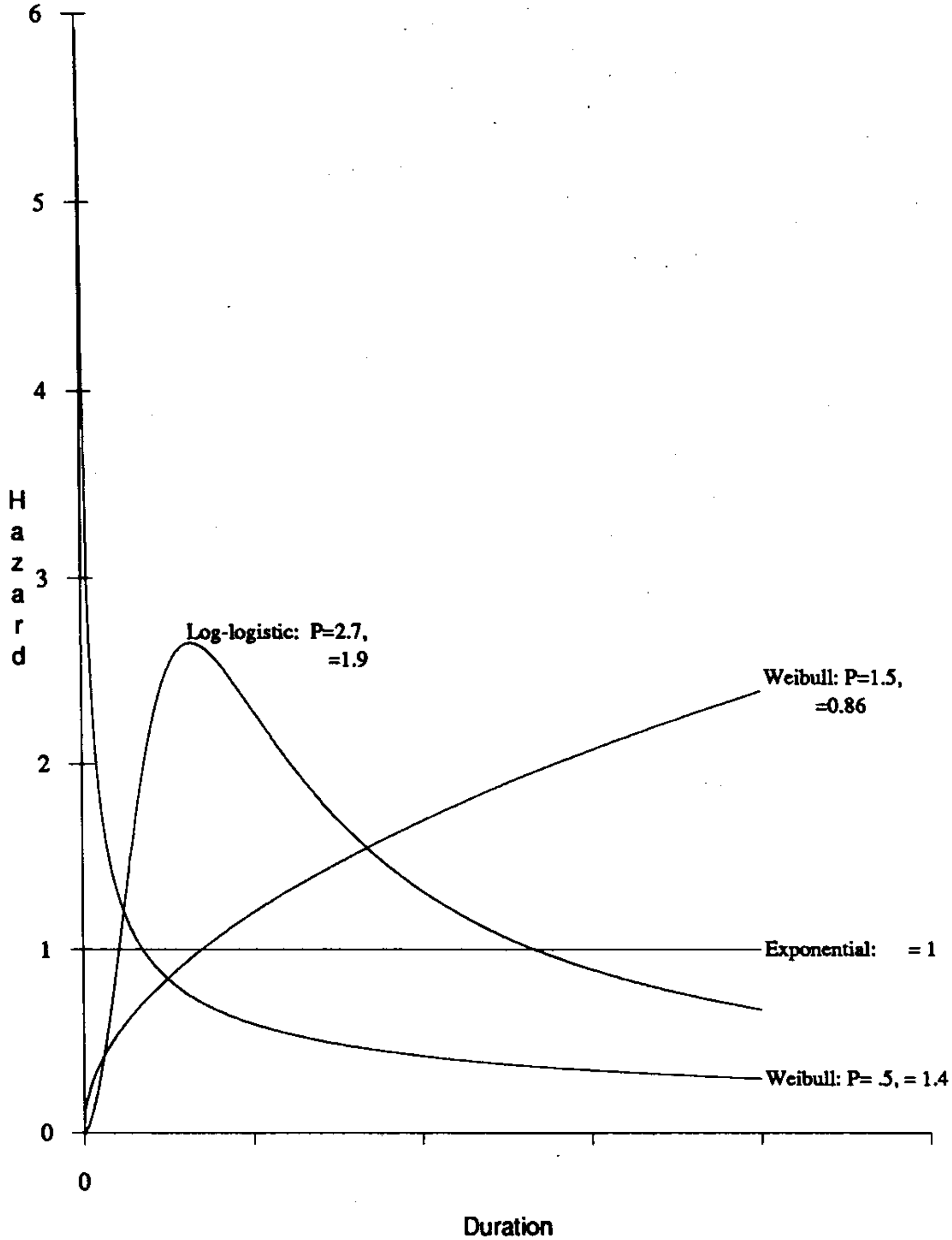

Figure 14. Parametric Model Family Hazard Function (10)

analysis, in which each person may have more than one accident and censored data, the project data were complete and included only one exit time per vehicle.

The Model

Service Time. The average service time for the entire 18-hour study period was 36 seconds, with a standard deviation of 27.8 seconds. Service time was defined as the time a vehicle began to move into the booth until the time it left the booth. It was not confined to the time that the border agent was questioning the occupants of the vehicle, as it also included some travel time. The database of the vehicles exiting the system was much larger than the matched record database and, therefore, provided 1,657 observations of service time. A significance test was conducted to determine whether there were significant differences between the means of the service times of one day to the next and between the matched records and the total. No significant differences existed at the 0.01 level.

Additionally, the researchers had to determine whether the service times were exponentially distributed, since traditional queueing analysis assumes that they are. They determined this with a parametric modeling technique found in the software package LIMDEP. Modeling the dependent variable, service time, against a constant (such as the independent variable in the exponential regression model) produced a log likelihood of -946.1, whereas the Weibull regression model produced a log likelihood of -120.56. Other possible distributions also proved to be inferior to the Weibull model (see Table 5).

The differences among these models were considered highly significant, showing that service times were not exponentially distributed. Furthermore, traditional queueing analysis needs the variables exit rate, arrival rate, and the number of lanes that are open. Because of the number of intersections at the crossings other than the Peace Arch that allow mid-queue entries, the total northbound arrival volumes would be difficult to determine. Without total volumes, wait time cannot be determined with queueing analysis techniques. Therefore, queueing analysis was not considered further.

Table 5. Service Time Distribution Comparison (t-statistic in parentheses)

Variable	Model			
	Exponential	Weibull	Log-Logistic	Log-Normal
Constant	3.43299 (27.466)	3.52801 (417.21)	3.41917 (343.89)	3.39333 (298.741)
Log Likelihood	-946.09	-120.56	-159.79	-175.24
Distribution Parameter, P	1	4.18	6.24	3.41

The dependent variable is the natural log of service time.

To evaluate the model to estimate the expected duration of delay, the model takes on the form

$$\eta(\beta, X_n) = \exp(-(\text{Constant} + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n))$$

where β = the coefficient determined by LIMDEP, and

X_i = the independent variables.

Dependent Variable. Two options were considered for the dependent variable, total time in the system (i.e., exit time minus arrival time) and wait time (t_W) (i.e., total time in system minus service time). The service time for each vehicle varied, whereas the wait time for any platoon of travelers should have been similar. Therefore, wait time was chosen as the dependent variable. Many other factors were involved in the duration of service time. Citizenship, the number of the occupants of a vehicle, how much was purchased, pets, and so on, were obvious factors affecting the time a traveler could expect to be questioned by border agents. Underlying, and not quite so obvious, factors that affected service time related to the personality and experience of the agent in the booth. For example, one border agent may work harder if he/she knows that no other agents are available to open another booth when the queues are excessive. On the other hand, another agent may not care whether another lane can be opened.

The model with the best independent variables will have the highest R^2, or alternatively, the highest log likelihood. The R^2 should be corrected for the number of variables (note that the R^2 will improve if variables are simply added to the model). Additionally, the t-statistics for each variable coefficient generally should be greater than 1 but should be tested for significance. Finally, the sign of the ß's should be consistent with the conditions being tested, i.e., the ß for opening a lane should be negative, showing a decrease in duration, and the ß for distance should be positive, showing that an increase in distance will result in an increase in wait time.

<u>Independent Variables</u>. The best regression model was found to include several independent variables. The following is a description of each of the independent variables used in the model.

- LDIST (Natural log of the length of queue)

  The natural log of queue length upon a vehicle's arrival was found to be much more significant than just the distance itself. The implication is 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.

- TF (Time factor)

  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.

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

  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.

- LOF (lane open factor)

  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.

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

  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 uses service times, length of queue, and others, to estimate the wait time.

Standard Linear Regression Model

Before parametric duration models were estimated, a simple ordinary least squares regression model was run. The following shows the ß corresponding to the independent variables used in the best model.

Variable	Constant	LDIST	TF	LLNOP	LOF	SV30
$ß_i$	-1.79850	.694373	.190637	-.176784	-.0297759	.0013118
t-stat	(-18.114)	(58.561)	(7.996)	(-4.955)	(-.927)	(.964)

$R^2 = 0.870$ corrected
Log likelihood = -178.86

The model was as follows:

$$\text{LWAIT} = \text{Constant} + ß_1\text{LDIST} + ß_2\text{TF} + ß_3\text{LLNOP} + ß_4\text{LOF} + ß_5\text{SV30} \qquad \text{(Equation 15)}$$

To use this model to estimate the delay that a motorist could expect on arriving at the back of the queue, the equation would then become

$$\text{WAIT} = \text{EXP(LWAIT)} \qquad \text{(Equation 16)}$$

Parametric Model of Duration

The ß's for each variable, as previously described, took on different values when the parametric duration modeling techniques, described above, were used. The researchers found these best independent variables by analyzing several combinations of variables. The model with the highest log likelihood at convergence would be considered the best model, providing the signs of the variables were plausible and the variables could be explained intuitively. Because four modeling distributions were available (i.e., exponential, Weibull, log-logistic, and log-normal), the researchers had to determine which model to use. In this case, the log-logistic model always had a higher log likelihood than the other models. The comparison of three of the four models and their specific characteristics in Table 6 shows that the log-logistic model was the best, as it had the highest log likelihood, the signs of the ß's were intuitive, and the variables could be explained.

Table 7 shows the development of the log-logistic model from a practical point. Model 1 used all of the variables described above, while Model 5 used only the LDIST variable. The significance of each model improved as relevant variables were added. Also of importance in this process was the determination of which variables were cost effective to invest in. As the variables were added to the model, the log likelihood increased, signifying that the model was explaining more of the dependent variable. In fact, Figure 15 shows this evolution graphically. Notice how the accuracy of the most significant and least significant models converged as higher tolerances were permitted.

Table 6. Other Parametric Distributions (t-statistics in parentheses)

Variable	Model		
	Log-Logistic Model 1	Exponential	Log-Normal
Constant	-1.75125 (-19.865)	-1.38381 (-1.37)	-1.79850 (-.19416)
LDIST	.693308 (81.529)	.630027 (11.366)	.694373 (114.691)
TF	.190224 (8.314)	.231509 (.709)	.190637 (6.620)
LLNOP	-.212012 (-5.960)	-.124392 (-.257)	-.176784 (-4.075)
LOF	-.0604531 (-2.048)	-.016446 (-.044)	-.0297759 (-.838)
SV30	.00189784 (1.451)	.0006070 (.035)	.00131182 (.835)
Distribution parameter, P	6.53668	1	3.39534
Log-Likelihood at convergence	-122.39	-948.42	-178.85

* Weibull model was unable to converge.

Table 7. Progressive Log-Logistic Model (t-statistic in parenthesis)

Variable	Model				
	Model 1	Model 2	Model 3	Model 4	Model 5
Constant	-1.75125 (-19.865)	-1.67252 (-22.785)	-1.65105 (-22.741)	-1.85209 (-35.929)	-2.21763 (-45.219)
LDIST	.693308 (81.529)	.685831 (83.827)	.682345 (84.444)	.674845 (80.788)	.740004 (100.504)
TF	.190224 (8.314)	.198273 (8.663)	.205283 (9.029)	.217250 (9.487)	
LLNOP	-.212012 (-5.960)	-.191568 (-5.537)	-.196634 (-5.739)		
LOF	-.060453 (-2.048)	-.056662 (-1.918)			
SV30	.0018978 (1.451)				
Distribution parameter, P	6.53668	6.52549	6.50149	6.31101	5.93028
Log-likelihood at convergence	-122.39	-123.60	-125.53	-147.95	-195.30
lambda	.06208	.06212	.06211	.06180	.06217
inflection point **	20.92	20.92	20.93	21.08	21.05

** from equation ($w_t = (P-1)^{1/P}/\lambda$)

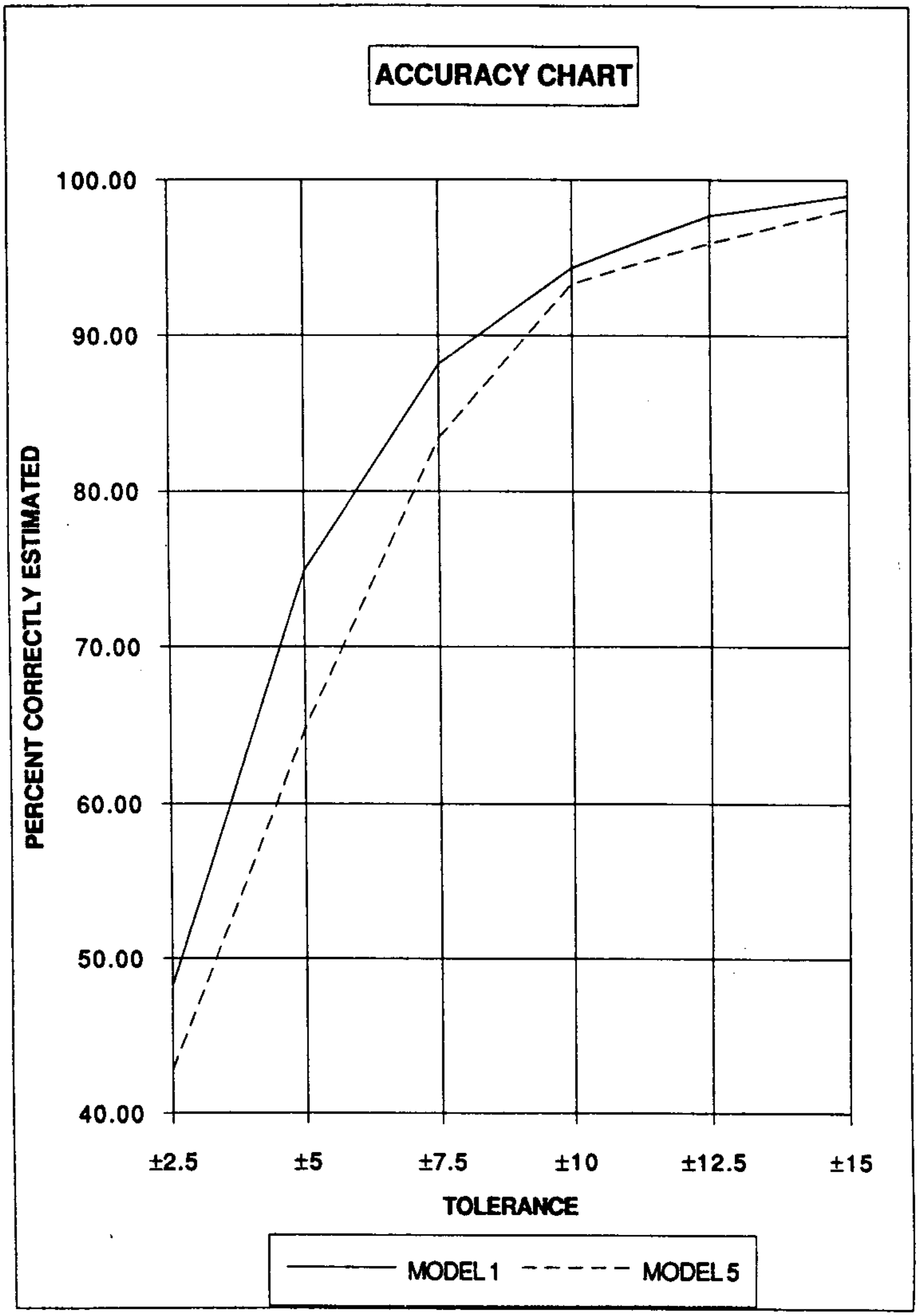

Figure 15. Tolerance Levels

To find the median of the estimated wait time, the equation for the normal and log-logistic models becomes as follows:

$$E[WAIT] = EXP[1/\text{-}(\text{Constant} + \beta_1 LDIST + \beta_2 TF + \beta_3 LLNOP + \beta_4 LOF + \beta_5 SV30)] \quad \text{(Equation 17)}$$

while the equation for the Weibull and exponential models is quite different.

