USDOT Region V Regional University Transportation Center Final Report

NEXTRANS Project No. 087OY04

DOCUMENTING TRUCK ACTIVITY TIMES AT INTERNATIONAL BORDER CROSSINGS

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Report Submission Date: April 2, 2014

ACKNOWLEDGMENTS AND DISCLAIMER

The investigators gratefully acknowledge the external support of Ray Cossette (CEVA Logistics) and Kirk Pettit (CEVA Logistics), as well as the assistance of Richard Dobson, Michael Billmire, David Banach, and Dante Mann, of the Michigan Tech Transport Institute.

Funding for this project was provided by the NEXTRANS Center, Purdue University under Grant No. DTRT07-G-005 of the U.S. Department of Transportation, Research and Innovative Technology Administration (RITA), University Transportation Centers Program, and by the Ohio State University's College of Engineering Transportation Research Endowment Program. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented, and not of any collaborator or funding institution. This document is disseminated under the sponsorship of the Department of Transportation, University Transportation Centers Program, in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof.

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1. Introduction

Documenting the times trucks incur when crossing an international border facility is valuable both to the private freight industry and to facility operators and planners. Private carriers and shippers can benefit from having objective travel time measures for trip planning and scheduling. By monitoring trends in the documented travel times, facilities operators and planners can detect when conditions have sufficiently changed to warrant changes in infrastructure or operations. In addition, developing, calibrating, and validating predictive models of how travel times respond to alternate infrastructure configurations or operations policies requires extensive and valid data on crossing times.

Contributing to the magnitude and variability in truck crossing times are the multiple activities involved with international truck crossings – *e.g.*, approaching the crossing on freeways or surface streets, waiting in queues, undergoing customs inspection, possibly visiting duty free facilities. Decomposing the overall travel time into its components helps in the identification of the critical activities affecting the overall crossing times, the management of components of the cross-border trip, and the development of behaviorally responsive models. For example, predicting the effects of increased demand would require an understanding of the interaction between customs screening rates and traffic volumes in producing queuing-induced delays. In addition, for planning and monitoring, it is important to adjust overall crossing times to remove the effect of voluntary activities, such as visiting duty free facilities, that add to the observed time incurred when crossing the border. Carrier management may also wish to measure the participation of its trucks in duty free activities to monitor productivity.

In a previous report (*1*), we described our geo-fence approach for determining truck activity times. The approach takes advantage of onboard position, timing, and communication systems that are already installed on many truck fleets. Data records with precise time stamps are triggered when the unit crosses the boundary of a virtual geo-fence, the coordinates of which are communicated remotely to the truck units. By designing the coordinates of the geo-fences so that the boundaries correspond to strategic locations, the truck times associated with multiple activities can be determined. We previously designed and installed geo-fences in onboard units of a major freight hauler, CEVA Logistics, to collect data and process the data into activity times at two of the busiest and most valuable North American truck border crossings – the Ambassador Bridge connecting Detroit, MI, and Windsor, ON, and the Blue Water Bridge connecting Port Huron, MI, and Sarnia, ON. Our implementation allowed us to produce unprecedented distributions of activity times at these border crossing facilities (*2*).

In the study reported here, we collected additional data and processed these and other recently collected data (see, *1*) to produce updated activity times. We summarize these data collection and processing effort in Section 2.

Parallel to past efforts, Transport Canada (TC) and the Ontario Ministry of Transportation were using a Bluetooth-based approach to collect truck data at these major border crossings. Our geo-fence based approach produced much higher resolution of truck activities than did the TC approach. However, the TC data were obtained from a truck population that is broader than our CEVA Logistics-only trucks. We had previously obtained a subset of the TC data that was concurrent with a subset of our geo-fence data. Anticipating the possibility that both the single-carrier, detailed geo-fence data and the less detailed TC data obtained from the broader truck population could continue to be collected, we conducted preliminary comparisons to investigate if the two types of data would be substitutes for each other or if the two datasets could be considered complementary (*1*).

The results indicated that the general time-of-day patterns in crossing times produced from the two datasets were sufficiently different that patterns obtained from one dataset would not be representative of the patterns produced from the other dataset. However, a preliminary investigation of crossing times produced from the two datasets for trucks crossing the border at approximately the same time indicated strong, positive associations in the crossing time deviations produced from the two datasets. Specifically, when one data set indicated that trucks using a facility on a given time and day were experiencing crossing times that were longer (shorter) than the median crossing time in the dataset, trucks from the other dataset using the facility at approximately the same time on the same day were also generally experiencing crossing times that were longer (shorter) than the median crossing time in its dataset. The positive association between the indications produced from the two datasets raised the possibility that information from the two datasets could be used in a complementary manner.

In the project described in this report, we refined and expanded our empirical comparisons between our single carrier, geo-fence based crossing times and the TC crossing times determined from the broader population of carriers using the Bluetooth-based approach. We reprocessed our data to refine the locations between which the geo-fence-based crossing times are determined to better match the locations used to determine crossing times in the TC data. The reprocessed data also allowed us to produce a better temporal match of “approximately concurrent” crossings in the two datasets. In Section 3, we present the revised investigations conducted with these reprocessed data and additional investigations that confirm the strong positive associations seen in our previous investigation for both directions of traffic at the Ambassador Bridge facility and for the Ontario-to-Michigan direction at the Blue Water Bridge facility. However, the revised investigations show a much weaker and not statistically significant association for Michigan-to-Ontario traffic at the Blue Water Bridge facility. We note that the Michigan-to-Ontario Blue Water Bridge crossing-direction experiences lowest variability in crossing times among the four crossing-directions considered and lowest magnitudes of times associated with queuing upstream of primary truck inspection. As such, one might expect weakest association between the two datasets for this crossing-direction.

We also conducted multiple empirical studies using our newly processed data. In Section 4, we present empirical results that quantify changes in geo-fence times resulting from a change in inspection facilities for Canada-bound traffic at the Blue Water Bridge, document the effect on truck times of the Black River Bridge construction project, identify systematic changes to duty free times for US bound trucks, and portray time-of-day patterns in times incurred on surface streets in Windsor.

The geo-fences installed on the CEVA trucks were designed several years ago. Infrastructure projects have changed traffic flow patterns around these facilities. In Section 5, we discuss these changes and how they motivate future changes in the geo-fences. In Section 6, we present results of efforts designed to visualize activity times and crossing volumes for better communication and discovery of patterns. Demonstrated interest in the type of results produced from the geo-fence approach expressed by a high ranking Canadian official and a Michigan Department of

Transportation border crossing data manager is summarized in Section 7. Finally, in Section 8, we summarize findings and discuss potential future work.

2. Data Acquisition and Processing

We continued to collect and process truck location and timing data obtained from CEVA trucks using the Ambassador Bridge or Blue Water Bridge facilities with the geo-fences previously implemented on CEVA trucks.

New CEVA truck movement data were collected from 08-28-2012 through 12-03-2013. No data were transmitted from the data provider for the dates September 29 and December 18 - 19, 2012, or for the dates February 20 – 21, April 28, August 13, and October 5, 2013. As discussed in McCord, *et al.* (*1*), data falling within regions of interest (ROI) around the Ambassador Bridge and Blue Water Bridge facilities are first selected from the broader dataset of CEVA truck records. For our entire database (dates 12-01-2008 through 12-03-2013), there are a total of 16,163,412 records in the database, with 4,624,289 records falling within the Ambassador Bridge ROI and 1,065,960 records falling within the Blue Water Bridge ROI.

The preliminary data processing steps described in McCord, *et al* (*1*) were applied to the data collected in this period. In McCord, *et al* (*1*), we reported on difficulties we were experiences with processing preliminary data into activity times that precluded our producing activity times for data collected between 03-01-2010 and 08-27-2012. We resolved these difficulties and processed data collected for that period and for the 08-28-2012-to-12-03-2013 period into activity times. Data processing consists of the following steps:

- E-mails are received nightly at Michigan Tech Research Institute (MTRI) from the truck company's contracted data provider (Webtech Wireless) containing the previous days' CEVA truck tracking data.
- MTRI investigators download data in the e-mails (3 or 4 .csv data files), rename the files using a standardized file naming protocol, and save them to the MTRI network.
- MTRI investigators copy the data into a working directory and a backup directory.
- MTRI investigators compile and import the data into (open source) PostgreSQL database using Python scripts.
- In PostgreSQL, MTRI investigators run scripts to
    - Delete duplicate records
    - Export data for BWB and AMB into separate .csv files
    - Create a database backup file
- MTRI posts the data to an ftp server.
- OSU investigators download and import the data (.csv files), along with their geo-spatial information into PostreSQL and store them in a database
- OSU investigators create special polygons to infer missing information, mostly related to state abbreviation.
- OSU investigators sort and export the data into files that are readable by the statistical analysis software R.

- OSU investigators use programs they developed in R to conduct "trip-chaining," the identification of the sequencing of records that correspond to a single truck trip.
- OSU investigators use other programs developed in R to process the trip-chained data into times spent in the geo-fences and in the gaps between fences.
- OSU investigators use the fence and gap times to determine activity times for each truck and distributions of activity times.

3. Refined Comparisons of Geo-fence based and Bluetooth based Data

As discussed above, we recently conducted preliminary investigations between geo-fence based crossing times we had previously processed and Bluetooth based crossing times extracted from a dataset we obtained from Transport Canada (TC) for truck crossings between February 9 and April 29, 2009. Our ability to reprocess the geo-fence based data allowed us to refine and expand on these investigations. Previously, we compared matched TC and CEVA crossing time data for trucks using a facility in a given direction within 15-minute windows on the same day. In the present project, we refined the locations between which the geo-fence crossing times are determined and the criterion used to match trucks arriving at the facility, and conducted additional comparisons. The crossing times for the TC data are determined from point *A* to *B*, depicted in Figures 3-1(a)-(d). The crossing times for the geo-fence based data were previously determined from point *a* to *b*, also depicted in Figures 3-1(a)-(d).

(a) Ambassador Bridge crossing, Michigan-to-Ontario direction

Figure 3-1: Indication of locations between which TC crossing times were determined (from point *A* to point *B)* and geo-fence based crossing (CEVA) were determined (from point *a* to point *b*) in previous investigation

(b) Ambassador Bridge crossing, Ontario-to-Michigan-to-Ontario direction

Figure 3-1 continued: Indication of locations between which TC crossing times were determined (from point *A* to point *B)* and geo-fence based crossing (CEVA) were determined (from point *a* to point *b*) in previous investigation

(c) Blue Water Bridge crossing, Michigan-to-Ontario direction

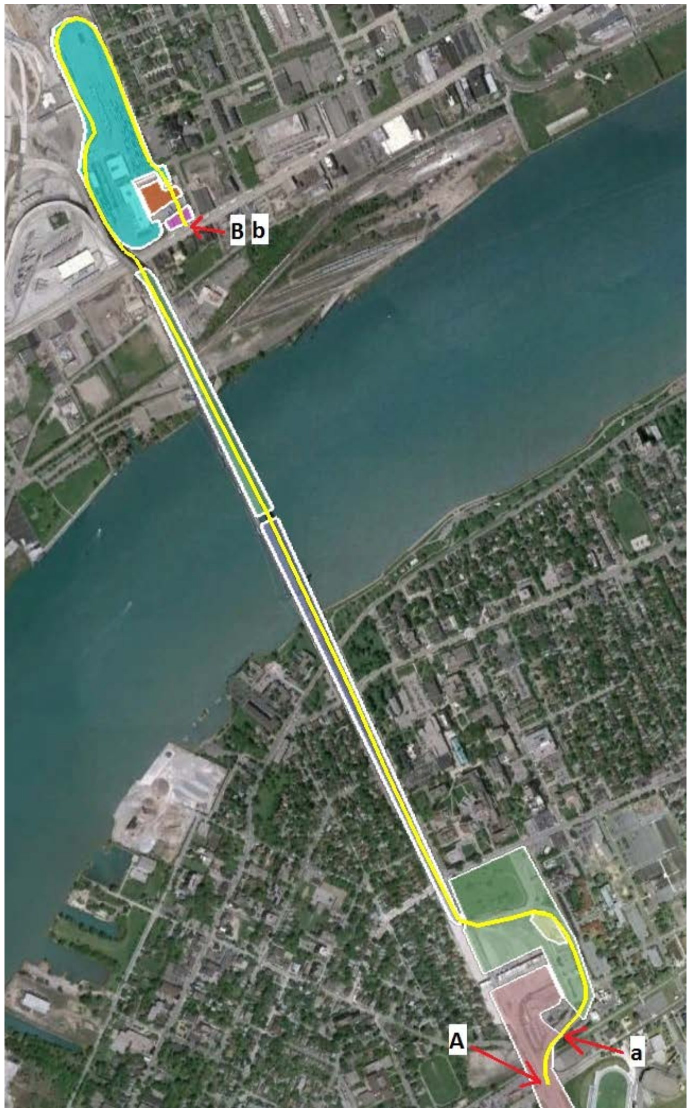
(d) Blue Water Bridge crossing, Ontario-to-Michigan direction

Figure 3-1 continued: Indication of locations between which TC crossing times were determined (from point *A* to point *B)* and geo-fence based crossing (CEVA) were determined (from point *a* to point *b*) in previous investigation

To better match the locations between which the TC crossing times were determined with geo-fence locations, we recomputed geo-fence based crossing times by using the locations depicted in Figures 3-2(a)-(d). The crossing times for the geo-fence based data (CEVA) were refined to be determined from point *a* to point *b*, depicted in Figures 3-2(a)-(d). The locations of the points used to determine TC crossing times – from point *A* to point *B* – are again depicted in the figures.