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). Though several distances were used, the signs of the ß's were either counter intuitive or the difference in coefficients were not significant. Splitting the distances is 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 a decrease in wait time.

EVALUATION

To evaluate the model, the wait time was estimated for each record in the database and was then compared to the measured wait time. Estimations of wait time were calculated for each model. Model 1 results, as described in Table 7, can be seen graphically in Figure 16 (see page 53). Note also in Figure 16 how the upper and lower limits of the measured wait time differed. According to the Canadian customs officials, this difference can be attributed to border agents who conducted both primary and secondary duties in the booth when only primary duties should have been conducted. This source of inefficiency could be greatly reduced if border agents limited the amount of secondary customs work being conducted in the booth. Secondary duties are usually conducted inside the customs offices. In addition, it was necessary to know the limits within which these models predicted the expected wait time. For example, one can ask what percentage of the estimations are within ±5 minutes of the measured wait time. Furthermore, the researchers had to determine whether the extra cost to provide detectors for the service time variable was worthwhile. Figure 15 shows a comparison of the accuracy of the model that was estimated with queue length as its only independent variable to the more descriptive model that used all the parameters found in the best model. Notice the convergence in the two models as greater tolerances were allowed. (A ±15 minute tolerance means that if the model estimated wait time to be 30 minutes, it could range between 15 and 45 minutes). This is important in that if the system required a ±5 minute tolerance for accuracy, additional detection equipment would have to be provided to produce the variables required for Model 1.

Note also that during the evaluation process, there was an inflection point in the hazard of the model at nearly 21 minutes (see Table 7). This inflection reflects the Canadian border agents' efforts to meet the imposed policy of a 20-minute maximum delay, even though the policy had been relaxed. As the wait time increased, customs officials worked harder and used more resources to maintain control of the delay. However, eventually the volumes increased beyond control. This point was the inflection point (see also Figure 14).

Elasticities are used to find the effect that a percentage change in an independent variable will have on the dependent variable when all other variables remain the same. For this study's model, the researchers wanted to know what effect a 1 percent increase in the length of queue would have on the estimated wait time. The average of the 910

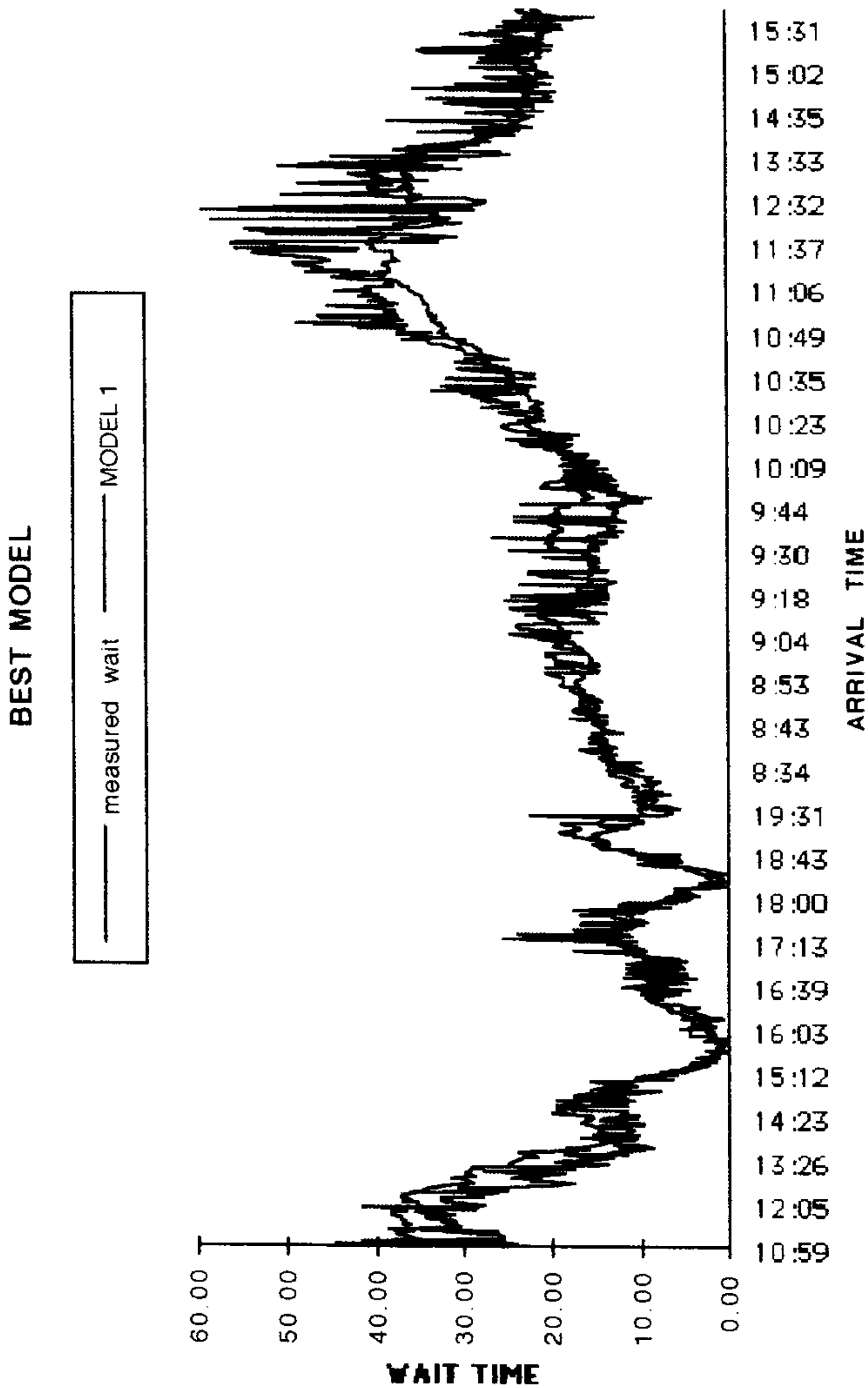

Figure 16. Estimated Wait vs. Measured Wait

independent estimates of wait time was 20.21 minutes. If the distance variable was multiplied by 1.01 and the wait time re-estimated, the average increased to 20.35 minutes. The elasticities could then be determined to be (20.35-20.21)/20.21, which = 0.69 percent. In other words, a 1 percent increase in distance would result in a 0.69 percent increase in expected wait time. In addition, the researchers wanted to know what effect a 1 percent increase in service time would have on the estimated wait time. This was similarly determined by running the model with 1 percent added to the service time. The result was a 0.05 percent increase in estimated wait time. This result suggested that service times were not as elastic as the distance variable. In addition, the value that the service time variable added to the model was significantly less than that of other variables in the model.

INTERPRETATION AND APPLICATION: REQUIREMENTS FOR AN AUTOMATED MOTORIST INFORMATION SYSTEM

TRAVELER INFORMATION SYSTEM GOAL

The goal of this traveler information system is to aid customs and transportation officials in more efficiently moving travelers through the border crossing facilities while reducing delay and travel related stress.

ISSUES

In order to accomplish the goal articulated above, motorists must perceive the travel information system as accurate and 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 maintenance departments' knowledge and expertise, whereas the use of new and unproven technologies will not only require extra work to fit the technology to the application but will 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. Because the purpose of traveler information systems is to cause route diversion, the guide signing of the designated alternative routes must accommodate travelers who may fall into what Lunenfeld called "local stranger" or "stranger" groups (8). Signing of each designated alternative route must be detailed enough to direct travelers who wish to return to their original routes.

SYSTEM IMPLEMENTATION

The U.S./Canadian border area in Whatcom county is more complex than the traffic study, discussed in an earlier chapter, was able to uncover. Therefore, additional data collection may be required before 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 β 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, but are not limited to, 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 queue was the most 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 17 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, 250 feet was used for the 500-foot interval spacing. If queues were between 1,000 and 2,000 feet, 500 feet was used for the 1,000-foot interval simulation.) This graphic 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,

ACCURACIES USING 500 OR 1000 FT DETECTOR SPACING

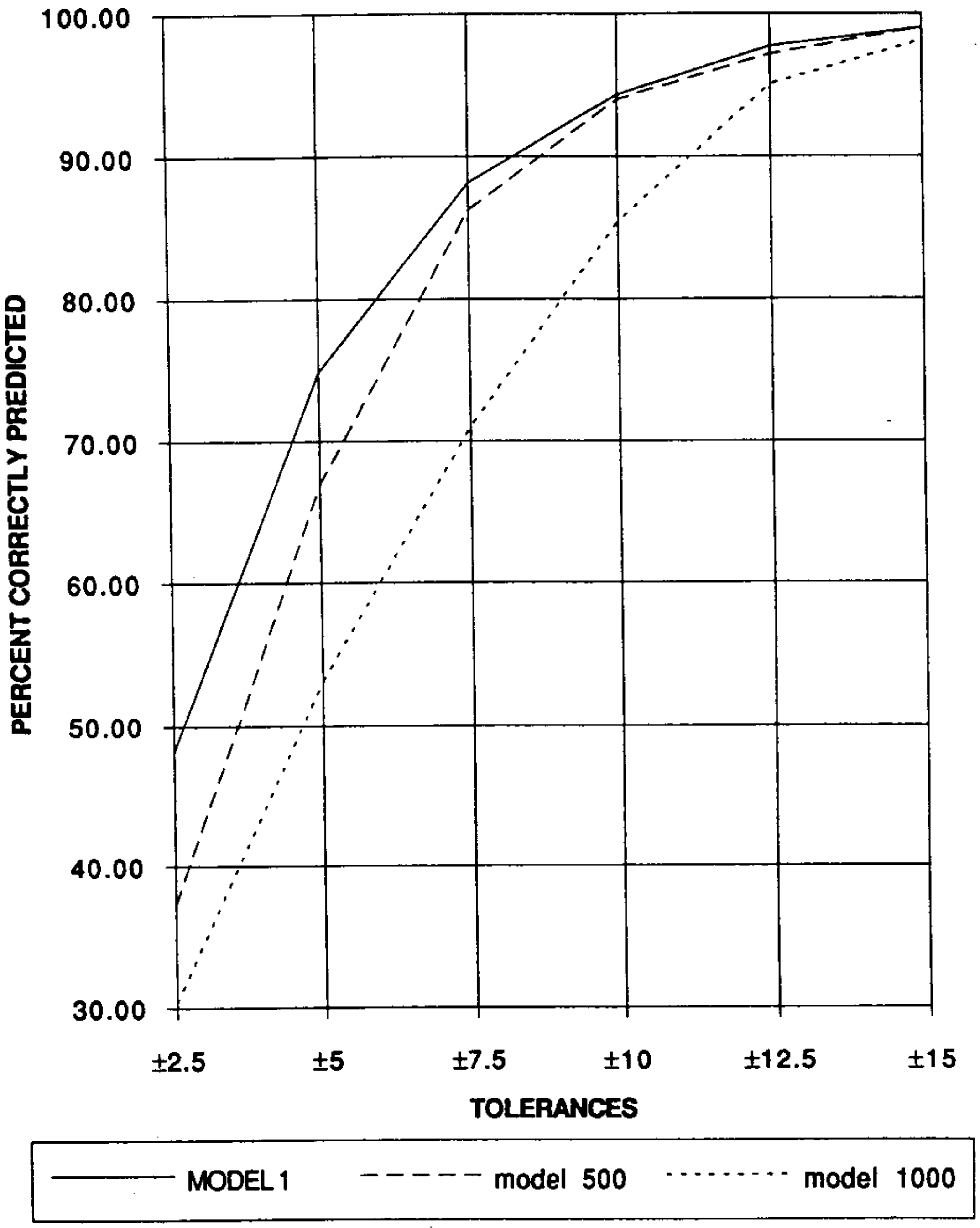

Figure 17. Detector Spacing

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, 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 detect 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 can 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 it 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 along with information gathered by the 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 lengthy.

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. A good model possesses a relatively high log likelihood and should always be negative; i.e., a value of -172 indicates a better model than a value of -1,000. A second indicator of a good model is the sign and t-statistic 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-statistic is from zero, the more significance it lends to the model.

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 18 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 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. A third sign near Lynden but south of the roadway leading to Sumas would display information pertinent to the Lynden and Sumas crossings (see Figure 19). This configuration would provide information to motorists who did not pass through Bellingham. Research indicates that travelers' stress levels increase when they change to alternative routes but have no way of knowing whether they have made the correct decision (9). 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 replace the VMS near Bellingham with a HAR system. 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.