(a) Ambassador Bridge crossing, Michigan-to-Ontario direction

Figure 3-2: Indications of locations between which geo-fence based (CEVA) crossing times are determined (from point *a* to point *b*) for the present study; Locations used to determine TC crossing times (from point *A* to point *B)* are again shown



(b) Ambassador Bridge crossing, Ontario-to-Michigan-to-Ontario direction

Figure 3-2 continued: Indications of locations between which geo-fence based (CEVA) crossing times are determined (from point *a* to point *b*) for the present study; Locations used to determine TC crossing times (from point *A* to point *B)* are again shown

(c) Blue Water Bridge crossing, Michigan-to-Ontario direction

(d) Blue Water Bridge crossing, Ontario-to-Michigan direction

Figure 3-2 continued: Indications of locations between which geo-fence based (CEVA) crossing times are determined (from point *a* to point *b*) for the present study; Locations used to determine TC crossing times (from point *A* to point *B)* are again shown

With the newly defined locations used to determine geo-fence based (CEVA) crossing times, we re-conducted the most disaggregate analysis presented in McCord *et al.* (*1*) designed to investigate the associations between the TC and CEVA crossing times. Specifically, we paired each CEVA crossing time to the median of all TC crossing times for which the TC truck trip was within 15 minutes of the CEVA truck trip. (For AMB: MI-ON, AMB: ON-MI and BWB: MI-ON, the times at points *A* and *a* were used to determine whether the truck trips were within 15 minutes of each other; for BWB: ON-MI, the times at point *B* and *b* were used.) We then calculated the median of all the matched TC crossing times and the median of all the matched CEVA crossing times and formed cross-tabulations of the paired data, based on whether the elements in the paired times were less than or equal to their respective marginal median times. We again divided the data into four mutually exclusive and collectively exhaustive groups:

- Group 1: (TC median crossing time in the pair ≤ overall median TC crossing time, CEVA crossing time in the pair ≤ overall median CEVA crossing time)
- Group 2: (TC median crossing time in the pair > overall median TC crossing time, CEVA crossing time in the pair ≤ overall median CEVA crossing time)
- Group 3: (TC median crossing time in the pair ≤ overall median TC crossing time, CEVA crossing time in the pair > overall median CEVA crossing time)
- Group 4: (TC median crossing time in the pair > overall median TC crossing time, CEVA crossing time in the pair > overall median CEVA crossing time)

The resulting cross tabulation tables for each crossing-direction are presented in Table 3-1. For each crossing-direction, the overall TC and CEVA median crossing times are shown, and the 2-by-2 table presents counts in each of the four categories.

Table 3-1: Cross-tabulations of matched CEVA and TC 15-minute crossing times by crossing-direction

Direction:		AMB: MI-ON	
Median crossing time			
CEVA	2.91	Mins	
TC	6.2	Mins	
		TC	
	p-value: 0.0002	N <= median	N > median
	N <= median	1054	943
CEVA	N > median	937	1062

Direction:		AMB: ON-MI	
Median crossing time			
CEVA	10.81	mins	
TC	7.3	mins	
		TC	
	p-value: <2.2e-16	N <= median	N > median
	N <= median	2424	909
CEVA	N > median	1032	2574

Direction:		BWB: MI-ON	
Median crossing time			
CEVA	2.88	Mins	
TC	4.75	Mins	
		TC	
	p-value: 0.4131	N <= median	N > median
	N <= median	166	165
CEVA	N > median	154	176

Direction:		BWB: ON-MI	
Median crossing time			
CEVA	4.29	mins	
TC	6.8	mins	
		TC	
	p-value: 0.001002	N <= median	N > median
	N <= median	275	248
CEVA	N > median	211	290

* *Medians based on crossing times in matched CEVA and TC data*

If there is no relationship between TC and CEVA crossing times, the numbers of TC-CEVA pairs in these four groups should be approximately evenly distributed and close to each other. The p-values used to test independence, are presented in the table. The low p-values for the AMB ON-MI, AMB ON-MI, and BWB ON-MI crossing-directions leads to rejecting the null hypothesis of independence between the sets of crossing times in favor of a strong association between the sets. Given the larger number of counts on the diagonals, the association is positive. Therefore, for these three crossing-directions, when the TC crossing time is shorter relative to the median over all time, the CEVA crossing time also tends to be relatively shorter, and vice versa.

In addition to comparing matched TC and CEVA times in 2-by-2 tables formed by referring to median values, we also compared the matched data in 10-by-10 tables formed by referring to their 10th percentiles. The 10th percentile values are presented in Table 3-2.

Table 3-2: Values of 10th percentile geo-fence based (CEVA) and TC crossing times by crossing-direction

(a) Ambassador Bridge, Michigan-to-Ontario

CEVA percentiles with Custom time (in seconds)										
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
137	193	208	223	236	257	284	323	390	516	1751
TC percentiles (in seconds)										
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
120	168	228	300	342	372	402	432	486	600	1782

(b) Ambassador Bridge, Ontario-to-Michigan

CEVA percentiles with Custom time										
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
297	404	454	500	571	649	760	877	1035	1297	1794
TC percentiles										
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
120	264	300	330	372	438	522	654	822	1081	1794

(c) Blue Water Bridge, Michigan-to-Ontario

CEVA percentiles with Custom time										
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
152	196	211	219	225	234	244	259	290	345	1351
TC percentiles										
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
66	186	216	240	258	285	324	411	630	1008	1794

(d) Blue Water Bridge, Ontario-to-Michigan

CEVA percentiles with Custom time										
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
171	256	281	303	331	369	413	525	650	847	1815
TC percentiles										
0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
102	162	198	234	288	408	569	762	972	1238	1776

Let $PCEVA_j$ denote the $(j * 10)^{th}$ percentile of CEVA crossing time ($j = 0,1, \ldots, 10$), with $PCEVA_0$ and $PCEVA_{10}$, respectively, denoting the minimum and maximum values . Similarly, let PTC_k denote the $(k * 10)^{th}$ percentile of TC crossing time ($k = 0,1, \ldots, 10$). For each pair *i* of matched TC-CEVA crossing times determined as above, we classify the pair as falling into one of the 100 categories:

$$(PTC_{k-1} \leq TC_i < PTC_k, PCEVA_{j-1} \leq CEVA_i < PCEVA_j), \; j, k = 1,2, \ldots ,10;$$

The resulting 10-by-10 cross tabulation tables for each crossing-direction are presented in Table 3-3, with the number of counts in each of the 100 cells shown. Higher values are indicated by reddish shading, and smaller values are indicated by bluish shading. As the values get closer to the median count of the table, the shading fades toward white. Also included in table are the *X-squared* statistic, the degrees of freedom *df*, and the *p-value* associated with Pearson's Chi-square test of independence. Low p-values, leading to a rejection the null hypothesis of independence between the two data sets, are again seen for the AMB ON-MI, AMB ON-MI, and BWB ON-MI crossing-directions, but not for the BWB MI-ON crossing direction.

Table 3-3: Cross-tabulations of CEVA and TC crossing times by crossing-direction

(a) Ambassador Bridge, Michigan-to-Ontario

		CEVA									
		< 10	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**>=90**
TC	**< 10**	47	39	49	42	33	43	38	47	37	29
	10-20	40	32	38	28	41	38	51	43	36	41
	20-30	33	45	35	46	43	39	45	45	40	42
	30-40	32	43	44	41	41	34	35	34	46	27
	40-50	46	53	46	42	55	31	35	42	36	29
	50-60	33	45	35	34	39	36	31	30	26	25
	60-70	46	47	37	38	42	32	41	43	33	27
	70-80	43	49	47	37	47	43	45	46	54	68
	80-90	36	45	42	22	44	44	59	45	41	31
	>=90	15	25	36	33	38	30	31	47	51	85

Pearson's Chi-squared test
X-squared = 173.9827, df = 81, p-value = 9.462e-09

Table 3-3 continued: Cross-tabulations of CEVA and TC crossing times by crossing-direction

(b) Ambassador Bridge, Ontario-to-Michigan

		CEVA									
		< 10	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**>=90**
TC	**< 10**	107	94	107	70	40	30	29	32	27	16
	10-20	127	140	123	99	52	60	32	31	31	20
	20-30	103	105	95	75	75	55	32	33	27	27
	30-40	87	107	92	103	84	51	31	34	20	27
	40-50	83	110	113	98	135	90	52	57	26	39
	50-60	44	63	46	96	112	108	89	59	44	42
	60-70	28	38	39	50	112	119	130	105	63	40
	70-80	19	25	36	38	59	99	152	153	100	53
	80-90	25	19	24	27	29	57	86	134	213	142
	>=90	14	17	21	28	23	31	58	77	138	282

Pearson's Chi-squared test
X-squared = 2992.281, df = 81, p-value < 2.2e-16

(c) Blue Water Bridge, Michigan-to-Ontario

		CEVA									
		< 10	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**>=90**
TC	**< 10**	9	3	5	2	7	5	4	7	9	3
	10-20	5	6	7	8	9	7	9	8	9	9
	20-30	8	5	4	4	7	12	3	5	9	3
	30-40	6	5	5	7	9	7	9	5	6	0
	40-50	4	11	9	7	9	11	6	11	8	5
	50-60	7	9	6	6	5	7	3	6	4	6
	60-70	8	8	10	7	3	7	5	6	5	12
	70-80	7	7	5	6	6	4	6	3	11	8
	80-90	5	6	5	7	8	10	10	11	7	8
	>=90	8	5	3	4	10	4	9	5	4	9

Pearson's Chi-squared test
X-squared = 73.4408, df = 81, p-value = 0.7125 (Chi-squared approximation may be incorrect)

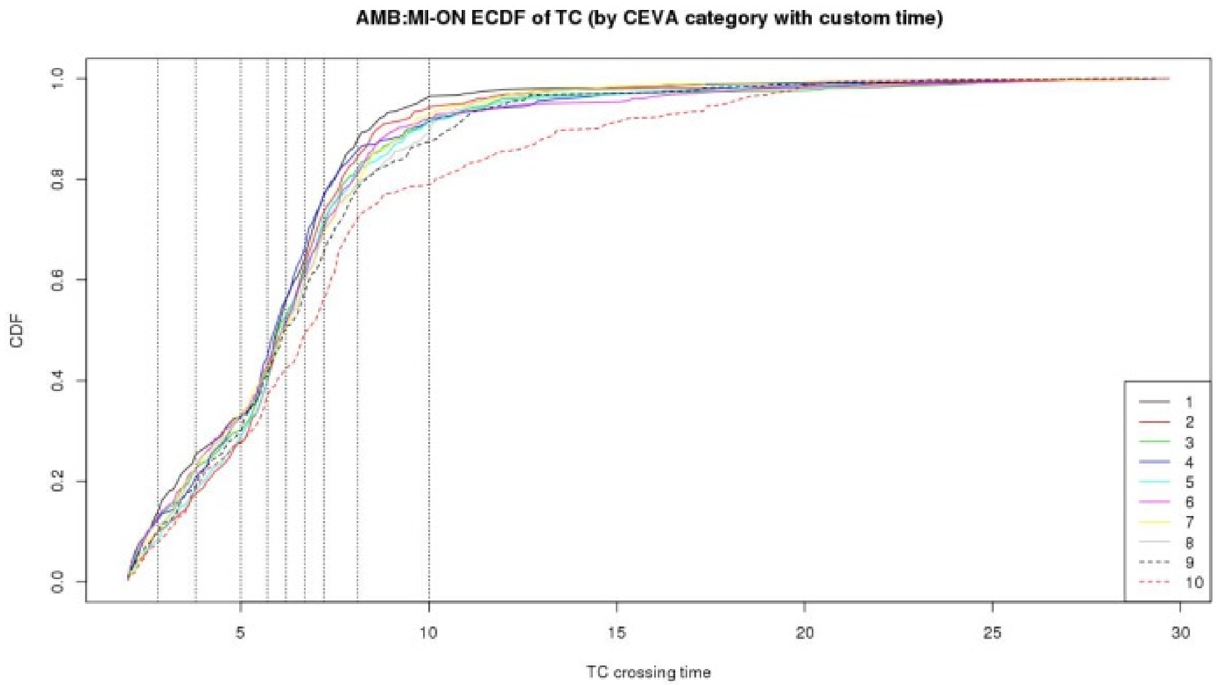
Table 3-3 continued: Cross-tabulations of CEVA and TC crossing times by crossing-direction

(d) Blue Water Bridge, Ontario-to-Michigan

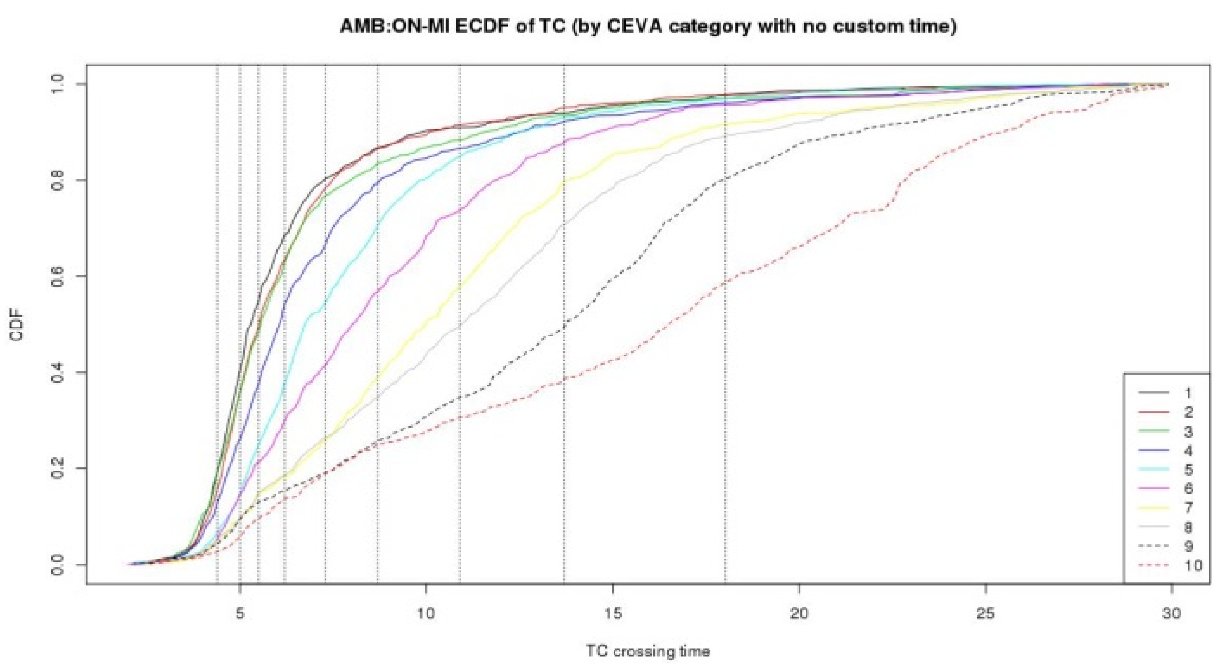
		CEVA									
		< 10	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**>=90**
TC	**< 10**	12	20	6	8	11	11	8	12	8	7
	10-20	19	11	10	9	11	9	14	11	5	7
	20-30	12	12	8	11	15	12	9	6	12	9
	30-40	15	10	10	8	12	10	7	15	11	10
	40-50	13	7	16	16	8	5	7	14	12	6
	50-60	9	3	9	12	5	13	10	14	10	17
	60-70	2	11	8	7	7	13	13	14	9	15
	70-80	5	10	12	7	10	11	9	15	10	10
	80-90	8	9	12	9	13	11	13	3	13	13
	>=90	5	8	6	8	8	14	13	7	13	11

Pearson's Chi-squared test
X-squared = 106.6938, df = 81, p-value = 0.02946

We also plotted the empirical cumulative distribution functions (ECDFs) of the TC crossing times, conditional on the matched CEVA times falling in the various 10^{th} percentile ranges. These conditional ECDFs appear in Figure 3-3 for the various crossing-directions. The numerical value of the colored plot indicates the 10^{th} percentile range, with 1 indicating 0-10^{th} percentile, 2 indicating 10^{th}-20^{th} percentile, and so on until 10 indicating 90^{th}-100^{th} percentile.

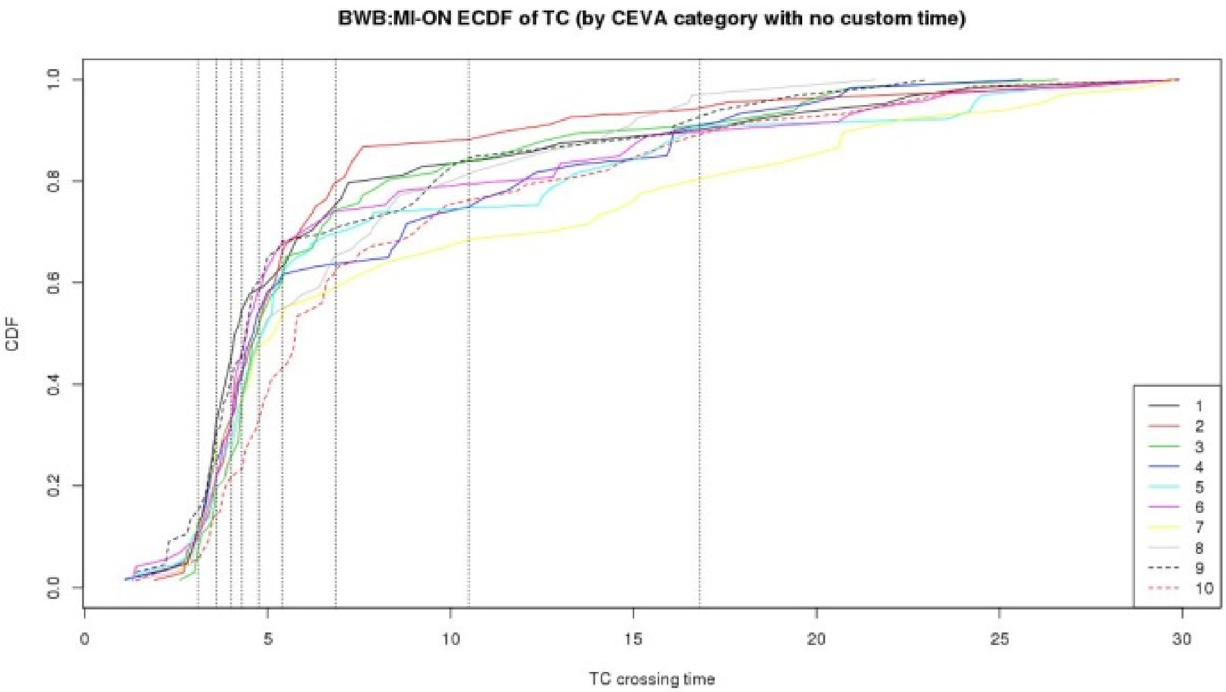


(a) Ambassador Bridge, Michigan-to-Ontario

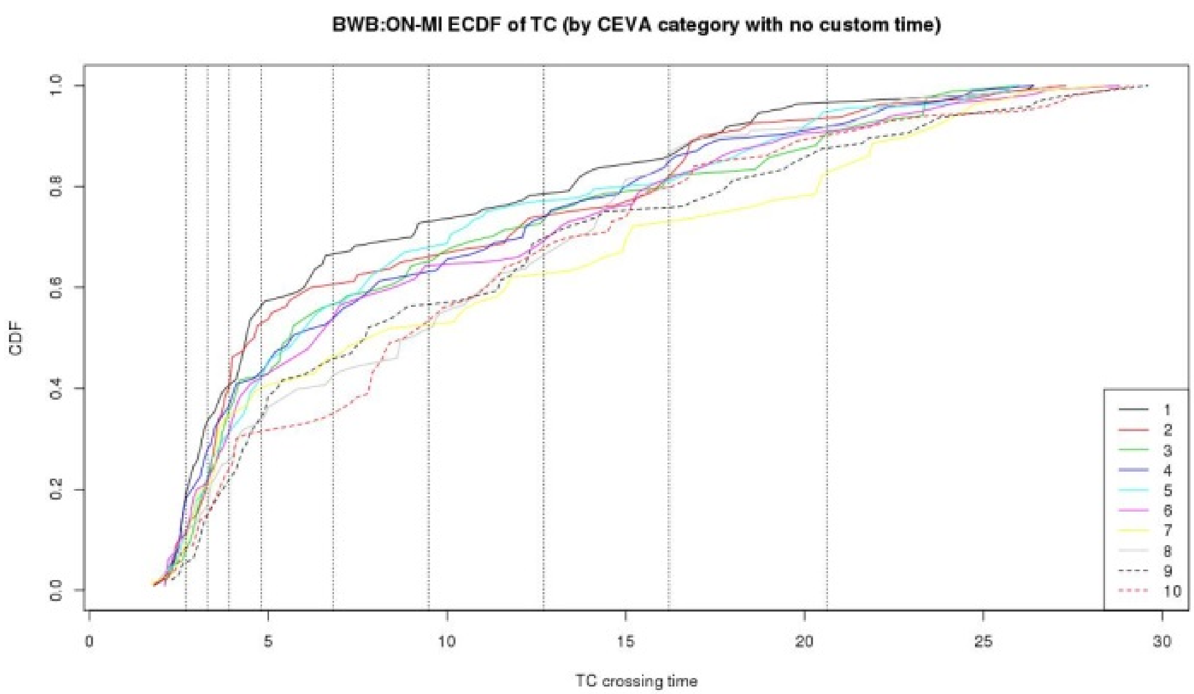


(b) Ambassador Bridge, Ontario-to-Michigan

Figure 3-3: ECDFs of TC crossing times categorized by 10th percentile ranges of CEVA crossing times



(c) Blue Water Bridge, Michigan-to-Ontario



(d) Blue Water Bridge, Ontario-to-Michigan

Figure 3-3 continued: ECDFs of TC crossing times categorized by 10th percentile ranges of CEVA crossing times

The conditional ECDFs are consistent with the results seen in the previous analyses. Specifically, the ECDFs of the TC crossing times that correspond to high percentile ranges of the CEVA crossing times tend to lie to the right (have higher values) of the other ECDFs, and the ECDFs of the TC crossing times that correspond to low percentile ranges of the CEVA crossing times tend to lie to the left (have lower values) of the other ECDFs for both directions at the Ambassador Bridge crossing and for the Ontario-to-Michigan direction at the Blue Water Bridge crossing, but not in the Michigan-to-Ontario direction at the Blue Water Bridge crossing. Previous investigations (*2; 3*) showed that among the four crossing-directions, the Michigan-to-Ontario Blue Water Bridge crossing-direction exhibited the lowest variability in crossing times and lowest magnitudes of queuing times upstream of primary inspection. As such, this crossing direction would be expected to exhibit the weakest systematic "responses" of crossing times to causal variables and, therefore, the weakest association between the two data sets. The pattern indicating the positive association between the two data sets is especially striking in the Ontario-to-Michigan direction at the Ambassador Bridge crossing, where crossing time variability and queuing time magnitudes were very noticeable (*2; 3*).