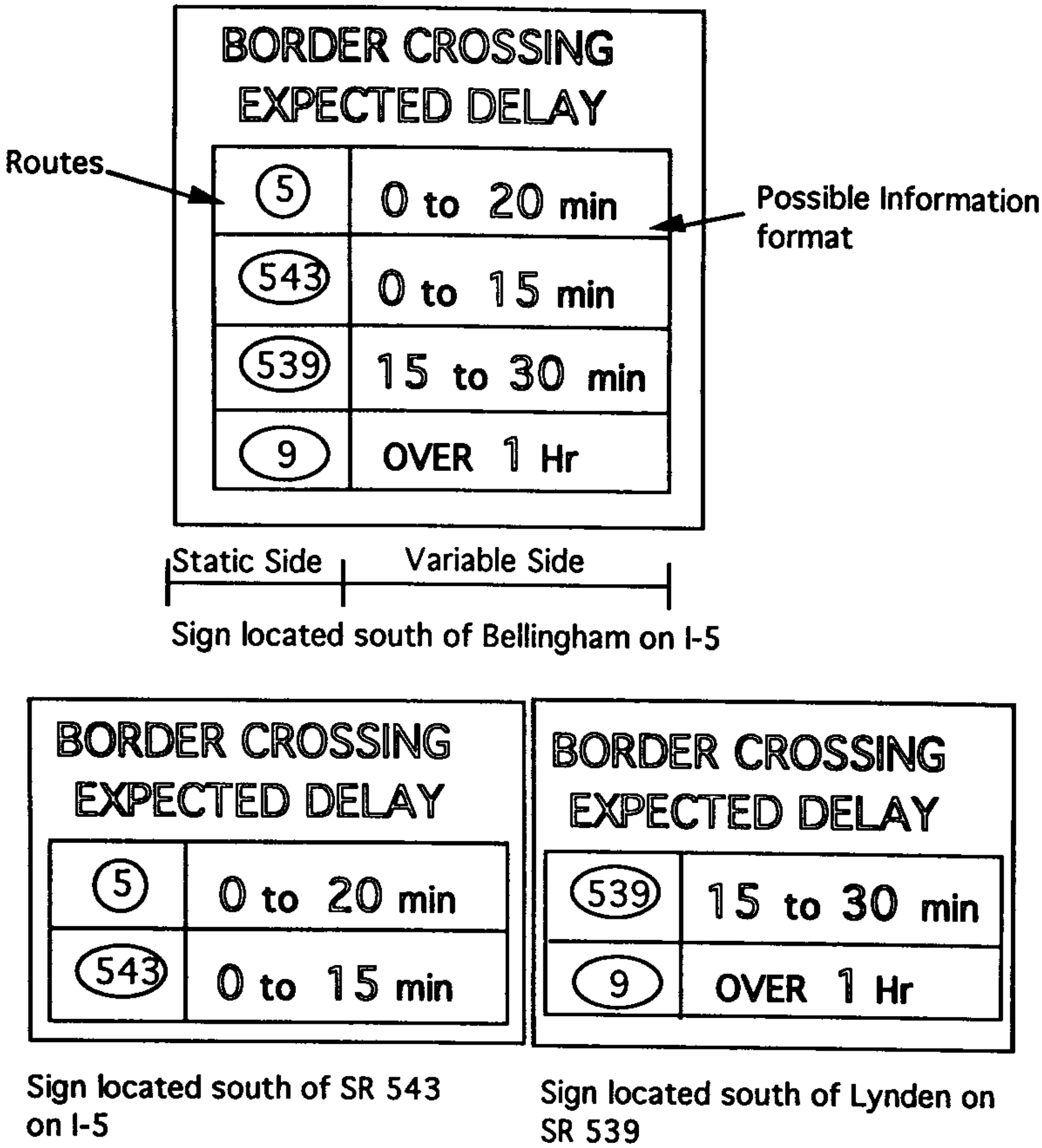

Figure 18. Possible Variable Message Sign Formats

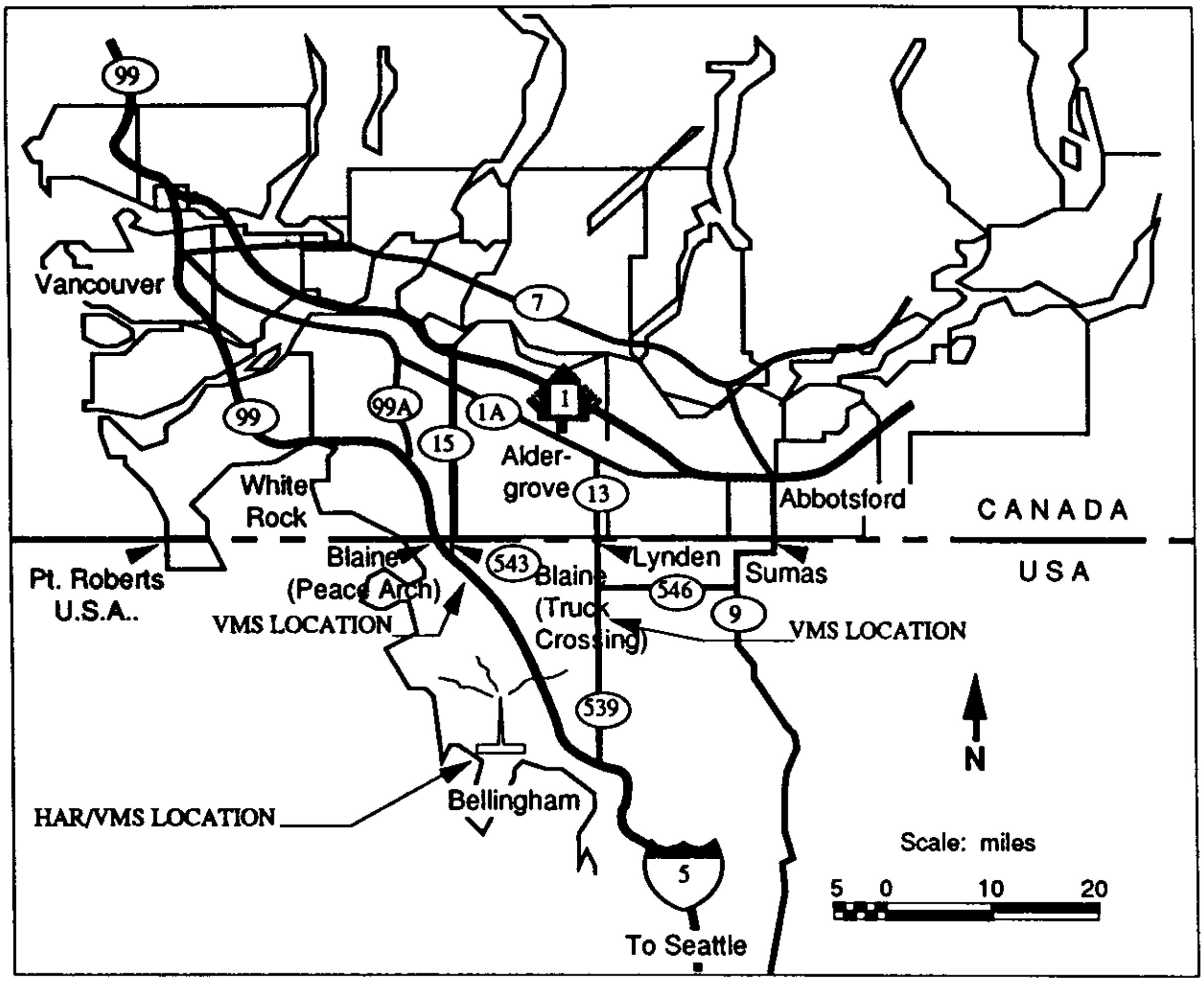

Figure 19. Vicinity Road Map Showing Location of VMS and HAR

Computer Terminal. Studies have shown that a percentage of the motorists who seek travel information do so before their departure (9). 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 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 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.

CONCLUSIONS

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 can choose alternative routes or departure times for their trips. Their choices will distribute the traffic and help to reduce delay and congestion at the border. The detection and analysis methods described will predict accurately expected delay, if they are maintained properly, and as additional data are gathered, the accuracy of the model will increase. Duration modeling is a new concept to traffic analysis, and if it is used properly, it can aid in uncovering traffic behavior relationships. Further research may be needed to help choose a detector for the system that will best meet the requirements of this traffic environment, i.e., long lead in cables and moving queues. Providing information to motorists through media such as HAR, VMS, and computer terminals will give a wide audience border information in ways that will best suit their needs. In addition, public radio and TV will have access to accurate and frequent information.

Other solutions will still need to be considered, and because geometric changes will be required for almost all other solutions, including the PACE lane, some planning should be done to assess priority areas. The PACE lane has the potential to greatly reduce the delay and congestion at the border, and as more and more motorists become aware of the advantages of the program, additional lanes may be required for improved efficiency.

The queues that form at the border are constantly moving, unlike those found at traffic signals. Therefore, some method of detecting these queues must be developed. Two options, occupancy or speed, seem relevant. Adjusting the controller to recognize a certain level of occupancy as a queue seems to be one possibility. However, if a large number of vehicles are in a platoon, then false readings may develop. The second method may also be appropriate to consider. If all six lanes are open, the average service time is 35 seconds per vehicle, and the assumed vehicle length is 16 feet, then the detector will need to recognize speeds of less than 2 miles per hour. Once the queue length can be determined at specific detector locations, it can be estimated between detectors to more accurately estimate border delay.

Travel delay at border crossings where volumes and service times cannot be accurately measured can be estimated with one of several duration modeling techniques. These modeling techniques can be modeled to fit many situations that are dependent on behavior processes. But because behavior processes change over time, these detection parameters must be evaluated regularly. Consideration must be given to the accuracy and credibility of the information system. Short cuts can be taken, but once public trust is lost, it will be difficult to regain. Over all, people want travel information when crossing the border. HAR and VMS should be effective media for disseminating this information. Even if these methods are not motorists' preferred methods of receiving information (9), motorists who want to use the information will have access to it.

To implement this system and evaluate its effectiveness, several events must take place. First, detectors must be installed to gather data across the border. Second, the data must be analyzed to determine whether a significant time advantage results from choosing one route over another at any given time. If there is a significant time advantage, then the information system must be implemented to provide motorists with the information. This type of study can also be used to justify the costs of system components. If the delay can be greatly reduced, then more costs can be justified. Finally, once the detectors have been placed and the range of delay across the border is available, the information can be tailored to motorists' needs. The information system can be implemented in a fully automatic manner, with the exception of regular evaluations and credibility checks.

IMPLEMENTATION STRATEGIES

COST BREAKDOWN

Several configurations are possible for an information system that is capable of delivering information to motorists near the U.S./Canadian border. The most extensive approach would involve gathering real-time data at the four crossings and delivering information to all possible dissemination sources, e.g., HAR, VMS, public radio, and shopping areas. However, this approach might be initially too expensive since the success of the recommended detection/analysis methods is unknown. Therefore, a more simplistic, cost effective approach might be to implement data gathering stations at the two crossings in Blaine and provide information to motorists through public radio. This option would match motorists' most preferred method of receiving travel information both before and during their trips (9). As knowledge about the detection parameters was gained, more of the crossings could be included in the system. To further develop the system to reach a broader range of travelers, more advanced information dissemination strategies could be developed to use HAR, VMS, and computer terminal technologies. Recommendations could then be made about potential application at the other border crossings.

The cost to implement a system that would provide information about the Peace Arch and Truck Crossing would be minimal in comparison to implementing a system that would provide information along each of the selected routes. The following is an approximate breakdown on the cost of implementing this two-crossing information system.

Data Gathering

The Peace Arch would require 21 inductive loop detectors (queue detectors spaced at 500-foot intervals), two two-channel controllers, controller cabinets, junction boxes, power supplies, amplifiers, and installation costs. The Truck Crossing would require 27 detectors and three two-channel controllers. Inductive loops and their installation cost approximately $1,500 each, and the controller and cabinets each cost about $2,000, including installation. The totals are approximately $35,500 to instrument the Peace Arch and $46,500 for the Truck Crossing. (Note: the number of detectors required would detect up to approximately one hour of delay).

<u>Data Analysis Equipment</u>

A microcomputer would be required to analyze the data to estimate the delay that a motorist could expect when crossing the border. This PC-type computer would require an environmentally sound cabinet. WSDOT plans to use a room located in the Bellingham maintenance yard as a computer room for this project. The PC cost would then be about $3,500. (The funding for the programming of this estimation analysis is included in a separate project.)

<u>Information Dissemination Components</u>

<u>**HAR**</u>. Because WSDOT already has a HAR site and equipment, only minimal upgrade funding would be required before implementation. The costs might be as high as $10,000 to completely ready the system, including the advanced highway signing.

<u>**VMS**</u>. The rotating drum VMS indicated in figures 18 and 19 cost approximately $25,000 to $30,000, including installation, for the two-drum and four-drum signs, respectively. Reflective disk systems can cost as high as $36,000 (1 line, 22 characters per line not installed) and fiber optic or LED systems can be $83,000 (2 lines, 22 characters per line not installed).

To summarize, a basic information system for the two I-5 crossings that would provide information to public radio would cost approximately $85,500, while the cost to provide information via HAR at Bellingham and a rotating drum VMS located on I-5 south of SR 543 would cost approximately $120,500.

PREDICTIVE APPROACH

Because the potential exists to provide information to motorists as far south as Bellingham, which is approximately 20 minutes of travel time from the border, a system that could predict delay as much as 20 minutes in advance of a vehicle's arrival would be ideal. One assumption that has to be made at this point, or at least until more data can be gathered, is that northbound volumes have a significant impact on border crossing traffic. This is important because much of the border traffic consists of Canadian motorists crossing the border and returning home without passing through Bellingham. Giving congestion predictions to motorists, if they perceive the information to be credible, can cause the volumes of traffic to change along main routes. By detecting these changes in volume, a computer system could re-estimate the delays and update the information. Of course, more data must be gathered and predictive algorithms developed before such a system would be practical. The key to this prediction would be volume data collected along the main routes near Bellingham, in addition to the data collected at each of the border crossing areas.

POTENTIAL IMPACTS

Three situations could affect the information dissemination process at the border. First, political policies and consumer behavior could remain the same; that is, Canadian shoppers would continue to come to the U.S. to shop. Second, public policy and consumer behavior might reverse so that U.S. shoppers traveled to Canada to shop. And third, public policy and consumer behavior might equalize, leaving no advantage to crossing the border to shop. Each of these situations would require somewhat different data gathering and analysis techniques to achieve a credible information system. Perhaps the least likely situation to develop is equalized policy and behavior. This least likely situation would also provide the most unpredictable traffic patterns. However, the use of duration modeling and in-place detectors would allow expected delays to be estimated under these conditions. The other two scenarios (the situation remains the same or reverses) are similar in behavior; however, the detection parameters would most likely change. The origin-destination matrix would change dramatically, and the need for border crossing information would remain. However, the system would still have the capability to develop current information.

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 effect queueing analysis; however, if queueing analysis was used, these variables would have to be closely observed.

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APPENDIX A

PACE PROGRAM INFORMATION

Peace Arch Crossing Entry Project

PARTICIPANT'S GUIDE

For Canadian participants

- Terms and Conditions
- How does PACE work?
- Traveller Declaration System
- PACE Tariff Guide
- Common Questions and Answers

TERMS AND CONDITIONS

FOR CANADIAN RESIDENTS

As a participant in the Canadian PACE program, it is important that you familiarize yourself with the following terms and conditions.

1. The PACE permit (decal) must be affixed to the windshield of your vehicle, and is **non transferable**. The permit holder is responsible for reporting loss, theft, or sale of the vehicle.
2. The letter of authority **must** be carried in the vehicle at all times.
3. Only those members of your immediate family listed on the application may be in the vehicle when using the Canadian PACE lane(s). However, passengers other than family members may travel in the vehicle provided they are listed under some other Canadian PACE permit. These individuals must either carry a copy of their letter of authority or be prepared to quote their PACE permit number if requested by a Customs Inspector. You must not, under any circumstances, transport any other persons in your vehicle when using the Canadian PACE lane(s). Remember, the U.S. program differs somewhat from Canadian procedures in this regard.
4. All goods which you have **purchased or acquired** while abroad **must be declared** to Customs upon your return. You will use the TDS Declaration card for this purpose. The permit holder is responsible for declaring to Customs all articles imported/contained in the vehicle. Failure to comply may result in strict enforcement action and removal from the program.
5. All items must be for your own personal use.
6. You may not transport any business material, professional goods, commercial goods, goods for resale, samples, tools or equipment in the PACE lanes.
7. The PACE lanes may not be used to import any goods which are **restricted, controlled**, or **prohibited** in any manner. Please see the PACE tariff guide or contact your nearest Customs office for information on goods which fall into this category.
8. **The PACE decal and the TDS declaration cards remain the property of The Department of National Revenue, Customs and Excise**. The Department reserves the right to remove these items and revoke the privileges at any time.

PENALTIES

Periodic checks will be performed to ensure proper use of the PACE lanes. Your participation in the PACE program is a privilege. Anyone violating the terms and conditions of the PACE program will be subject to severe penalties including revocation of the permit; seizure of the vehicle and/or any goods found unlawfully therein; as well as possible fines and/or prosecution. Those persons attempting the illegal entry of non PACE approved participants will be subject to the prosecution provisions of the Canada Immigration Act. Visitors may face possible deportation from Canada. **The law will be strictly enforced.**

PACE PROJECT AT A GLANCE

HOW DOES IT WORK?

STEP 1: Read the contents of this package thoroughly and completely. Should you have any questions you may call the PACE office at 535-9346.

STEP 2: Affix the PACE decal to the upper inside centre portion of your vehicle windshield. On most vehicles this will be directly behind the rear view mirror. Please retain the "letter of authority" in the glove box.

STEP 3: APPROACHING THE BORDER

CANADIAN RESIDENTS

NORTHBOUND

1 Complete your declaration form. (No declaration form is necessary if no goods were acquired.)
2. Keep right and follow the signs to the PACE booth.
3. Slow down upon your arrival to allow for visual inspection.
4. Deposit your declaration card into the PACE deposit box.
5. Proceed slowly unless you are directed to stop by a Customs Inspector.

U.S. RESIDENTS

NORTHBOUND

1. Keep right and follow the signs to the PACE booth.
2. Slow down upon your arrival to allow for visual inspection.
3. Proceed slowly unless you are directed to stop by a Customs Inspector.

Hours of Service

While operating hours will vary depending upon traffic volume, the PACE lane(s) will normally be open during peak traffic hours from 12 noon till 8 p.m.. Signs will direct traffic and advise you when the lane is open. As this is a pilot project, these hours will be adjusted during the course of the project to best meet the needs of PACE participants.

NON PACE HOURS

During non-PACE hours, PACE permit holders will join the regular traffic lanes at the Douglas crossing for normal Customs/Immigration processing. After a brief interview, returning Canadian PACE holders may simply hand the Customs Inspector their Traveller Declaration Card for goods acquired or received during their absence.

TRAVELLER DECLARATION SYSTEM (TDS) FOR CANADIAN RESIDENTS

As a Canadian PACE traveller returning from the United States, you will be permitted to essentially drive through Customs without the usual interview, stopping only if items have been purchased or acquired and only long enough to drop off the Traveller Declaration Card. On occasion you may also be directed to stop by a Customs Inspector. You must complete the declaration card **prior to your arrival** at Customs as it represents your complete declaration to Customs of all goods purchased or acquired. It also represents your authority to assess any duties and taxes directly to your credit card held on file. Remember, no credit card billings can be made by Customs without your expressed written consent.

RATES OF DUTY

The present Customs tariff contains thousands of individual tariff items, each with a corresponding rate of duty. Up until now, Customs officers have applied the tariff to a traveller's declared items and collected the duty. The PACE project offers a much simpler option based on both speed and ease of use. The thousands of tariff items have been condensed to nine categories and you will be asked to declare your goods according to these categories. In compressing the existing tariff, there will be instances where the true rate of duty is slightly higher or lower than one of the selected 9 categories. These categories represent a grouping of existing duty rates, which we feel provides an equitable application of the duties and taxes. As the amounts payable under the program are relatively small, these variations are not considered to be significant when considering the speed and ease of the operation involved. In addition, it is important to remember that you always have the option of travelling in the regular lanes should you wish a more specific tariff or rate of application.

The following sections will describe in some detail the procedures for completing the card, the limitations, an explanation of the nine categories and a PACE Tariff Guide that assists travellers in estimating the duties and taxes payable on any particular importation.

ACCOUNTING FOR DUTY AND TAXES

The TRAVELLER DECLARATION SYSTEM (TDS) CARD is an important component of the PACE program, as it allows you to pay the duties and taxes owing on any goods imported automatically through your credit card. The personal declaration cards included in this package have been cryptically encoded to match your credit card number. It is therefore important that you maintain your declaration cards in a safe and secure location. All charges to your credit card will be based only on the information you provide on the declaration card. The card is your declaration to Canada Customs, and as such, it is very important that you complete it correctly.

On the face of the card there are nine categories. It will be your responsibility to declare your goods according to these categories. The PACE Tariff Guide will assist you in this task. Once you have determined the correct category, you must then code the information onto the declaration card so that it may be read by the computer. The process is relatively straightforward as the design is similar to a popular lottery format.

COMPLETING THE CARD

One card per vehicle is to be completed. (For claiming a 24 hour or 48 hour exemption please see the explanation below.) If you wish to claim your yearly ($300.00) exemption, you must use the regular traffic lanes as a formal written declaration is required. The maximum amount which may be declared per card is $500.00 (U.S.). If you should exceed this amount, you must use the regular lanes. The following is a step by step explanation of how to complete your declaration card. Please refer to the examples provided.

1. Indicate in numerical format the total value of your goods in **United States funds** (e.g. $31.99). The Customs computer system will convert this amount to Canadian funds according to the Bank of Canada rate for that day. Duty and taxes are calculated on this converted value of the goods (i.e. expressed in Canadian funds).
2. Shade the boxes to correspond to the total value in United States funds, rounding your figures to the nearest $5.00.
3. Shade the boxes to correspond to the total number of people in the vehicle.
4. **Sign and date** the declaration card.
5. Drop off the **top copy** of the completed card in the PACE deposit box located adjacent to the Inspector's booth. Retain the second copy as your record of the transaction. Please remember to complete it **before** your arrival at Customs to avoid delays to you and other travellers.

CLAIMING THE 24 HOUR OR 48 HOUR PERSONAL EXEMPTIONS

Each person claiming a 24 hour or 48 hour exemption must complete a **separate card**. (As there are additional and specific conditions for claiming the personal exemptions, it is important that you consult the enclosed " I DECLARE " pamphlet.)

1. As above, indicate in numerical format the **total value** of your goods in **United States funds**. List all goods purchased or acquired.
2. Shade the boxes to correspond to this amount, rounding your figures to the nearest $5.00.
3. Only the driver of the vehicle **must** complete the section concerning the total number of people in the vehicle. The passengers will leave this section blank.
4. **Each person claiming the exemption must shade the 24 hour or 48 hour personal exemption box as well as sign and date their own card.**

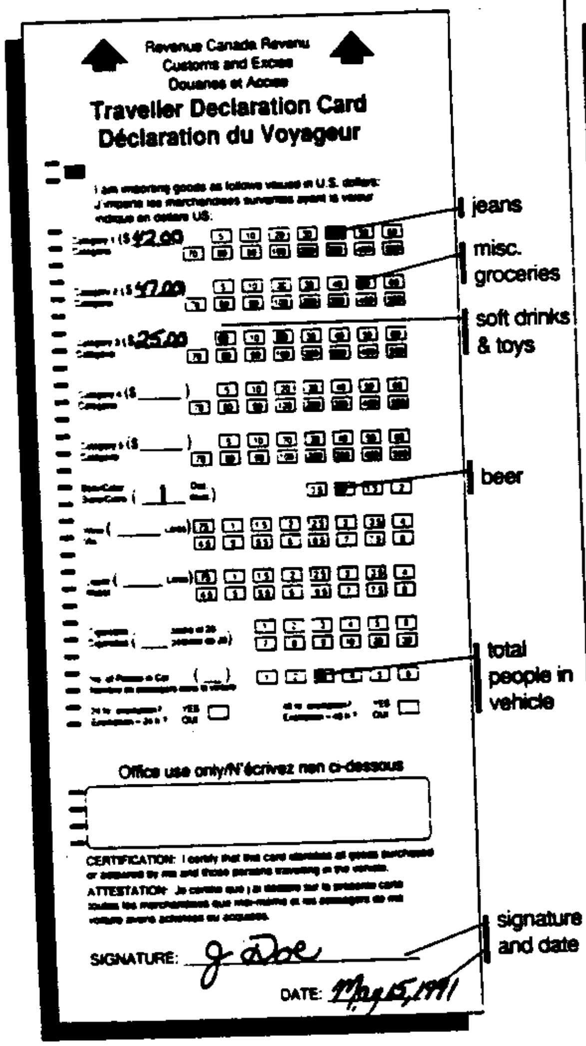
NOTE: Please use black or blue ink to shade the boxes. **Do not use red ink.** *It is important that you carefully complete the card as the machine will read any marks made on the card. If you should you make an error. please complete a new declaration card.*

EXAMPLES

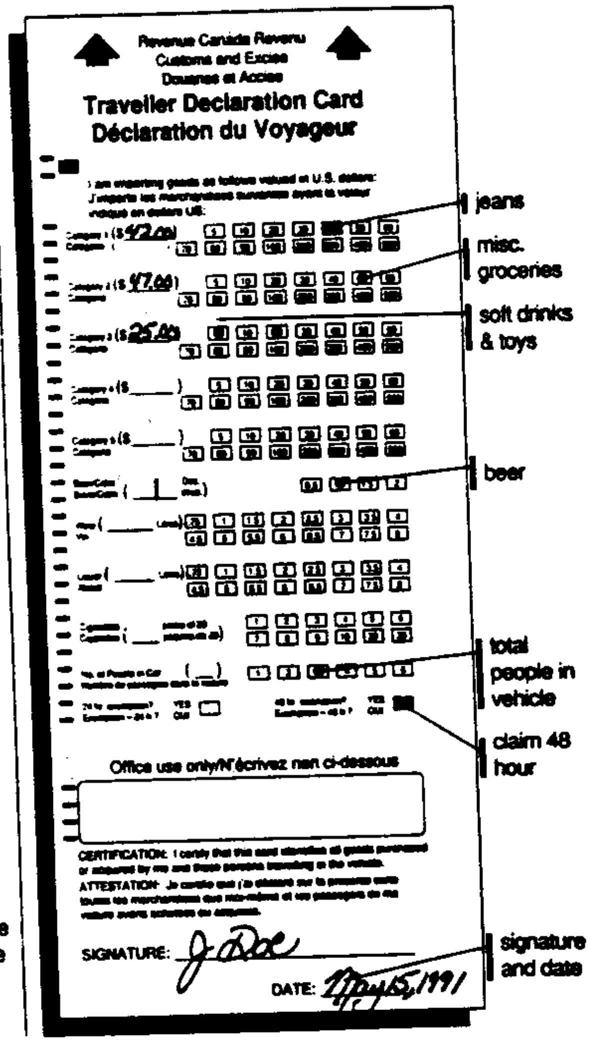
Lets presume that you are returning to Canada with the following items:

Articles	Value US Dollars
1 pair of jeans	$42.00
misc. groceries	$47.00
2 cases of soft drinks	$10.00
1 dozen beer	$ 6.00
1 teddy bear	$15.00

Example 1: *shows how you would complete the declaration card if you were absent from Canada for* ***2 hours; no exemption applies.***



Example 2: *shows the same goods being declared, however in this instance you left Canada on Friday night and you are returning home Sunday evening, after an absence of* ***48 hours.***



PACE TARIFF GUIDE

This guide is intended to help you determine in which category to declare your goods on the declaration card. The list is by no means exhaustive, however we hope that it will be sufficient to meet your needs. If the items which you are importing are not listed, please place the items in category 3 (i.e. miscellaneous goods). For your convenience we have included a compound rate of duty and taxes beside each category. You may use this rate to estimate the total duty and taxes payable on your goods.

NOTE:
To qualify for the PACE tariff rates, the goods being imported must be of U.S. and/or Canadian origin and be for your personal use. They must be acquired in the U.S. and must not indicate (on labels or markings) that they were produced in any other country other than the U.S. or Canada.