4. Targeted Empirical Investigations

We used the activity time distributions we produced to conduct various empirical studies which demonstrate the breadth of issues that can be investigated with the geo-fence based activity times.

4.1 Change in Location of Primary Inspection Facilities for Michigan-to-Ontario Traffic at Blue Water Bridge Facility

We previously noted changes to the primary truck inspection facilities in the Michigan-to-Ontario direction at the Blue Water Bridge facility *(1)*. Analysis of our calculated activity times indicated that the change occurred in July 2011. A web-search revealed infrastructure changes at this location around this time. Detailed analysis of our geo-fenced based truck data points indicated that the change occurred on July 20, 2011. Figure 4.1-1 depicts the changes to the primary inspection location. Originally, the truck inspection lanes were located directly adjacent to the car inspection lanes. The new infrastructure provided trucks with their own booths, which were spatially separated from the car inspection area.

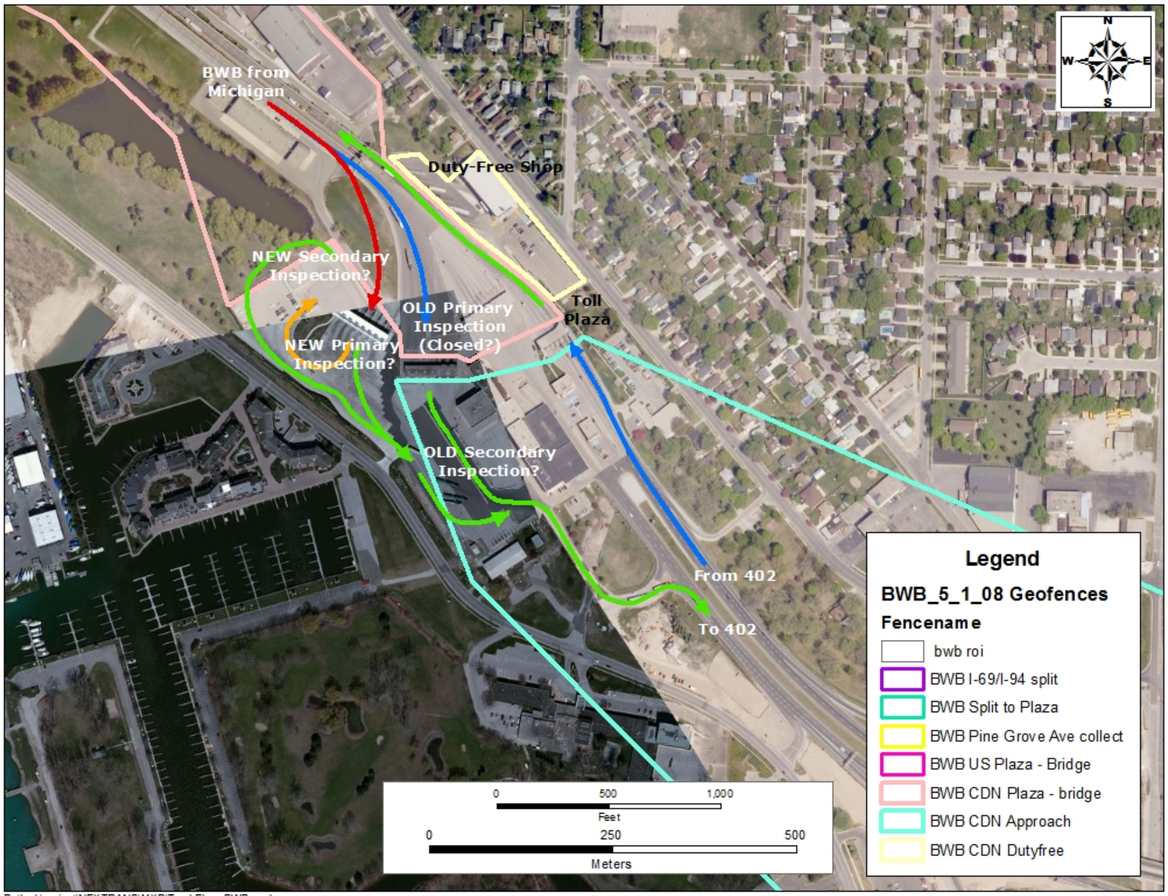
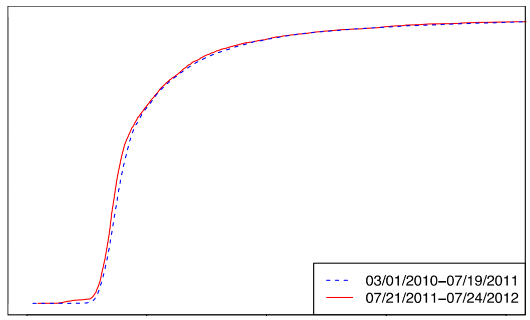


Figure 4.1-1: Illustration of old and new locations of primary truck inspection facilities for Michigan-to-Ontario traffic at the Blue Water Bridge facility

Although we noticed this change of location of the truck inspection facilities during the period corresponding to our previous project, as mentioned above, we were unable to process data in the time period corresponding to that project. Therefore, we processed data in the context of the project being reported here. In Figure 4.1-2, we present the empirical cumulative distribution functions (ECDFs) corresponding to truck times incurred in the geo-fences presently implemented to capture times immediately upstream of inspection (*i.e.*, the *caplazabridge* geo-fence) and immediately downstream of inspection (*i.e.*, the *caapproach* geo-fence) for a "before" period that consisted of data from 03/01/2010 to 07/19/2011 and for an "after" period that consisted of data from 07/21/2011 to 07/24/2012. We also present the ECDFs of what we determined to be inspection times using the presently implemented geo-fences for the before and after periods.

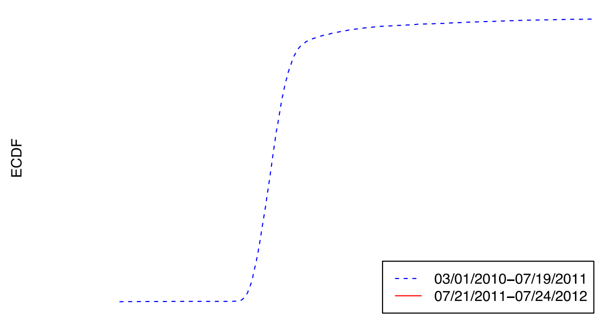


Time (mins)

(a) Upstream Geo-fence

Time (mins)

(b) Inspection Geo-fence



Time (mins)

(c) Downstream Geo-fence

Figure 4.1-2: ECDFs of upstream of inspection, downstream of inspection, and inspection geo-fence times at Blue Water Bridge for Michigan-to-Ontario

Figure 4.1-.2(a) shows that the distribution of times incurred in the geo-fence upstream of inspection did not change with the change in the location of the inspection facilities. In Figure 4.1-2 (b), the plots indicate an increase in the time attributed to primary inspection (by the present geo-fences) after the primary inspection location changed; *i.e.,* the “after” (red) curve is to the right of the “before” (blue) curve. Finally, Figure 4.1-2 (c) indicates that the times incurred in the geo-fence intended to capture times downstream of primary inspection decreased after the location of the inspection facility changed; *i.e.,* the “after” (red) curve is to the left of the “before” (blue) curve. We present summary statistics of the corresponding times in Table 4.1-1

Table 4.1-1: Summary statistics of the distributions of times determined to be upstream of inspection, in inspection, and downstream of inspection according to presently implemented geo-fences before and after movement of primary inspection facilities at the Blue Water Bridge facility in the Michigan-to-Ontario direction; p represents “percentile”; # represents number of observations

	Before 07/19/2011			After 07/21/2011		
	Upstream	Inspection	Downstream	Upstream	Inspection	Downstream
#	8960	8970	8949	3909	3910	3895
mean	2.235	1.019	6.120	2.163	1.341	5.293
SD	2.417	0.525	4.701	2.067	0.640	1.497
max	126.233	13.300	209.917	67.067	11.133	32.917
min	0.100	-2.817	0.750	0.183	-0.050	0.833
90P	3.533	1.417	6.520	3.467	1.783	5.900
75P	2.250	1.117	5.917	2.233	1.433	5.450
50P	1.650	0.933	5.550	1.567	1.217	5.067
25P	1.433	0.783	5.200	1.383	1.050	4.800
10P	1.283	0.667	4.950	1.250	0.917	4.600
SD/mean	1.081	0.515	0.768	0.956	0.477	0.283
90P-50P	1.883	0.483	0.970	1.900	0.567	0.833
(90P-50P)/50P	1.141	0.518	0.175	1.213	0.466	0.164

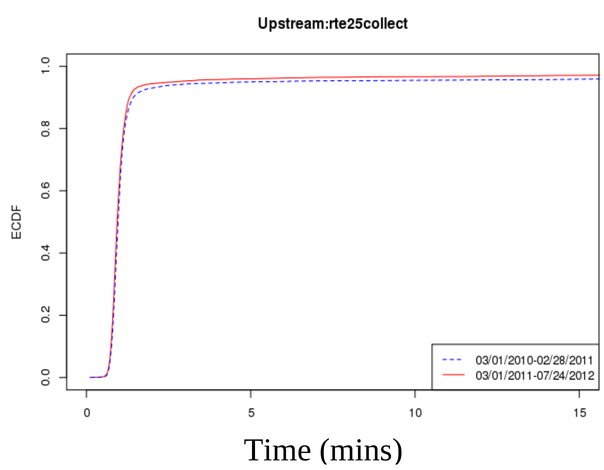
From Table 4.1-1, it can be seen that the mean time spent in the upstream fence is almost the same in the before and after period (a change of only 0.072 minutes), whereas the mean of the times that would be attributed to inspection and to travel in the downstream fence increased by 0.323 minutes and decreased by 0.826 minutes, respectively. The same pattern of approximately identical times attributed to upstream travel, slight increase in times attributed to inspection, and larger decrease in times attributed to downstream travel can be seen for the other percentile values as well.

The relatively large changes in times that would be attributed to inspection and travel downstream of inspection motivate changing the coordinates of the corresponding geo-fences. Since we cannot retroactively change the locations of these fences, having quantitative estimates of the implications on empirical times, such as those obtained from the statistics presented in Table 4.1-1, will be helpful in appropriately using and interpreting activity times determined with existing geo-fences before and after the change in the location of the inspection facilities.