* Remember, you always have the option of utilizing the regular lanes for a specific duty rate application.

CATEGORY 1.

18% + 7% GST.

When compounded for a combined rate of approximately 26%.

carpeting
clothing
footwear
textile articles
- -towels
- -bedding
- -curtains

jewelry

CATEGORY 2.

12% + 0% GST.

basic groceries (non taxable)
including:
- -poultry, meat
- -fish
- -fresh fruit and vegetables
- -milk
- -frozen food items
- -canned food goods
- -fruit juices (large containers, more than single serving)
- -cakes and pies
- -other baked goods (in packages of 6 or more)

CATEGORY 3.

10% + 7% GST.

When compounded for a combined rate of approximately 18%.

Other grocery items (taxable) including :

- -snack foods
- -soft drinks
- -single serving containers of yogurt, pudding.
- -candy
- -paper products
- -cleansers
- -toiletries

audio tape, recorded (cassette or reel)
beauty aids, including all skin and hair products
canoes
clothes dryers
dishwashers
gas barbecues
golf clubs
microwave ovens
records
refrigerators
sports equipment
ranges, electric
toys
watches
tires (car, truck, and motorcycle)
articles of plastic, miscellaneous
articles of steel, miscellaneous
articles of rubber, miscellaneous
sundry/miscellaneous goods not elsewhere specified in this guide

CATEGORY 4.

6% + 7% GST.

When compounded for a combined rate of approximately 13.5%.

audio tape, unrecorded
automotive parts
cameras, still
coffee makers
compact discs (C.D.'s)
furniture
luggage
medications, including vitamins
machinery (wood planer, tablesaw, chainsaws, knitting machines)
speakers
televisions
tools, electric hand held
video tape recorders (VCR's)
video tape, unrecorded
electrical apparatus, miscellaneous
articles of wood

CATEGORY 5.

DUTY FREE + 7% GST.

amateur radios, receive or transmit on the amateur band
books
computers
compact disc players
fax machines
motorcycle parts
pet foods
skates, ice and roller
ranges, gas
telephones, including portable and cellular
typewriters, electric
tools, pneumatic powered only
video cameras

CATEGORY 6.

(includes all federal and provincial charges)

$3.58 /dozen.

beer
cider

CATEGORY 7.

(includes all federal and provincial charges)

$4.66 / litre.

wine, all types
wine coolers

CATEGORY 8.

(includes all federal and provincial charges)

$13.18 / 1.14 litre.

hard liquor
liquors

CATEGORY 9.

$2.16 / pack of 20.

cigarettes

Example

The following illustrates how the duties and taxes will be calculated for each item. This calculation represents how the Customs system will treat each completed category.

Description of goods:

Teddy bear (category # 3)	U.S. value	$15.00
	rate of exchange (e.g.)	1.20

Calculation method:

U.S value	*Exchange (@1.20)*	*Cdn value*	*Duty 10%*	*Duty paid value*	*GST 7%*	*Total Revenue Payable (duty + GST)*
15.00	3.00	18.00	1.80	19.80	1.39	(1.80 +1.39) = $3.19

REFUNDS

When things go wrong.

Travellers will note that the Declaration Card shows two amounts, one written in numerical format and other completed by shading the appropriate boxes. We recognize that mistakes are made and if they are, refunds will be authorized. Travellers should bring their copy of the Declaration Card to the Douglas PACE office; explain the error (most often these errors may be in marking off the dollar "boxes") and a refund will be processed in due course.

LIMITATIONS

The following lists the limitations on commodities which are most commonly imported. The limits shown are applicable to each individual.

meat	20kg	
poultry		
	- turkey whole	1.
	- turkey parts	10 kg.
	- chicken	9 kg.
fish	11.34 kg	
eggs	2 dozen	
dairy products	$20.00 (CDN)	

The PACE lanes may **NOT** be used to import the following goods which are **restricted, controlled, prohibited** in any manner, or where special documentation is required.

- all motor vehicles and trailers;
- live animals;
- pornography;
- hate propaganda;
- weapons of any type, including all firearms and martial art weapons;
- ammunition, fireworks;
- species of plants and animals which are protected under the Convention on International Trade in Endangered Species. The restrictions extend to any products made from the fur, skin, feathers, bone, etc. of these creatures;
- cultural property: this restriction extends to articles which could be considered to have historical significance to their country of origin.

For further information regarding the importation of any of the articles listed above, please contact your local Customs office.

ALCOHOLIC BEVERAGES

If you are over the age of nineteen, you may import under your 48 hour personal exemption, 1.14 litres of wine or liquor, or 24 x 355ml cans or bottles of beer or ale free of duty and tax. You may exceed this free allowance by up to 9.1 extra litres without any special advance authority, however the applicable duty and taxes can be prohibitive. Please see the "I Declare" pamphlet for further details.

FRUITS & VEGETABLES RESTRICTIONS

The following fruit and vegetables are **PROHIBITED**.

- apples, peaches, pears, apricots, plums, nectarines, quince and hawthorn
- corn-on-the-cob and potatoes.

COMMON QUESTIONS AND ANSWERS FOR CANADIAN PACE PERMIT HOLDERS

1. *Can I use my PACE privilege at other border crossings?*

No. The PACE project is a pilot program designed to facilitate travel and duty collection. During the test period, it will be available only at the Peace Arch crossing. Should the project prove successful and beneficial to travellers, it will be extended to other border crossings.

2. *What should I do when the PACE lanes are closed ?*

The PACE lane(s) will remain open during busy hours of the day at Douglas (12 noon till 8 p.m.). Signs will be posted for travellers in advance of the border crossing. When the PACE lane(s) are closed. please be prepared to join the regular traffic and proceed through the normal Customs/Immigration formalities

3. *What if I know the rate of duty is less than the category as specified in PACE ?*

If you know that the rate of duty is less than the category, you have the option of using the regular lanes and being assessed the specific rate of duty.

4. *What if I forget to declare something ?*

The PACE system (and the Traveller Declaration System) is a privilege granted to the traveller in order to expedite traffic and duty collection. The onus is on the user to abide by the terms and conditions of this privilege. Violation of the terms and conditions may result in severe penalties.

5. *When I have completed my TDS book, where do I obtain a new one ?*

Once you have used your twentieth TDS voucher, a new book will be assigned to you. It may be claimed in person at the PACE office.

6. *What if I loose my TDS Declaration book ?*

You should report the loss immediately to the PACE office located at the Douglas border crossing. Please bring your letter of authorization and some identification. The lost book will be cancelled and a new book will be issued to you.

7. *What if my windshield is destroyed in an accident ?*

You should report the damage immediately to the PACE office. A new decal will be issued to you upon verification of the report.

8. *What if I sell my car ?*

As the decal is vehicle specific, the onus is on you to protect your interest to remove the decal prior to your selling the vehicle. (As in Question # 7) .

9. *When will the duties and taxes assessed appear on my credit card statement ?*

Revenue collected will be processed as a normal VISA/MasterCard transaction. The amount assessed will appear on your next statement, depending on your billing date. Your VISA/MasterCard statements, along with the second copy of your TDS card, will serve as prove of legal entry for the goods imported.

10. Will anyone be able to make charges to my credit card ?

No. Only your personal declaration card can be matched to your credit card. A unique number has been encoded on your declaration card which prevents cross billing from occurring. The declaration card is mechanically read, duties are assessed by the computer and the credit card amounts are electronically transmitted to the credit card companies/banks. Travellers are cautioned however, to maintain their Traveller Declaration Cards in a safe and secure location.

11. What if my credit card is stolen ?

You should report it through the normal channels i.e., to the financial institution that issued the card. Then report it to the PACE office. You will be required to surrender any remaining TDS cards which you may have and submit a new application with your new credit card number. The PACE decal will not be reissued.

12. Why can't I use my American Express card ?

At this time, the Government of Canada does not have an agreement with American Express for business transactions. Canada Customs has merely extended current existing credit agreements to the PACE project.

Peace Arch Crossing Entry Project

PARTICIPANT'S GUIDE

For United States participants

- Terms and Conditions
- How does PACE work?
- Limitations
- Common Questions and Answers

TERMS AND CONDITIONS

FOR U.S. RESIDENTS

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2. The letter of authority **must** be carried in the vehicle at all times.
3. Only those members of your immediate family listed on the application may normally be in the vehicle when using the Canadian PACE lane. Passengers other than family members may travel in the vehicle provided they are listed under some other Canadian PACE permit. These individuals must either carry a copy of their letter of authority or to be prepared to quote their PACE permit number if requested by a Customs Inspector. Remember, the U.S. program differs somewhat from Canadian procedures in this regard.
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7. **The PACE decal remains the property of The Department of National Revenue, Customs and Excise.**The Department reserves the right to remove the these items and revoke the privileges at any time.

PENALTIES

Periodic checks will be performed to ensure proper use of the PACE lanes.Your participation in the PACE program is a privilege. Anyone violating the terms and conditions of the PACE program will be subject to severe penalties including revocation of the permit; seizure of the vehicle and/or any goods found unlawfully therein; as well as possible fines and/or prosecution. Visitors may face possible deportation from Canada. **The law will be strictly enforced.**

PACE PROJECT AT A GLANCE

HOW DOES IT WORK?

STEP 1: Read the contents of this package thoroughly and completely. Should you have any questions you may call the PACE office at 535-9346.

STEP 2: Affix the PACE decal to the upper inside centre portion of your vehicle windshield. On most vehicles this will be directly behind the rear view mirror. Please retain the "letter of authority" in the glove box.

STEP 3: APPROACHING THE BORDER

CANADIAN RESIDENTS

NORTHBOUND

1 Complete your declaration form. (No declaration form is necessary if no goods were acquired.)
2. Keep right and follow the signs to the PACE booth.
3. Slow down upon your arrival to allow for visual inspection.
4. Deposit your declaration card into the PACE deposit box.
5. Proceed slowly unless you are directed to stop by a Customs Inspector.

U.S. RESIDENTS

NORTHBOUND

1. Keep right and follow the signs to the PACE booth.
2. Slow down upon your arrival to allow for visual inspection.
3. Proceed slowly unless you are directed to stop by a Customs Inspector.

Hours of Service

While operating hours will vary depending upon traffic volume, the PACE lane(s) will normally be open during peak traffic hours from 12 noon till 8 p.m.. Signs will direct traffic and advise you when the lane is open. As this is a pilot project, these hours will be adjusted during the course of the project to best meet the needs of PACE participants.

NON PACE HOURS

During non-PACE hours, PACE permit holders will join the regular traffic lanes at the Douglas crossing for normal Customs/Immigration processing. After a brief interview, returning Canadian PACE holders may simply hand the Customs Inspector their Traveller Declaration Card for goods acquired or received during their absence.

LIMITATIONS

The following lists the limitations on commodities which are most commonly imported. The limits shown are applicable to each individual.

meat	20kg
poultry	
- turkey whole	1
- turkey parts	10 kg.
- chicken	9 kg.
fish	11.34 kg
eggs	2 dozen
dairy products	$20.00 (CDN)

The PACE lane(s) may **NOT** be used to import the following goods which are **restricted, controlled, prohibited** in any manner, or where special documentation is required.

- all motor vehicles and trailers;
- live animals;
- pornography;
- hate propaganda;
- weapons of any type, including all firearms and martial art weapons;
- ammunition, fireworks;
- species of plants and animals which are protected under the Convention on International Trade in Endangered Species. The restrictions extend to any products made from the fur, skin, feathers, bone, etc. of these creatures;
- cultural property: this restriction extends to articles which could be considered to have historical significance to their country of origin.

For further information regarding the importation of any of the articles listed above, please contact your local Canadian Customs office.

ALCOHOLIC BEVERAGES

As a visitor to Canada you are entitled to import duty free either, 1.1 litres of liquor or wine, or 24 x 355 ml (12 ounce) cans or bottles or beer or ale and 200 cigarettes. For specific details on the limitations of commodities you may import, please refer to the enclosed pamphlet, "Travel Information." Should you have any goods in excess of the limitations or any goods which are to remain in Canada, **you must use the regular traffic lanes.**

FRUITS & VEGETABLES RESTRICTIONS

The following fruit and vegetables are **PROHIBITED.**

- apples, peaches, pears, apricots, plums, nectarines, quince and hawthorn
- corn-on-the-cob and potatoes.

COMMON QUESTIONS AND ANSWERS FOR United States PACE PERMIT HOLDERS

1. Can I use my PACE privilege at other border crossings?

No. The PACE project is a pilot program designed to facilitate travel. During the test period, it will be available only at the Peace Arch crossing. Should the project prove successful and beneficial to travellers, it will be extended to other border crossings.

2. What should I do when the PACE lanes are closed ?

The PACE lane(s) will remain open during busy hours of the day at Douglas (12 noon till 8 p.m.). Signs will be posted for travellers in advance of the border crossing. When the PACE lane(s) are closed, please be prepared to join the regular traffic and proceed through the normal Customs/Immigration formalities

3. What if my windshield is destroyed in an accident ?

You should report the damage immediately to the PACE office. A new decal will be issued to you upon verification of the report.

4 What if I sell my car ?

As the decal is vehicle specific, the onus is on you to protect your interest to remove the decal prior to your selling the vehicle.

APPENDIX B

LITERATURE REVIEW: ELEMENTS OF AUTOMATED TRAVELER INFORMATION SYSTEMS

ELEMENTS OF AUTOMATED TRAVELER INFORMATION SYSTEMS

This appendix reviews recent projects and concepts related to advanced traveler information systems (ATIS). Elements of ATIS include motorist behavior, vehicle detection, and information dissemination systems. This information was a basis for the project and helped to focus attention on priority areas.

Much literature exists on the relationship between human factors and motorist information. Paper topics range from how the mind processes data to selecting a target audience for information. Some papers combine motorist behavior with a discussion of the media that can best reach motorists both en route and before their departures. Over all, the papers present the idea that the information, as well as the information system as a whole, should be designed for the user first, and the technology should meet the needs of the user, not vice versa.

Vehicle detection is a primary element of any ATIS and is a rapidly developing technology. Many new and innovative vehicle detection methods are being developed to better report vehicle movement and to allow data to be transferred to and from vehicles while they are in transit. The innovative technologies include vehicle tracking with inductive loop signature matching, inductive loop radio, and video image processing (VIP). VIP systems have recently seen great advances in the vehicle detection area. VIP technology, however, is dependent almost entirely upon gains in the computer industry, while the objectives of VIP are no different than existing detection methods.

To deliver the traffic information to the motorist, several dissemination system possibilities exist. These systems can be categorized as either pre-trip systems, in-vehicle/en route systems or roadside en route systems. Pre-trip systems include telephone, radio, TV, computer terminal, and variable message signs available to pedestrians, such as in shopping malls. In-vehicle/en route systems include commercial radio, state-of-the-art vehicle radio, computer terminal systems (currently being developed), and highway advisory radio (HAR). Car phones can also be a component of the in-vehicle system. The variable message sign is an example of a roadside en route system. Each of these systems have strengths and weaknesses, of which cost and availability are perhaps the most important.

Figure B1 shows how the three components of an ATIS interact. In continuous circle of events, motorists react to a given message, thereby causing changes in vehicle detection patterns, which in turn cause a change in the information that is sent to motorists, which allows motorists to modify their behavior and so on. The accuracy and placement of the detectors and the location of the information dissemination system are crucial to the success of the system. A measure of success is the number of people who modify their behavior by changing their trip departure time or route choice, or show enthusiasm over simply knowing about traffic conditions, even if no changes are possible.

MOTORIST BEHAVIOR

Many of the studies relating to motorist behavior or human factors have sought to uncover the best method of relaying the information to the motorist. Haselkorn and Barfield (1) discovered that in the Puget Sound region, groups of route changers, non-changers, route and time changers, and pre-trip changers use information differently and suggested that information be provided to these groups in a manner consistent with their needs. Others believe that everyone should have access to all information. While nearly all of the projects have dealt with the urban environment, many of their discoveries and questions do apply to the rural environment as well.

Studies have also shown that total system efficiency, is dependent upon the percentage of motorists who have accurate information. System efficiency is defined as the lowest total travel time experienced by all motorists on a given origin-destination

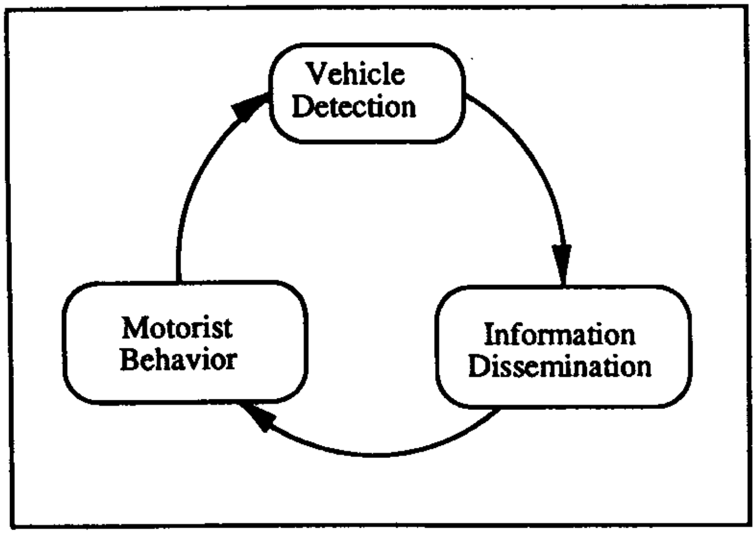

Figure B1. ATIS Element Interaction

matrix during some time interval, t. The best system efficiency usually occurs when approximately 50 percent to 70 percent of motorists have accurate and timely information (2). The questions remain, is it acceptable to provide information to only a portion of the travelling public? And if so, who decides who gets the information? More realistically, not everyone will use the information even if it is available, nor will everyone be able to receive the information (e.g., the cost of the equipment may be too high, people may not view the information as credible, and some may not view travel time as the most important route choice variable). To some extent, the questions above do not need to be resolved until the time that everyone has access to the information and demonstrates the ability to use it.

General Behavior

As the roadway network continues to become more complex and congested, drivers will continue to face an increasing navigational challenge. Therefore, drivers need navigation information. Drivers need this information because of the nature of the driving task and its navigation component, because of the overwhelming number of decisions they have to make, and to reduce the possibility of route selection error inherent in the current system.

The type of information that drivers may require is dependent on many variables. These variables include the location of the highway network (rural or urban), the purpose of the drivers' trips, the level of traffic congestion, and how familiar drivers are to their surroundings. Drivers need navigation information that corresponds to their trip purposes and desires, and they need to know how to follow their plans once they are en route (3). Many times drivers find themselves on a route that was not in their travel plans. The problem may be a result of inadequate signing, highway construction, or inadequate travel plans. An information system that is designed to provide route guidance under these circumstances will help to reduce needless delay and pollutants emitted into the air. Drivers also need to know what to do if they are forced off of their desired path. Lunenfeld (3) placed drivers in three classifications. "Locals" are completely familiar with a location's geography and road system; "strangers" are completely unfamiliar with all aspects of an area; and "local strangers" are somewhere in between. Nearly all strangers, half of the local strangers, and none of the locals develop a formal trip plan, regardless of their trip purpose. Each of these groups has different navigational information needs. For example, a local does not require route guidance information but does benefit from knowledge of congested routes. On the other hand, strangers benefit from route guidance information. Many strangers most likely stick to a known route, regardless of urban congestion, simply because they have not studied alternative routes. However, as route guidance information merges with congestion information, "stranger" drivers may begin to modify their behavior. Many questions remain concerning the effectiveness of these information systems but until operational experience has been gained, only hypothetical studies can indicate the effectiveness of the systems and how they affect the efficiency and safety of the highway system.

Research is underway to develop consistent, standardized, in-vehicle systems. In fact, the Federal Highway Administration has initiated a major study that will begin the standardization process of in-vehicle information systems. This study, titled Assessment of Effects of In-Vehicle Display Systems on Driver Performance, should be available sometime in early 1992. In the meantime, en route navigation information systems will continue to be provided by media such as the radio and variable message signs.

Observational Studies

Recently Haselkorn, Spyridakis, Conquest, and Barfield (4) conducted a study on commuter behavior and information needs for the Puget Sound area. The study targeted a single major freeway corridor (I-5) in Seattle, Washington, and distributed mail-in surveys at specific off-ramps along that corridor. Some of the surveys were followed up with an in-person survey. The goal of the mail-in survey was to identify statistically distinct commuter types and their use of and preferences for motorist information. The goal of the in-person survey was to assess, in further detail, motorists' daily activities related to their commutes. Out of the 9,652 mail-in surveys that were distributed, 3,893 were returned and processed. This was perhaps the largest sample size recorded for this type of topic.

As stated earlier, the researchers found that commuters were not a single, homogeneous audience for motorist information, but rather comprised four subgroups, which they labeled (1) route changers, (2) non-changers, (3) route and time changers, and (4) pre-trip changers.

Cluster analysis uncovered various types of traffic information and general household classification characteristics. First, the cluster analysis classified motorists into the four sub-groups mentioned above. The route changer group (20.6 percent) comprised motorists who were willing to change their routes on or before entering the route being studied. Members of the non-changer group (23.4 percent) were unwilling to change either route selection or trip departure time. The route and time changers (40.1 percent) were willing to change both their routes and their departure times, depending upon the information they received. Finally, the pre-trip changers

(15.9 percent) were willing to make time, mode, and route changes before leaving their houses, but were unwilling to change once en route.

The report suggested that the goal of a motorist information system is to improve traffic flow and that while a significant improvement in freeway through-put can be achieved by change from a relatively small percentage of drivers, an identical change in behavior by 100 percent of the driving population could be disastrous. This is especially true for route choice. If an extremely high percentage of commuters responded similarly to an ATIS message, the problem would simply move to another portion of the transportation system. If the goal of the information system is to spread the time over which a given volume of commuters uses a particular freeway corridor, then one possible target audience consists of commuters who use that corridor and who are particularly susceptible to changing departure times.

To improve the overall transportation system of a certain area, the report suggested that information must be provided to a target group of people who are willing to both seek out and use the information that can be provided. The education and communication efforts required to both reach and impact a group of people who are unlikely to modify their driving behavior and claim to never have received available information far outweigh the benefits. This is especially true when significant groups of motorists, such as the pre-trip changers, are willing to modify their behavior and actively seek information to help them do so.

Commuters questioned the credibility of motorist information and said that when they did modify their trip times, routes or modes, they did not know whether they had made the correct decision. Having decided to use an alternative route, they reported that their stress increased rather than decreased.

Another important aspect of motorist behavior is where drivers prefer to receive traffic information. In the Haselkorn study, 53 percent responded that they preferred to receive traffic information before driving, and almost 40 percent preferred to receive traffic information after beginning their commute, but before entering their main route (I-5). In addition, motorists least preferred to receive information after entering I-5, a finding that was consistent with a 1971 Texas survey that showed that once motorists were on the main route they did not care to receive traffic information (5).

When an alternative route was familiar to drivers, the non- and pre-trip changing groups would divert if the expected delay was 17.5 minutes or more, whereas the route group would divert with knowledge of only 13.5 minutes of expected delay. Similarly, for an unfamiliar alternative route, the non- and pre-trip changing groups would divert if the expected delay was 27.4 minutes, while the route changing group would divert to the alternative route if the expected delay was 22.1 minutes.

Analysis of the route, route and time, and pre-trip groups together showed that at least 65 percent of all these groups never received traffic information via the television, and about 50 percent of all of the groups never received information from variable message signs. In addition, 50 percent of the changers and 65 percent of the nonchangers never received information from highway advisory radio (HAR). From 75 percent to 85 percent of all groups preferred commercial radio for receiving traffic information both before leaving and while driving, and approximately 90 percent of all groups had a radio available to them both at home and at work. TV was the next best choice before leaving home, and VMS was the second choice for receiving information while driving. From 7 percent to 28 percent of the respondents found TV somewhat or very helpful, 28 percent to 40 percent found VMS to be helpful, 19 percent to 39 percent liked HAR, and 75 percent to 95 percent preferred commercial radio.

In another motorist information study, David M. Mark (6) defined navigation as any activity in which an organism or machine controls movement through large-scale geographic space to a specific destination. His paper focused on navigation by people. Others have stated that, until recently, the term navigation was a nautical term and gradually became used in air traffic vocabulary. Most recently, the term vehicle navigation has been applied to the automotive and truck industry to categorize the process of finding a position and path.

Mark defined the components of the vehicle navigation system (VNS) as follows: (1) the mind of the driver of the vehicle; (2) the minds of other people who participate in the navigation activities during travel, either within the vehicle or from a remote location; and (3) any vehicle navigation aids (VNA) used by any of the participants of the navigation process. A significant part of the navigation process takes place in the mind. Mark also said that the mind is busy processing all types of sensory data to aid in the navigation process. The vehicle navigation aid system includes paper road maps and procedural directions, but because of rapidly developing technologies, the future role of the road map in vehicle navigation must be reassessed. The procedural direction step has two elements: what to do next and when to do it. These directions can be transmitted to drivers through words, icons, or graphics and either visually or aurally. Mark included several models that illustrated the way in which various vehicle navigation function takes place; the primary model is shown in Figure B2.

From this model, researchers can focus their attention to any one of these components and their associated links. Mark pointed out that in this model alone there were enough research problems to challenge engineers, cognitive scientists, geographers, and others for some time to come.

In yet another study, Outram and Thompson (7) conducted a survey of motorists in the United Kingdom to study the effects of drivers and route choice. Approximately 70 percent of the drivers in that survey selected the quickest route, 10 percent selected the shortest route, and 10 percent knew of no other alternative when determining which route to take. The remainder took either scenic routes for leisure trips or specified routes for commercial vehicles (see Table B1).

In fact, 15.4 percent of the commercial vehicles took a specified route, while 28.8 percent of the leisure drivers took the scenic route.

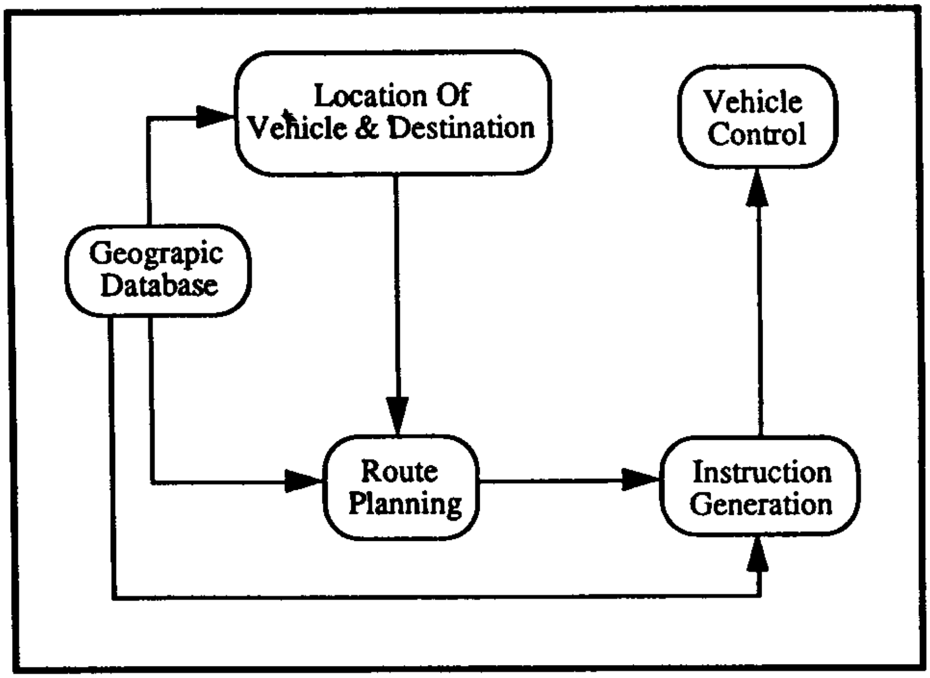

Figure B2. Vehicle Navigation Process (6)

Table B1. Effects of Drivers and Route Choice

Trip Purpose	Quickest	Shortest	Scenic	Specified	No Known Alternate
To work	76.0	11.4	0.9	0.5	10.4
Firm's business	73.6	9.3	3.5	2.8	10.0
Commercial Vehicle	68.6	8.5	0.8	15.4	6.5
Leisure	47.9	10.3	28.8	0.8	10.9

Source: Wootton & Ness, 1989 (8)

While this information is not overwhelmingly new, it does lend credibility to the theories of both the user equilibrium and system optimal route choice methods of assigning traffic to a specific route for simulation purposes.