4.2 Effects of Black River Bridge Infrastructure Disruption

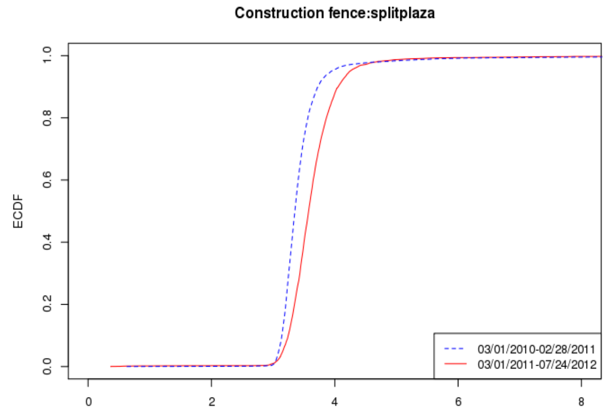
To improve safety and mobility on I-94/I-69 in St. Clair County as this combined stretch of interstate approaches the Blue Water Bridge,, the Michigan Department of Transportation (MDOT) began a major infrastructure project around the Black River Bridge in 2012. The location of the project lies within our *splitplaza* geo-fence. We used our geo-fence data to quantify the effect on truck traffic of the project. According to the project schedule posted on MDOT website (http://www.michigan.gov/documents/mdot/MDOT_I-94_Reconstrflyer_380674_7.pdf; accessed on 09-25-2012), westbound construction started in 2012, but the exact date is unknown. Therefore we chose to use the date stated as corresponding to the beginning of eastbound construction (Feb 28, 2011) to mark the separation of "before" and "during" infrastructure disruption.

In Figure 4.2-1, we plot the ECDFs of the times incurred in the fences *6994splt* (downstream fence for westbound traffic and upstream for eastbound), *splitplaza* (construction fence), and *rte25collect* (upstream fence for westbound traffic and downstream for eastbound) before and during the infrastructure disruptions for westbound traffic. We plot the ECDFs for eastbound traffic in Figure 4.2-2.



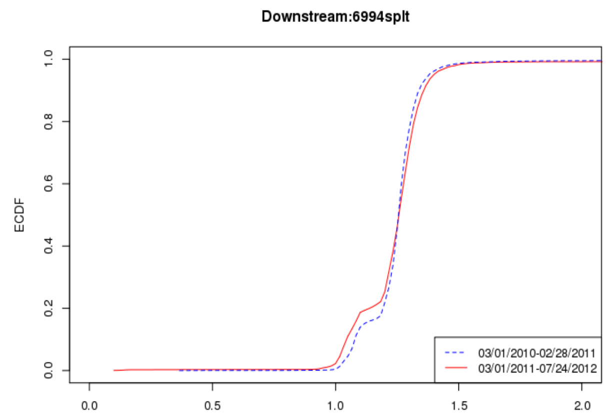
(a) Upstream Geo-fence

Figure 4.2-1: ECDFs of truck times incurred in geo-fences downstream of Black River Bridge infrastructure project, encompassing the project, and upstream of the project for westbound traffic.



Time (mins)

(b) Geo-fence Encompassing Construction



Time (mins)

(c) Downstream Geo-fence

Figure 4.2-1 continued: ECDFs of truck times incurred in geo-fences downstream of Black River Bridge infrastructure project, encompassing the project, and upstream of the project for westbound traffic.

The “during” ECDFs are noticeably to the right of the “before” ECDFs in Figures 4.2-1(b) and 4.2-2(b), indicating that the times incurred in the geo-fence encompassing the project were greater during the project than before the project. The similarities of the “during” and “before” ECDFs for the upstream and downstream geo-fences in Figures 4.2-1(a), 4.2-1(c), 4.2-2(a), and 4.2-2(c) increase the likelihood that the differences in the times seen in the geo-fence encompassing the construction are likely a result of the project and not of other confounding factors.

Although the increased truck travel times during the construction project are noticeable, the magnitudes of the increases are small. The largest difference in the "before" and during" curves, which occurs at high percentile values, is only about half a minute. It appears that control of traffic operations was fairly effective during the project.

4.3 Investigation of Duty-free Times

Many of our empirical investigations are focused on using the CEVA trucks as probe vehicles to determine general conditions and patterns at the border crossing facilities. However, some of the geo-fence based activity times can be of specific interest to the carrier. General patterns in times the trucks spend at duty-free facilities is one activity of interest. (To retain widespread support for our analyses, we avoid providing information on individual trucks.) Presently implemented geo-fences allow us to approximate the times US-bound trucks incur when they divert from direct passage through the border crossing facility to take a route near the duty-free facilities. We use these times to represent times associated with duty-free facilities. It is possible that the times may not always be completely associated with visiting the duty-free facilities. (For example, there may be another reason the driver took a longer route.) However, CEVA representatives confirm that these are appropriate indicators of time spent at duty-free facilities.

In Figure 4.3-1 we plot the 90th percentile values of the distributions of these duty-free times at the Ambassador Bridge facility by month for several years. In Figure 4.3-2, we plot the 90th percentile values for the Blue Water Bridge facility. Years are plotted by month, with different years represented by different colored segments, to control for monthly effects. We do not show the magnitude of the times on the ordinates to protect possible sensitive information. The noticeable decrease in the 90th percentile values at both facilities beginning in March 2010 is apparent.

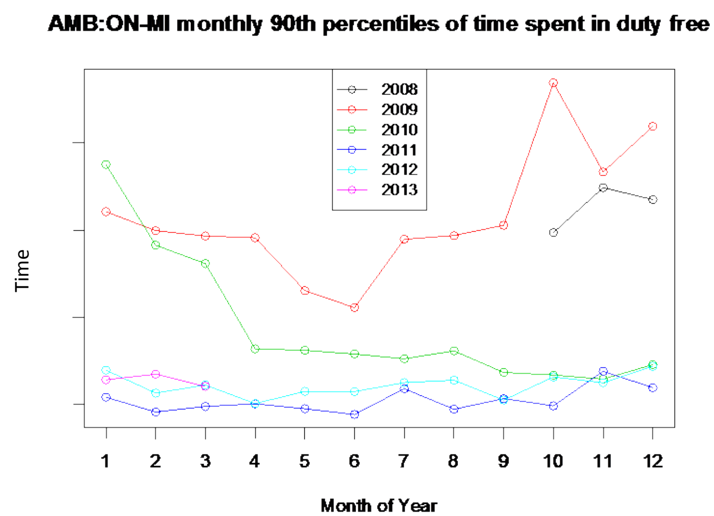


Figure 4.3-1: Monthly 90th percentiles of duty-free times incurred by US-bound traffic at the Ambassador Bridge facility (magnitudes of times purposely not shown)

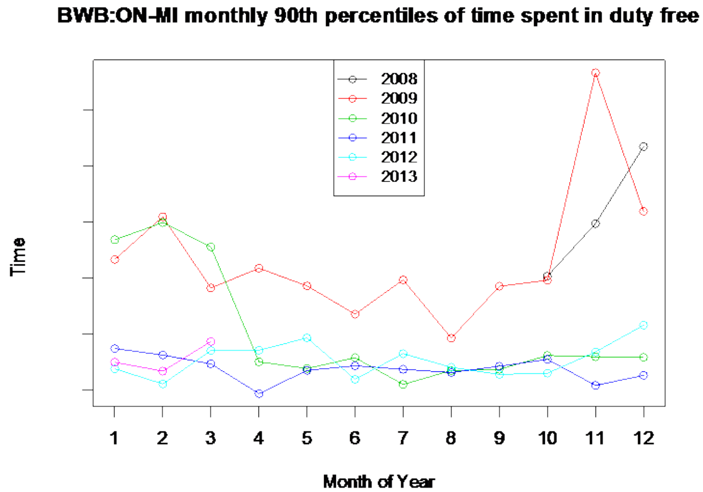


Figure 4.3-2: Monthly 90th percentiles of duty-free times incurred by US-bound traffic at the Blue Water Bridge facility (magnitudes of times purposely not shown)

4.4 Times Incurred on Surface Streets

Truck traffic using the Ambassador Bridge facility must use surface streets in Windsor, Ontario. Previous results (*2*) show that travel on these streets can be an important component of the time associated with trucks using the Ambassador Bridge. In addition, the times spent on these surface streets can be used for general transportation planning in Windsor. -The *caapproach* and *huronchrchrd* geo-fences encompass 6.58 miles (10.59 kilometers) of surface streets in Windsor.

In Figure 4.4-1, the medians of the distributions of times incurred on these surface streets are plotted by hour-of-day and day-of-week for the US-bound trucks. In Figure 4.4-2, the medians for Canada-bound traffic are plotted in the same manner. The medians were determined for data from 03/01/2010 to 04/08/2013.

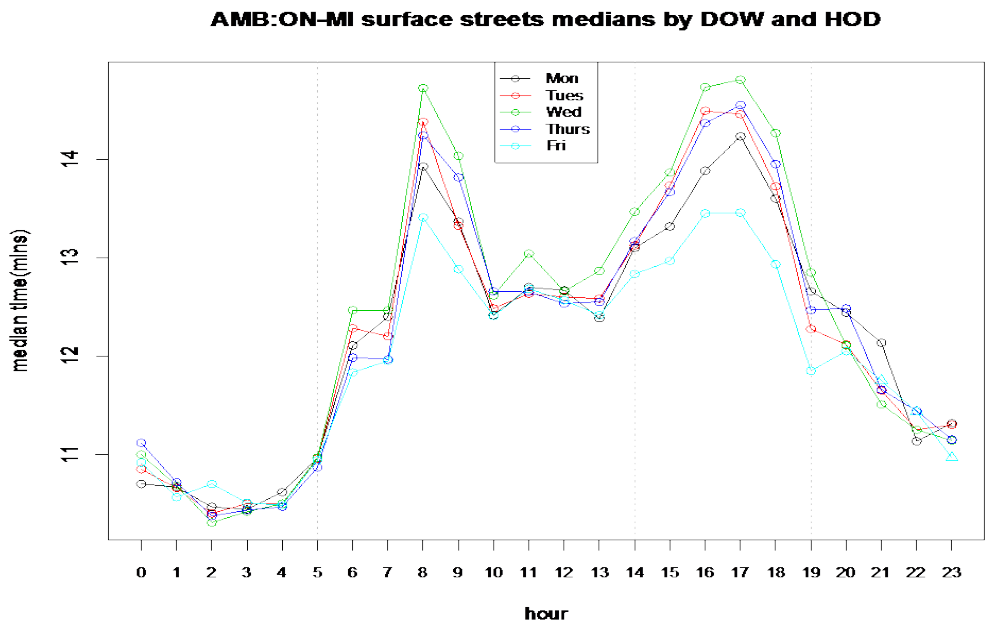


Figure 4.4-1: Median of times incurred on surface streets in Windsor, ON, by hour-of-day and day-of-week for US-bound traffic

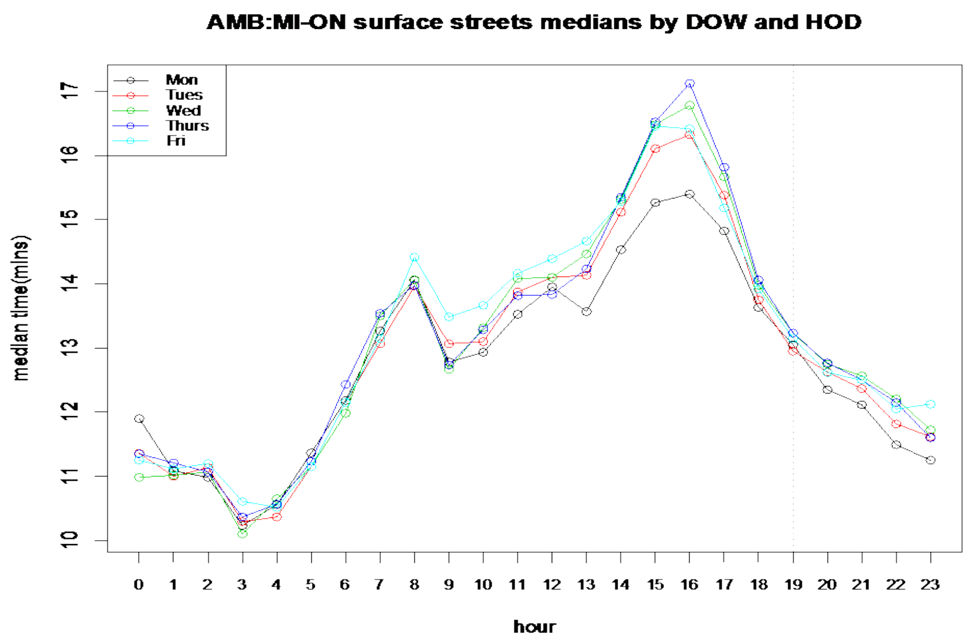


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Figure 4.4-2: Median of times incurred on surface streets in Windsor, ON, by hour-of-day and day-of-week for Canada-bound traffic

The plots show morning and afternoon peaks in travel times at approximately the same hours-of-day (approximately 8-9 AM and 4-6 PM), for all (weekday) days-of-week. Friday appears to have the lowest median time during the morning and afternoon peaks for the US-bound traffic, but not for Canada-bound traffic. One can also notice that the morning peak corresponding to the

US-bound direction is more pronounced than for the Canada-bound direction, although the median times in the peaks are both approximately 14 or 15 minutes. The peaking appears less pronounced in the Canada-bound direction because the median times increase to a larger median afternoon peak time in the Canada-bound direction than in the US-bound direction. The median time in the afternoon peak is between one and three minutes greater in the Canada-bound direction than in the US-bound direction.

The systematic peaks are consistent with typical peak period traffic patterns for local traffic, indicating that the truck times are noticeably affected by local traffic on the surface streets. The results also indicate that the geo-fence based times can be used to portray and quantify systematic patterns in surface street travel times.

5. Proposed Geo-fence Revisions

As discussed in McCord, *et al*. (*1*), we previously noted important infrastructure projects and changes at the Ambassador Bridge and Blue Water Bridge crossings. Examination of imagery revealed that these projects affected paths of Canada-bound trucks at the I-69/I-94 interchange (on the US side of the Blue Water Bridge), through the US Plaza of the Ambassador Bridge, and at primary Michigan-to-Ontario truck inspection facility on the Canadian side of the Blue Water Bridge. Based on these changes, we designed some changes to presently implemented geo-fences for future consideration.

Possible changes to Ambassador Bridge geo-fences: The presently implemented geo-fence configurations were established based on plaza configuration and commercial traffic flow in spring, 2008 (Figure 5-1). Since that time, construction projects such as MDOT's Gateway project at the US Plaza of the Ambassador Bridge in Detroit (Figure 5-2 and Figure 5-3; affecting Canada-bound traffic). Proposed changes based on the current geo-fence configuration and the construction changes can be found in Figure 5-4 through 5-6).

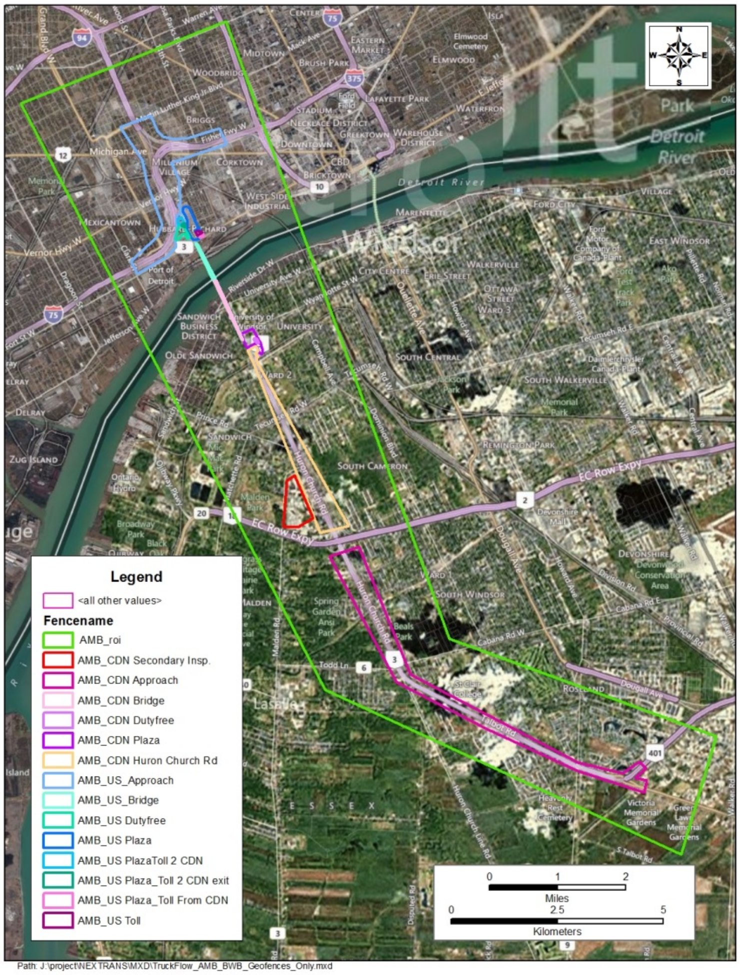


Figure 5-1: Synoptic view of the Ambassador Bridge geo-fences and region of interest as developed in May, 2008.

Figure 5-2: The Ambassador Bridge US plazas as of May 2007, before construction began on the Gateway project. *Compare the ramp alignment and traffic flow in this aerial image to Figure 5-3 below.*

Figure 5-3: US Duty Free Plaza at the Ambassador Bridge. Note changes between US Duty Free geo-fence and actual configuration of the duty free zone and approach to the bridge.

Based on the noted observations, we are considering the following changes to geo-fence shapefiles at the Ambassador Bridge (see, Figure 5-4 through 5-6):

- US Duty free expands to encompass the new duty free/fueling area and new configuration of ramps to the bridge and I-75.
- Ambassador US [Customs] Plaza enlarges to minimize extra GPS points caused by limited GPS satellite reception.
- US Toll to Canada and US toll to Canada Exit are eliminated. Commercial traffic no longer passes through those geo-fences. (Toll booths are now within the US Duty Free geo-fence; see Figure 5-3).
- The widths of the US Bridge (*amb_usbridge*) and Canada Bridge (*amb_cabridge*) geo-fences are expanded to reduce 'jumping' in and out of a geo-fence caused by variations in GPS accuracy when trucks are parallel to and near the geo-fence. The 'jumping' increases the number of data points collected but does not add value to the data. Truck data 'pings' were used to help define the extent of geo-fence changes.

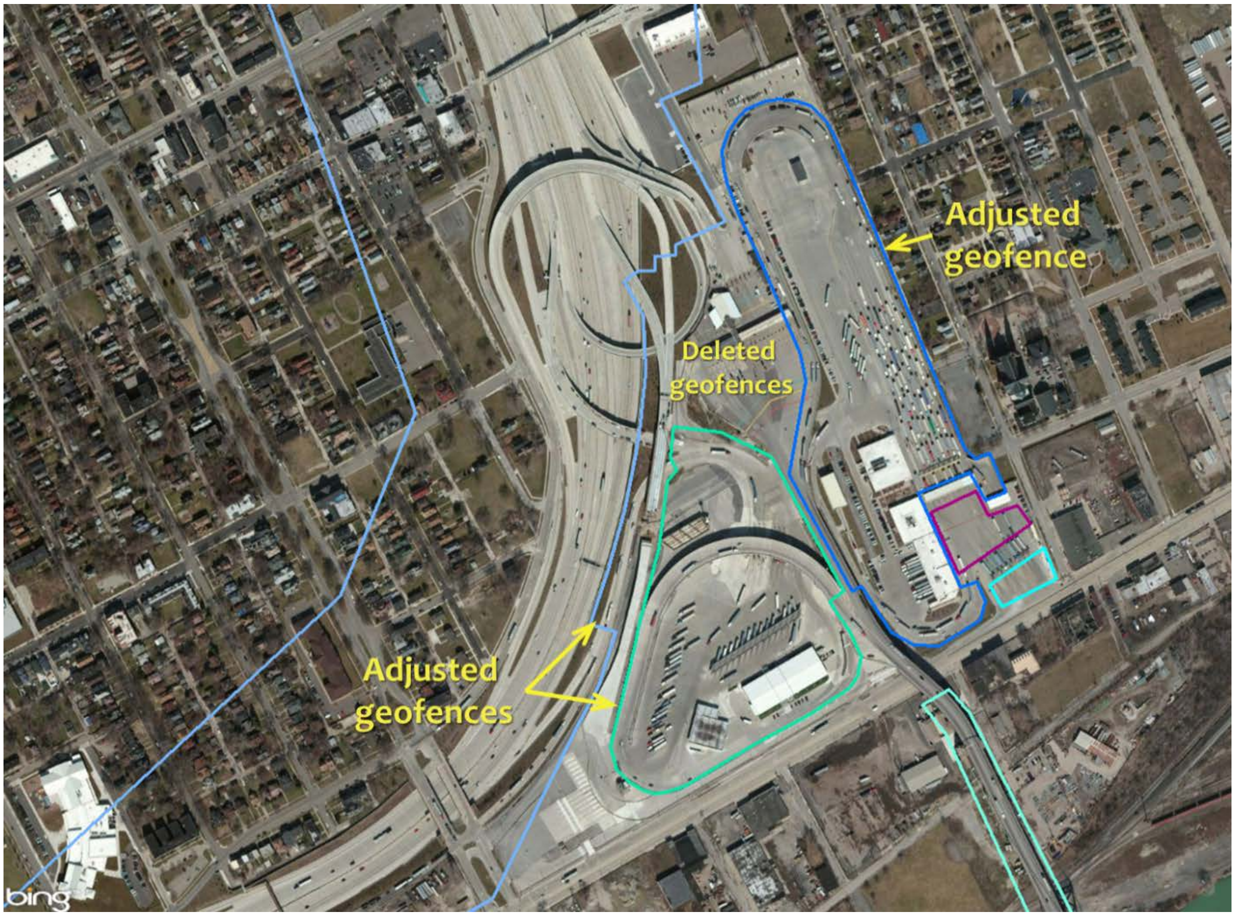
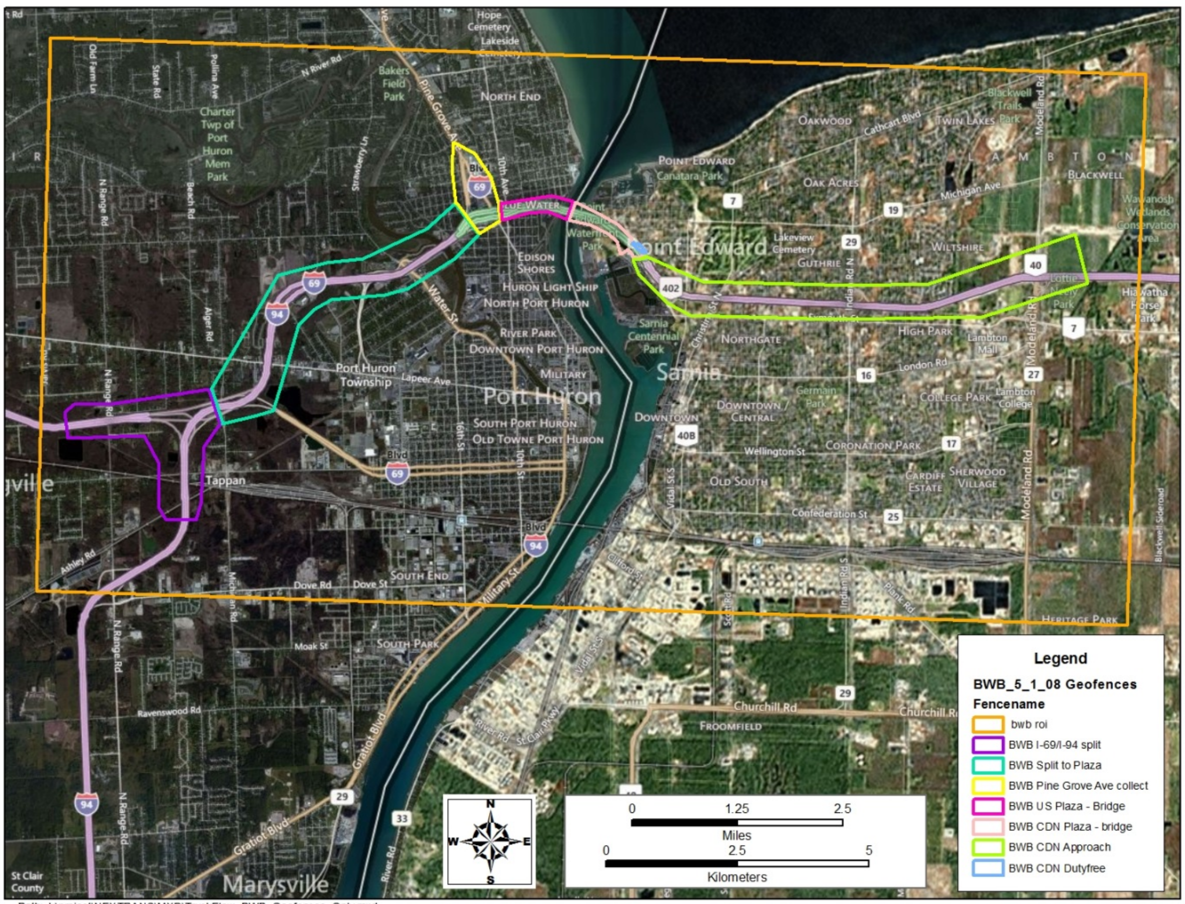