VEHICLE DETECTION

Shortly after the invention of the automobile the need arose (either perceived or real) for some method of detecting vehicular traffic. Vehicle detection has progressed from manual observation, supported largely by estimation, to fully automated, computer based data collection. Many of the technologies, such as infrared, microwave, and inductive loop detectors, have been around for quite some time. Recent research and innovations have led to substantial improvements in and new discoveries about these components. In addition, through the combined use of computers and video technology, a process called video imaging has been developing. Although this process is still in its infancy, it shows great promise for a new level of vehicle detection.

Video image processing system (VIPS) technology promises to improve not only the way data are collected but the type of data collected. What this means is that a much greater understanding of traffic movement is on the horizon. For example, traffic engineers may be able to better understand weaving sections, lane changes, incident detection, pedestrian movement, and a host of other unstudied features of today's roadway/pedestrian interfaces.

Types of Detectors

Detectors can be separated into two groups, depending upon the detection process. One group includes mechanically coupled detectors that rely on some mechanical means of activating the detection process. Examples of these detectors include pressure switches and pneumatic tubes. The other group is the energy-change group and includes magnetic, radar, sonic, light emitting, and inductive loop technologies. The video imaging detection technology is also an example of the energy-change type; however, the energy-change takes place within the graphics section of a computer.

This section provides general information pertaining to the types of detectors that are suitable for queue detection, followed by a report on areas where current research is improving detection technology. The detection types found most suitable for queue detection are the inductive loop, magnetometer, sonic (pulsed), light emission photoelectric, and infrared.

Inductive Loop Detector (ILD). The inductive loop detector (ILD) system is currently the most popular detection technology in use in America today. The ILD consists of insulated loop wire buried in a saw cut in the pavement. This wire is connected to an electronic unit housed in a control box nearby (see Figure B3). The electronic detector unit energizes the loop at frequencies of 20 to 200 kHz. When the ILD is energized, the wire loop becomes the inductive element of the system, and when a vehicle passes over the loop or is stopped within the loop, the inductance measured through the loop is changed. This change in inductance causes the detection recording process to begin. (9)

Inductive loop detectors have many advantages. The size and shape of the detection zone can be easily set up in the design phase, allowing detection to occur over a variety of situations. Inductive loops provide the capability to measure traffic parameters such as count, presence, speed, occupancy, and queue length and are not adversely affected by environmental factors such as rain, snow, wind, or fog.

The disadvantages of the inductive loops are greatly reduced if they are installed properly in a good pavement section. If they are installed improperly or in poor pavement sections, their chance of failure is increased. During installation traffic flow must be interrupted, which may or may not be acceptable. To minimize the possibility of detecting vehicles in adjacent lanes, the detection zone must be carefully defined, since the induction zone covers up to approximately 2 feet outside of the perimeter of the wire

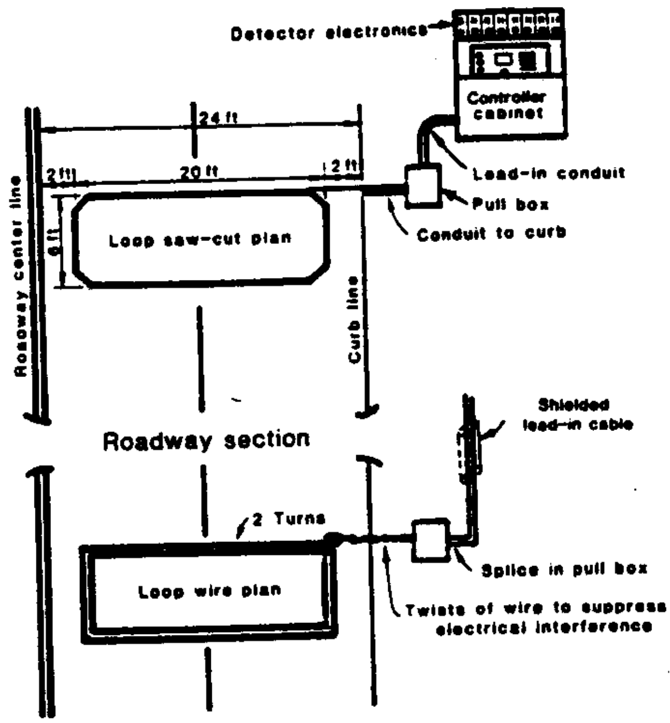

Figure B3. Inductive Loop Detector System (9)

loop. In addition, when a vehicle is changing lanes over loops in adjacent lanes, double counting occurs.

Magnetometer. The magnetometer detector includes magnetic probes placed in the roadway pavement section. These are connected to an electronic detection unit housed in a nearby cabinet (see Figure B4). Magnetometers measure the vertical component of the earth's magnetic field. When a vehicle (magnetic particle) passes over one of the magnetic probes, the controller senses a voltage change. Vehicles travelling from 0 to 100 mph influence the magnetometer, thus allowing vehicle presence to be detected. These detectors are an alternative to the ILD, as they are easy to install and are suitable for use in poor pavement sections. A single probe cannot accurately locate the exact perimeter of the vehicle; however, when more than one probe is installed, vehicle speed can be determined. As with the ILD, traffic must be interrupted for installation (9).

Sonic Detectors. Sonic and radar detectors operate on the same principal. Both transmit a beam of energy into a defined detection zone and receive a reflected beam from whatever may be in the zone. The presence of a vehicle in the zone causes the reflected beam to be different from that of an empty zone. This difference, when

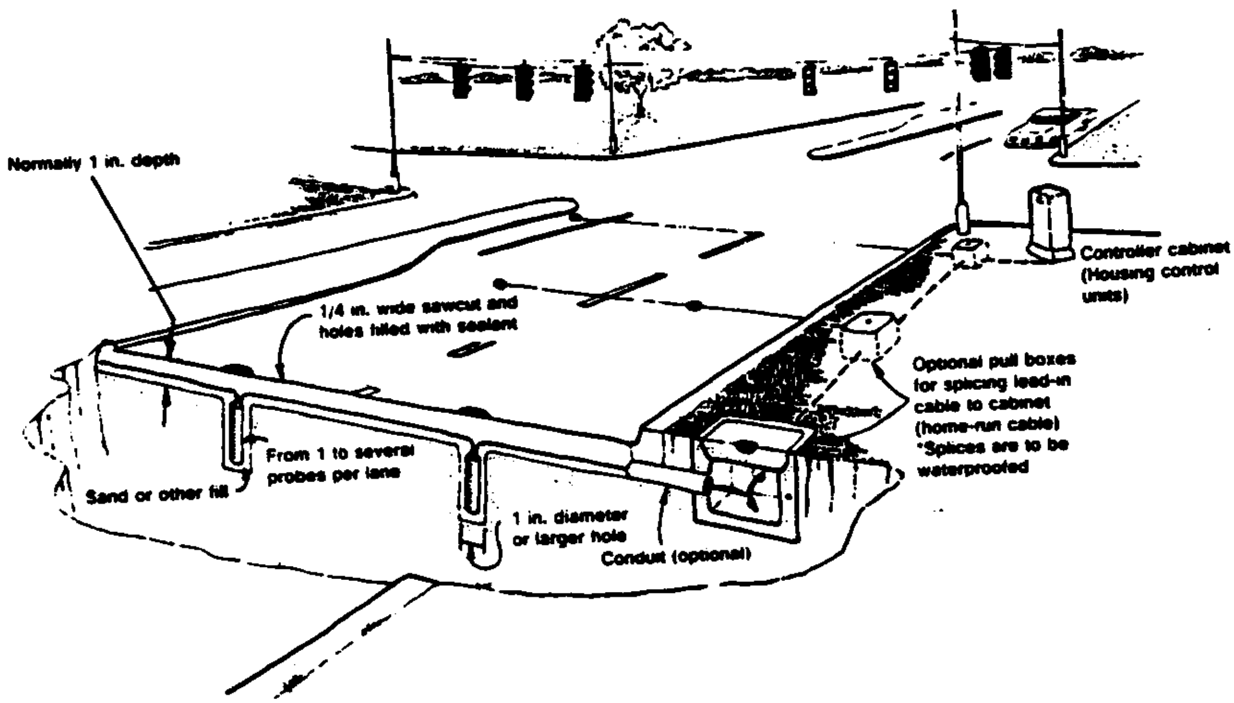

Figure B4. Magnetometer Detector System (9)

detected, initiates the detection recording process. The sonic detector transmits either a pulse or a continuous wave of ultrasonic energy through a transducer toward the detection zone. Continuous wave sonic detectors and radar detectors operate on the Doppler principal, which only allows the detection of movement, thereby eliminating the detection of vehicle presence. However, pulsed sonic detectors emit bursts of energy at a rate of approximately 20 times each second, enabling them to measure all traffic parameters, including vehicle height, for classification (see Figure B5). There are a few advantages to the use of pulse energy. The sonic detector is mounted above the flow of traffic, thereby negating the need to disrupt traffic for installation. However, in some situations a pole

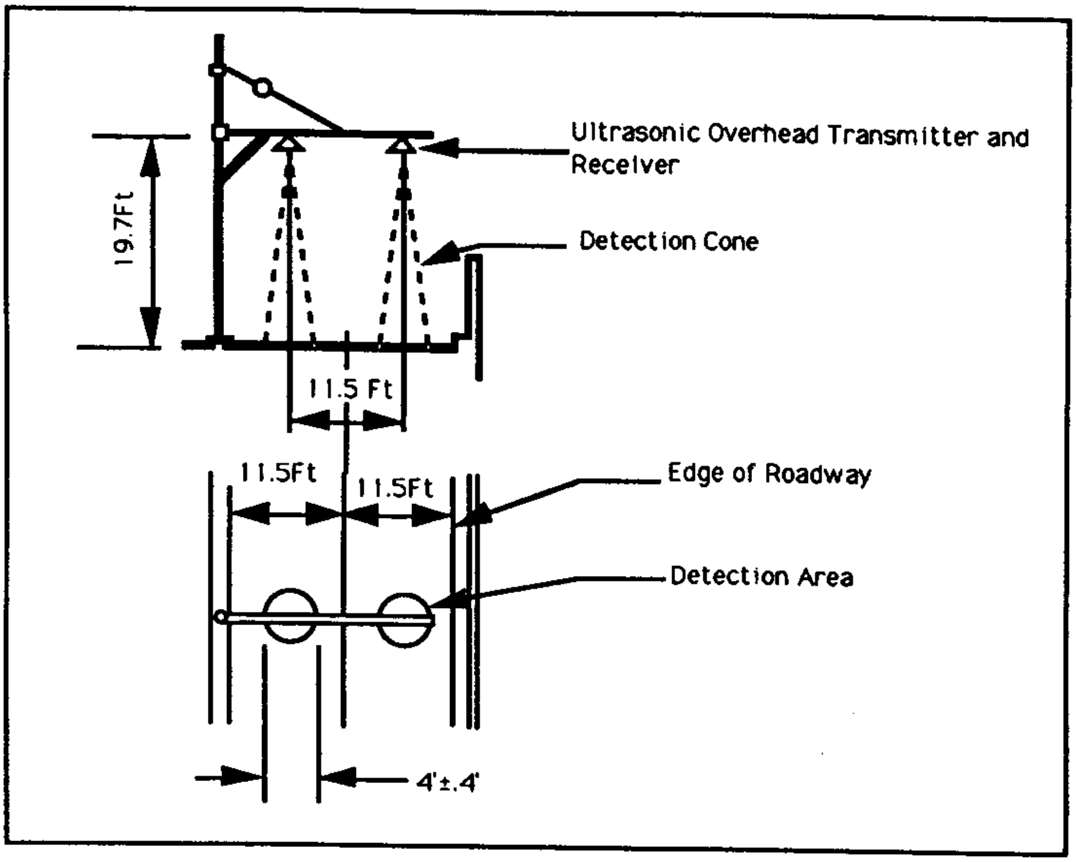

Figure B5. Sonic Transmitter Configuration

may have to be installed along the road for detector placement, which may cause some disruption in the flow of traffic. Because these detectors are mounted overhead, they are not influenced by poor roadway sections. As for the disadvantages of the sonic detectors, the list is quite lengthy. They are relatively expensive to purchase and install, particularly if existing poles are not available for mounting. They are somewhat inaccurate because of the conical detection zone and wide variations in vehicle configurations and height. Sonic detectors are nondirectional and sensitive to environmental conditions. Finally, accuracy suffers when congestion levels increase. Although some sonic detectors are still used today, their use has been curtailed over the past few years.

<u>Photoelectric</u>. Photoelectric detectors that operate on the interrupted beam principal include the light emission photoelectric and infrared interrupted beam detectors.

These detectors emit a beam of light to a receiver located across a lane of traffic. The area between the light source and the receiver then becomes the detection zone. The detection process begins when the beam of light is interrupted by a vehicle, pedestrian, or any other object. The system is capable of detecting all traffic parameters under uniform light conditions if set up across a single lane of traffic. Variations in light conditions may be caused by inclement weather, dawn or dusk transitions, or artificial lighting sources.

Infrared, Reflected Beam. This type of infrared detector uses a single housing for transmitting and receiving the light beam. The light is emitted from an overhead housing toward the detection zone, and the receiver sends signals to the controller when changes in reflectivity exist. Because of the nature of this reflectivity detector, it is most suitable for conditions of uniform light. As weather conditions and day to night transitions develop, the accuracy of these systems falter. However, when light levels are uniform this detector can be used to detect all traffic parameters. This type of infrared system is an expensive alternative to traffic detection and is considered inaccurate because of the reflectivity difference.

Video Image Processing. Video image processing technology has been undergoing great advances in the vehicle detection area. However, the technology is dependent almost entirely upon gains in computer industry. The objectives of video image processing systems (VIPS) are no different than existing detection methods. However, traffic parameters may be more easily computed with the aid of VIPS. The following are the most recognized of the objectives for data collection using a VIPS: vehicle count, speed, vehicle length, vehicle tracking, automatic incident detection, lane change maneuvers, vehicle classification, and intersection control (10).