Figure 5-4: Proposed US Plaza (*amb_usplaza*) geo-fence configuration overlaid on an aerial image from Spring 2012. Construction on ramps from I-75 and I-96 to the bridge is complete, construction on the ramp for commercial vehicles from US Customs to I-75/I-96is nearly complete. *Some changes were made to the configuration of the Duty Free plaza after this image was captured.*

Figure 5-5: A low oblique image of the completed US approach to the Ambassador Bridge. *This new duty free plaza /bridge approach complex serves all Canada-bound traffic crossing the bridge.*

Figure 5-6: Geo-fence adjustments made at the Ambassador Bridge Canada Customs plaza in Windsor, ON. *The changes made were minor, and intended to minimize trucks 'jumping' in and out of geo-fences.*

Possible changes to Blue Water Bridge geo-fences: A figure depicting the existing Blue Water Bridge geo-fences can be found in Figure 5-7. During this study there was significant bridge and ramp construction on I-94/I-69 approaching the Blue Water Bridge. However, most of the construction was contained within existing geo-fences and only minor changes to the geo-fences on the US side of the St. Clair River are necessary. During construction, a ramp from the approach to the Blue Water Bridge to Pine Grove Avenue was added (Figure 5-8). The ramp extended just outside the “Pine Grove Ave collect” (*bwb_rte25collect*) geo-fence, resulting in an unnecessary out-in pair of data points should a truck driver visit the Duty Free store, located just north of the US Plaza. A minor adjustment to the extent of the “Pine Grove Ave collect” to encompass the new ramp was made.



Path: J:\project\NEXTRANS\MXD\TruckFlow_BWB_Geofences_Only.mxd

Figure 5-7: Synoptic view of the Blue Water Bridge geo-fences and Area of Interest as provided at the beginning of the project.

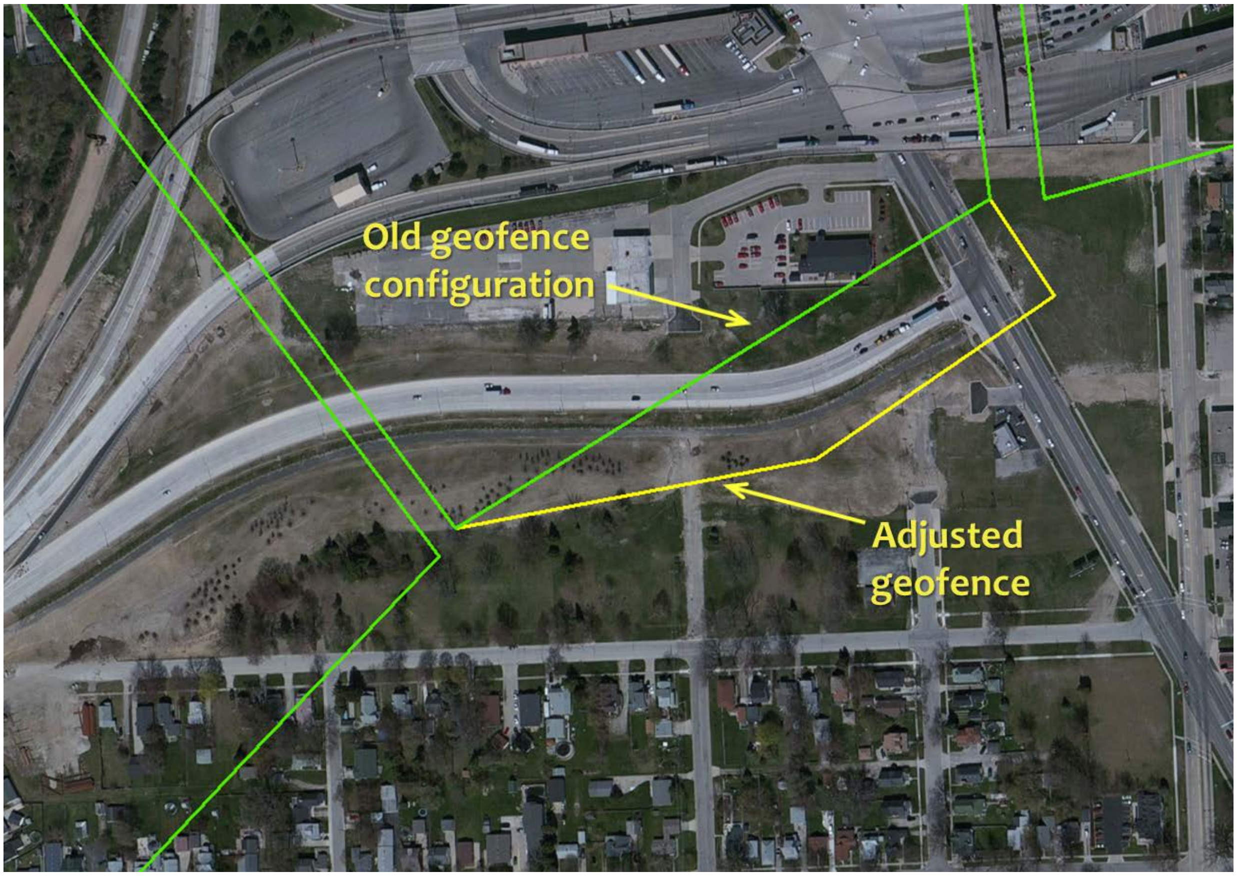


Figure 5-8: Adjustments to the "Pine Grove Ave collect" (*bwb_rte25collect*) geo-fence intended to keep exiting traffic headed to the Duty Free store within the geo-fence.

The construction of new primary inspection booths for Canada customs discussed in Section 4.1 motivates adjustments to the *bwb_caapproach* and *bwb_caplazabridge* geo-fences to reflect changes in truck traffic patterns that occurred when the new customs inspection location opened. Little information was available about the construction project or when the changeover from the existing inspection lanes to the new ones would take place. The date of the move to the new primary inspection location was determined by observing traffic patterns in the CEVA data, as seen in the images of Figure 5-9, Figure 5-10 and Figure 5-11. Figure 5-12 shows the recommended new geo-fence configuration for this side of the Blue Water Bridge.

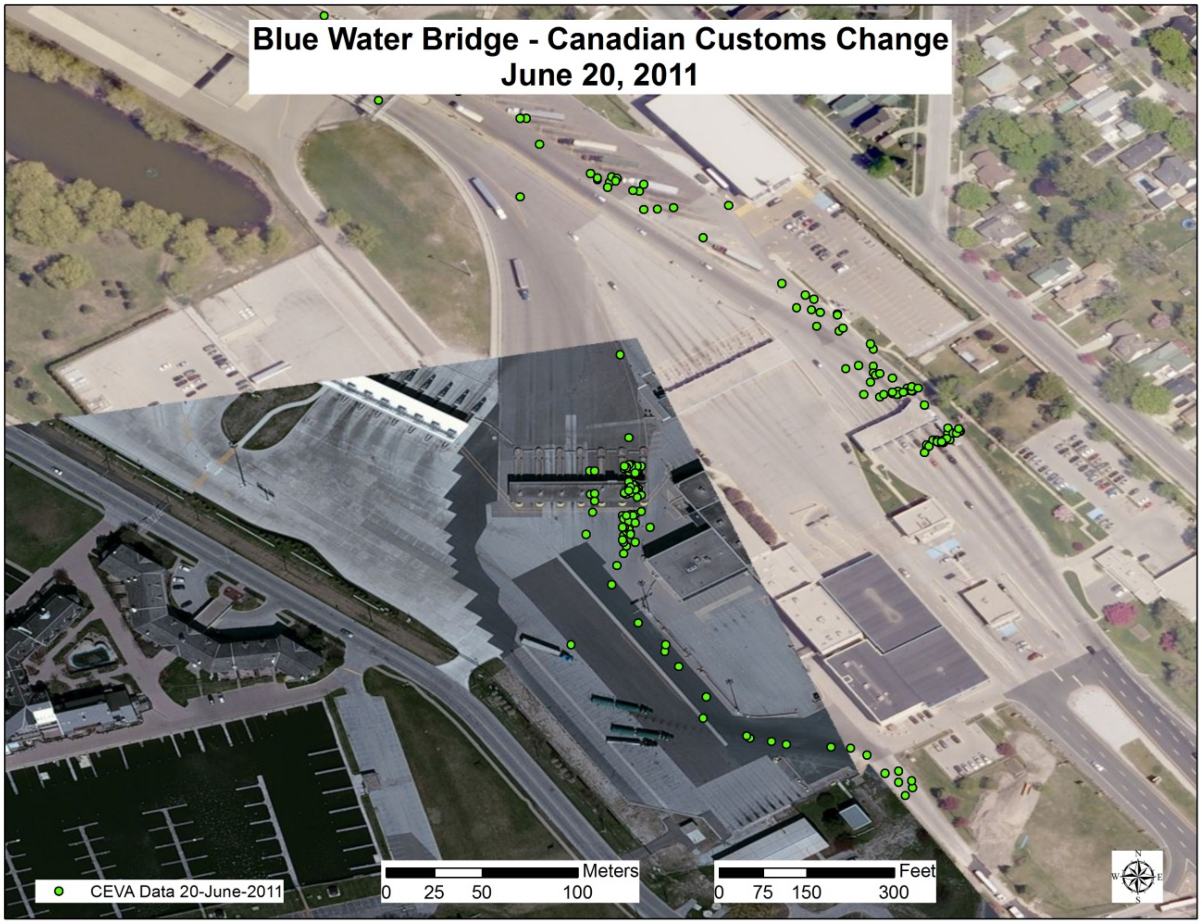


Figure 5-9: Commercial traffic flow through the Canada Customs primary inspection lanes on July 20, 2011. Commercial traffic appears to transit the old primary inspection lanes.