The advantage of the VIPS in performing basic detection is that it can simultaneously derive many traffic measurements in real time. Other secondary tasks include (1) collecting and processing data to be used in conjunction with existing traffic software packages, (2) revealing the nature of an incident by transmitting images of the scene, (3) recording data for accident analysis and reconstruction, and (4) evaluating measures of effectiveness (MOE) for traffic studies (11).

More recently, the California Polytechnic State University has been testing the feasibility of eight video imaging processing systems, three of which are marketable today (12). The study included 29 tests of various parameters. Among the parameters were the following conditions: large and small number of lanes, day to night transition, camera angles, night conditions, fog, rain, shaking camera mount, heavy traffic, stop and go traffic, heavy shadows, and combinations of the above. The initial results indicated that an over 95 percent accuracy rate was achieved by most systems with typical traffic. The transition from day to night reduced the accuracy about 75 percent, while shadows and reflections each contributed about 20 percent error.

This study concluded that VIPS are deployable; however, certain accuracies need to be improved. System costs have decreased over the past two years and are competitive with other detection systems. In several cases, the systems provide superior features and performance.

In other work, Rourke and Bell (13) of the U.K. have developed a detection system that uses a digitized video image. Because the typical digitized image contains 256 kbytes of data, and because a video camera can produce 25 to 30 such images each second, it is not yet possible to use the total digitized image. The system of Rourke and Bell reduces the data rate from 6.25 Mbytes/sec to 2 to 4 kbytes/sec by processing the digitized image of only specific detection zones defined by the user. Queue detection is an example where every frame from the digitized image does not have to be processed, and the detection zone only has to be defined where the queue forms. For queue detection, data collection every 1 to 5 seconds was found to be adequate. This means that the user-defined detection zone from only one digitized image is processed every 1 to 5 seconds. Even so, specialized equipment is required to process the data. The use of image processing to detect queues is as follows. The pixel data in the user defined window are regarded as a digitized, one-dimensional wave form. Each pixel represents a sample of the wave, and its grey value represents the wave's amplitude at that point. The data are then processed with the Fast Fourier Transform (FFT). When queues are not present, the frequency spectrum shows a strong dc component along with some noise. When vehicles are present to form queues, there is a significant change in the frequency of the wave form. The current version of this system requires that a cycle time of 3 to 4 seconds be used; however, vehicles stationary for less than 3 to 4 seconds can be missed.

An application of video image processing that is similar to this border crossing project is a toll operation in France. The problem is similar: increasing traffic volumes (14). This project tested both automatic toll collection (ATC) for specific lanes and video imaging for traffic detection. The toll facility had five lanes (two with manual toll collection, three with ATC). The detection system was made up of two image processing cameras and one surveillance camera at each toll plaza. The image processing cameras were standard, fixed, monochrome, CCD-type, with 8 mm lenses and automatic gain correction. Each camera was connected to an image processing unit (IPU), which was a 386 microcomputer with a digital imaging card. The IPU was then connected to a master PC for initialization, parameter changes, and on-line direct visualization. Once every minute queue lengths and travel times were reported to the master PC. These data were compared to magnetic loop data that were obtained at the entry and exit points of the facility. Volumes and occupancy rates, transaction times, queue lengths and times, and a congestion indicator were reported.

By drawing an axis along the queue area and allocating a binary presence/absence code based on the change in grey scale of the axis, an algorithm could detect queues. The algorithm began at the bottom of the axis, proceeded upward and stopped when some prespecified interval was reached and when at least one stop had been detected during the minute. The average length of the queue was determined for each minute by calculating the arithmetic mean value of the 120 algorithm values (two per second). The queue time measurements were determined by tracking random vehicles from their entry points and averaging the mean value of queueing times for each selected vehicle once each minute. In the French study, queue lengths were highly correlated to individual vehicle travel times.

INRETS, a French research firm, has made recent improvements to the video imaging system to allow one camera to simultaneously monitor three to four queues of up to 120 meters (394 ft.) long. In addition, software is being developed to provide the operator of the toll facility with statistical information pertinent to the operation of the facility. This information should contribute to queue prediction.

Summary

Because queue length is a function of vehicle presence, any detector that can detect the presence of a vehicle can report queue lengths. All of the above detectors can record vehicle presence; therefore, they can be set up to report queue length. Additionally, detectors that are planned for highway applications in the Pacific Northwest should be accurate in any weather condition, as well as under varying levels of light.

Table B2 is a summary of the systems described above and shows a comparison of features.

INFORMATION DISSEMINATION SYSTEMS

Providing information to motorists or travelers can be done through many media. Among these media are radio (public or private), television (public or subscriber cable), road signs (static and changeable), telephone, and computer terminals. Many combinations of these media make up the motorist information systems used today. However, there are three critical problems with today's systems. First, the only method of feedback is to observe motorists' reaction to a given message. This method has serious limitations in that not only is it the costly, but it is nearly impossible to make any rational sense out of the observations. Instead, the feedback that is most often heard is in the form

Table B2. Detector Features

Detector Type	Features	Benefit
Inductive Loop	1. Size and shape of detection zone easily set 2. Excellent presence detector 3. Easy to install 4. Higher installation cost than magnetometer 5. Disrupt traffic to install 6. Allows 2500 feet of lead in cable from loop to controller	⊗
Magnetometer	1. Unique presence detector 2. Unlimited hold time 3. Allows 5000 feet lead in cable from probe to controller 4. Reduced installation costs 5. Simple installation 6. Higher reliability than inductive loops 7. Proven and reliable 8. Disrupt traffic to install.	ϴ
Sonic Pulsed	1. Does not require closing lanes for installation 2. Does not require FCC license to operate 3. Installed overhead 4. Somewhat inaccurate because of conical detection zone and vehicle size and shape. 5. Sensitive to environmental conditions. 6. Somewhat inaccurate under congested conditions. 7. Relatively expensive to purchase and install, particularly if existing poles are not available for use.	⊕
Infrared Reflected Beam	1. Most suitable for conditions of uniform light 2. Installed overhead 3. Expensive 4. Sensitive to ambient light and pavement colors. 5. Sensitive to weather conditions. 6. Inaccurate because of reflective difference.	⊕
Video Imaging	1. Promising new technology 2. Detects all parameters including presence, passage, speed, flow rate, volume and occupancy, time headway, and classification. 3. Visual graphic and numerical report generation. 4. Installed overhead. 5. User specified detection zones through interactive graphics 6. Flexible and rapid detection. 7. Accepts video from camera or VCR 8. Continuous and reliable operation under sever weather and lighting conditions 9. Detection zone good up to 400 feet per camera. 10. Some systems allow input from two or more image sources. 11. Not proven yet.	⊗

ϴ Most Preferred, ⊗ Second Preference, ⊕ Least Preferred of complaints or accidents. Second, many motorists do not believe the systems an credible.

Perhaps the lack in credibility is due in part to the lack of available feedback channels. Credibility is lost mostly through deficient surveillance and detection techniques. For the most part, today's information is reactive. That is, information is provided to motorists after traffic problems have happened. There is also an inherent time lag between the time the congestion diminishes and the time the normal condition is reported to the motorists. Third, an often overlooked component of today's motorists information system consists of the design criteria. Do the requirements and desires of the motorists play an active role in the design, or does the available technology control the design?

The next section briefly describes three ATMS projects. One project, Traffic Reporter, is in Seattle,Washington, and uses a computer terminal display. Another is in Toronto, Canada, and uses the variable message sign (VMS) technology. The third is in Indiana and may use a combination of highway advisory radio (HAR) and VMS.

<u>ATIS Projects</u>

Haselkorn et al. (<u>15</u>) described the "Traffic Reporter" system being developed to provide information to commuters who would most likely modify their travel behavior if they had accurate information. Traffic Reporter is a PC-based, graphical, interactive traveler information system designed to meet the needs of specific Seattle area commuters.

Traffic Reporter is being studied on and applied to a 15-mile section of Interstate 5 in Seattle, Washington. I-5 is a north-south freeway running the length of California, Oregon, and Washington. I-5 runs through metropolitan Seattle with as many as five lanes in each direction, with a three-lane reversible expressway. Traffic Reporter uses one-second data compiled into one-minute time slices of data from individual inductive loops placed at or near one-half mile intervals along the study section. From the volume and occupancy data, Traffic Reporter estimates travel speeds and times for each of the sections between inductive loops. These estimated speeds and times are then displayed both numerically and graphically on Traffic Reporter's display screen.

The graphical portion of the screen displays a schematic of the freeway, both north and south directions. Each roadway section between detectors is then color coded to represent the estimated travel speeds. There are five colors: green for 50+ mph, yellow for 35-49 mph, purple for 20-34 mph, red for 0-19 mph, and blue for malfunctioning detectors. From the graphical portion of the screen, users can zoom in on an area and view the average speed instead of the speed range indicated by the color. If users want to know the average speed between two freeway ramps, they click the mouse on any two ramps and a dialog box shows the estimated speed and travel time between those two ramps. Another feature of Traffic Reporter is that it provides information pertaining to the "best" exit or entry ramp, for a given trip. The user selects an exit (entry) ramp, and Traffic Reporter shows all possible entry (exit) ramps and their respective travel times. Traffic Reporter can (1) provide up-to-the-minute data on vehicle volume and occupancy, (2) indicate a malfunctioning detector station, and (3) store and play back commute data for statistical analysis or planning.

The next phases of Traffic Reporter should (1) expand it to show other areas of Seattle traffic, (2) improve the conversion and accuracy of sensor data, (3) add features such as a prediction mode, (4) be delivered to commuters via TV and radio traffic reporters and through the development of a touch screen, (5) explore other methods of delivery such as dedicated cable TV, PCs at home or work, and in-vehicle delivery, and (6) record data for monitoring traffic patterns and establishing norms of freeway performance.

In a second study, the Ministry of Transportation of Ontario, Canada, (MTO) is implementing a real-time traffic information system through the use of three subsystems: vehicle detection, closed circuit television (CCTV), and VMS on the highway 401 corridor in Toronto, Canada (16). Highway 401 traverses metropolitan Toronto and has an average annual daily traffic (AADT) of 300,000 vehicles carried over 12 to 14 lanes in most locations. This multi-lane facility has parallel express and collector roadways to facilitate diverted traffic. Inductive loop detectors are spaced approximately every 600 m along the freeway to detect vehicular data such as occupancy, volume, vehicle length, and speed. The detector data are then collected by Type 170 controllers, which process and accumulate data and transmit them to the Traffic Management Center (TMC) at 20 second intervals for further processing and storage. The CCTV surveillance system consists of pole-mounted cameras located at 1-km intervals to provide the operators of the TMC with full visual range of the freeway 24 hours a day. The cameras are mounted on a 15-m pole and have full pan, tilt, and zoom capability.

High intensity outdoor LED variable message signs (VMS) have been placed on overhead structures at strategic locations along the freeway and collecting roadways. They have the capability to display both graphical and text information. Generally, the VMS's located over Highway 401 are placed to communicate to traffic diverting to the parallel roadways when adverse downstream conditions are evident. The following is a summary of placement guidelines for the VMS's located over Highway 401:

- Locate 900 to 1200 m upstream of a diversion point;
- Locate 300 m upstream of any existing sign;
- Locate 400 m downstream of any existing sign or obstruction;
- Locate them such that all drivers entering the freeway have an opportunity to view a VMS before their first opportunity to utilize a collector/express transfer road or other major point;
- Desirable minimum spacing between VMS's is 3,000 m, and desirable maximum spacing is 5,000 m; and
- Locate VMS's, in the adjacent express lanes more than 150 m apart along the freeway.

The VMS can display a "travelling arrow" to indicate the direction a driver should move; control the brightness relative to ambient light and message importance; space the letters proportionally; and display in many colors. Fiber optic cable and equipment are used to communicate the information from the control center and the field equipment. The fiber optics will provide higher transmission performance and expansibility over the life of the system.

There are three driver information strategies for this system: incident management, congestion management, and situation advisory strategies. Incident management strategies include information regarding the location and severity of the incident. The congestion management strategy is set up to serve the recurrent congestion that is normally associated with rush-hour traffic. Special situation advisory strategies are focused on non-recurrent congestion. For each of these strategies, traffic response plans are to be used for the network of zones and sub-zones within the system.

In a third study, the Indiana Department of Transportation is in the process of implementing an electronic surveillance and control system that will consist of three components: (1) traffic surveillance, (2) motorist information, and (3) traffic management (17). Consideration was given to the potential for implementation in the near future in that all elements in the surveillance and control system had to be implementable and could not require additional development.

Inductive loops are being considered for several reasons. They are reasonably cost efficient and can detect vehicle speeds, counts, lengths, and classifications if used in pairs. The installation of loops on the mainline would be placed at one half mile intervals and as necessary on the on-ramps. The inductive loops can be processed on-site using Type 170 microprocessors which will enable control center interaction. In addition CCTV cameras will be placed at one half to three fourths mile intervals to provide a full view of the expressway.

The study's objective for the motorist information system is to provide drivers with real-time traffic information that will improve safety, operation, and public image. Variable message signs (VMS) and highway advisory radio (HAR) are the two media being considered for disseminating information to motorists. The most reliable existing VMS for this application appears to be the rotating drum, which consists of three rows of six-sided rotating drums. Each face of the drum can deliver one fixed informational message to the motorist. While the light emitting diode (LED) VMS provides superior flexibility and legibility and is capability of displaying messages and graphics in different colors, it is not as cost effective. HAR is being considered to supplement the VMS system and will most likely operate over a public radio station. However, if implemented, the "leaky cable" installed along the median barrier is also being considered as a potential antennae.

Summary

With technology such as the Traffic Reporter, which uses real-time information, both motorists and travelers can have access to information when it is convenient for them. In addition, public radio and television stations can use the information when situations develop, thereby eliminating the redundant broadcasts of recurrent congestion situations. This computer terminal technology can also be made available to area businesses that wish to provide information to their customers. Other potential applications include roadside information areas, rest areas, and gas stations. This service could be especially valuable to motorists who are in an unfamiliar area, since at these locations motorists are off of the road and can consult maps and other travel aids to make better informed alternative route decisions.

VMS and HAR technologies have been used for quite some time. However, the MTO and Indiana projects are providing an extensive en route information system by combining several technologies. It is first important to accurately detect traffic conditions, then that information must be provided when and where it can be used.

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