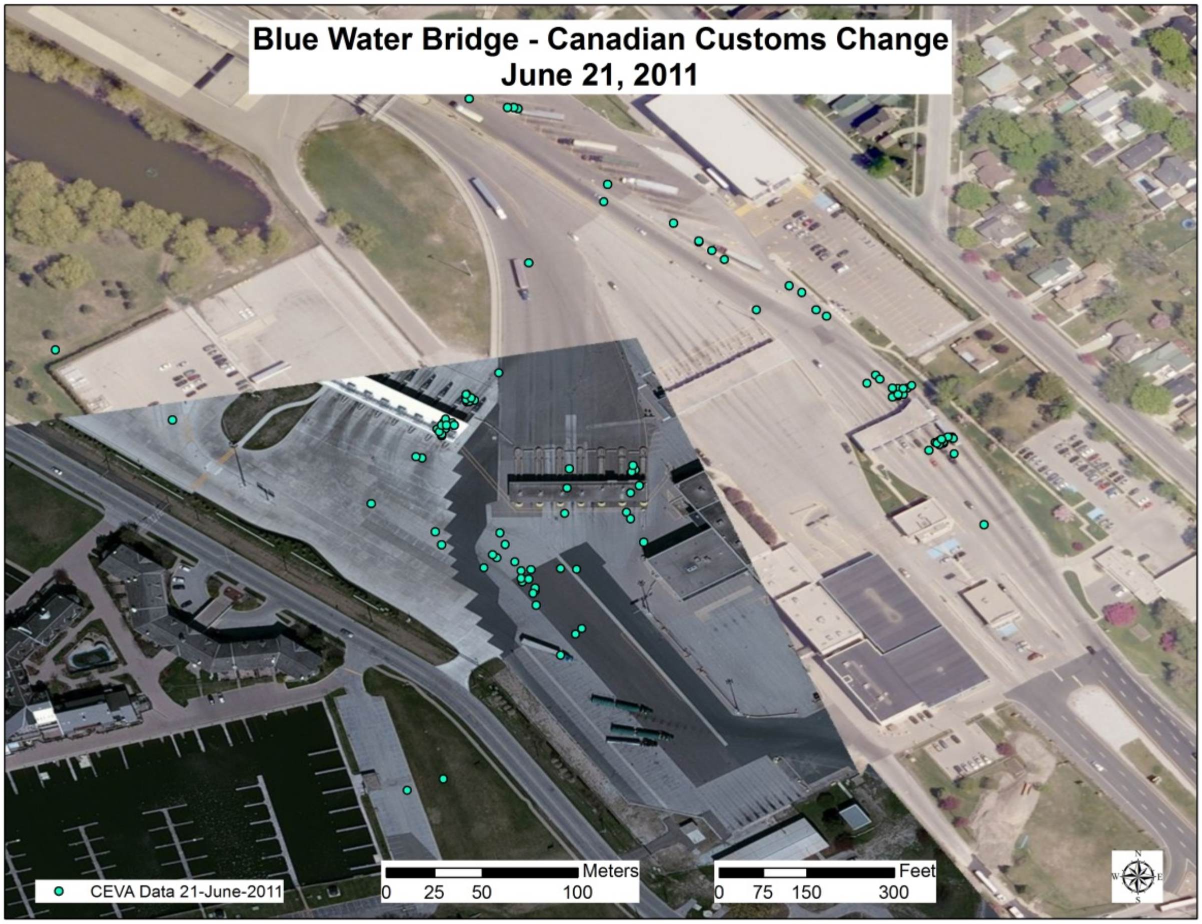


Figure 5-10: Commercial traffic flow through the Canada Customs primary inspection lanes on July 21, 2011. *Note that the GPS tracks indicate that both the old and new primary inspection lanes appear to be used on this date.*

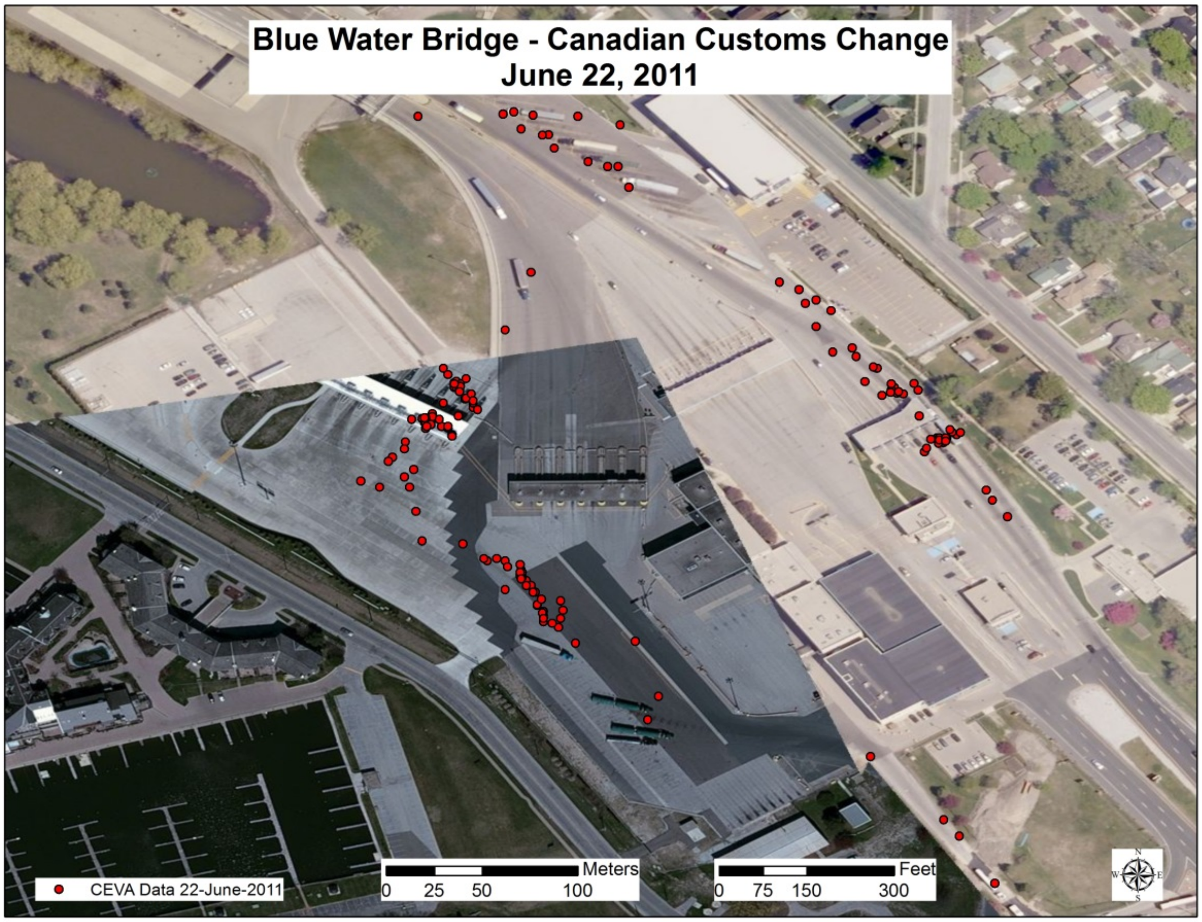


Figure 5-11 Commercial traffic flow through the Canada Customs primary inspection lanes on July 22, 2011. *Note that the GPS tracks indicate that only the new primary inspection lanes appear to be open on this date.*

Figure 5-12: Proposed changes to geo-fences at the Canada Customs primary inspection station to reflect construction of new inspection lanes which opened in July, 2011.

6. Data Visualizations

Discovering and communicating relationships in graphs and tabular data can be challenging. Visualizing data in innovative ways may uncover relationships that are not obvious in graphs and tabular data. The location and time components of our geo-fence based data can allow geo-temporal data representations of the times we have been determining and the truck volumes involved with these calculations.

Sub-datasets of crossing times and volumes were created and visualized within Google Earth for preliminary exploration and demonstration. Truck crossing times in both directions at the Ambassador Bridge facility during January 2013 were used. For US-bound traffic, crossing times were considered to begin at the entrance to the Canadian Plaza geo-fence and end at the departure from the US Plaza Toll geo-fence (Fort Street). For Canada-bound traffic, crossing times were considered to begin at the entrance to the US Duty Free geo-fence and end at the entrance to the Huron Church Road geo-fence. The present geo-fence configurations allowed subtraction of duty-free times from the US-bound crossing times but not from Canada-bound crossing times. In addition, secondary inspections times were also noted and included in the total crossing time. At the Blue Water Bridge facility, empirical explorations were based on truck volumes by direction in our data set using the facility between September 2012 and September 2013.

The geo-fence boundaries were imported onto three-dimensional bridge models (Figure 6-1), and an image of a truck was used to set three Google Earth placemarkers at different locations at each facility: one near the facility's US plaza, one near the middle of the facility's bridge, and one near the facility's Canadian plaza. In addition to the graphs shown in Figures 6-2 and 6-3, animations were also attached to each representative placemarker. The animations are linked to a secure Screencast.com account where the videos are password protected to respect the wishes of the data provider. To view the graphs and videos in Google Earth, the placemarker is selected. The representative graph will then appear on the screen, along with the link to an animation.

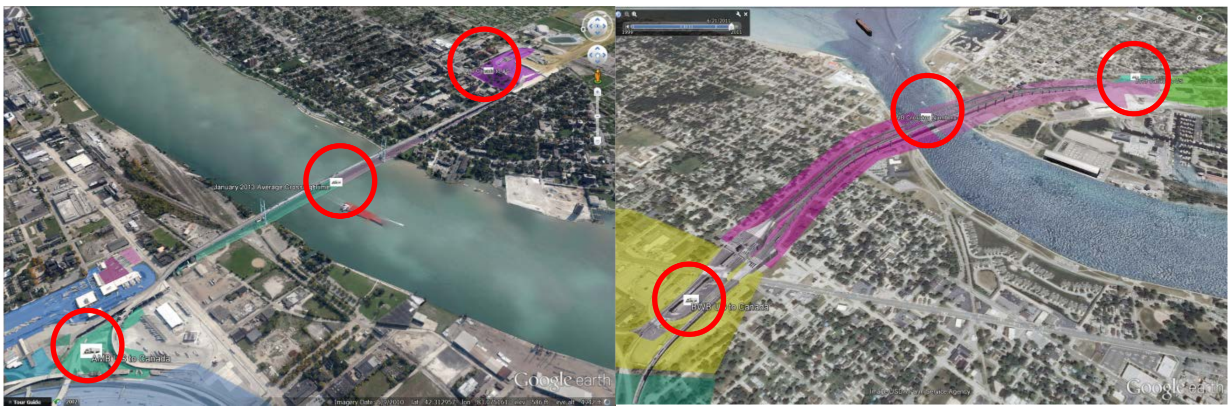


Figure 6-1: A 3-D representation of the Ambassador Bridge (left) and Blue Water Bridge (right) in Google Earth. *Placemarkers are located in the middle and on each side of the bridge (red circles).*

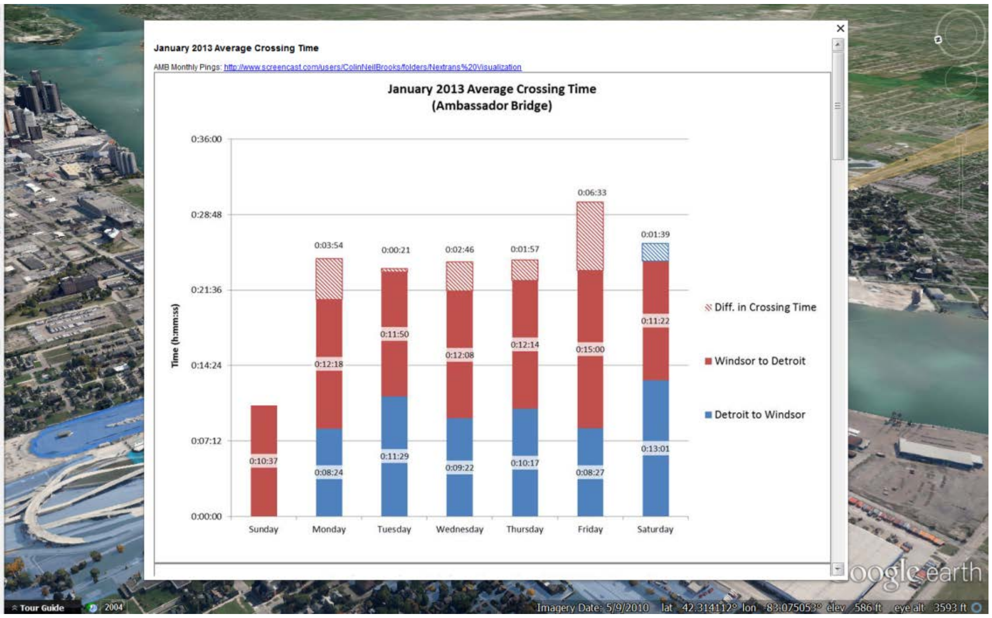


Figure 6-2: Graphs and links to animations appear on the screen upon selection a truck placemarker. *Each placemarker contains data that is representative of its location.*

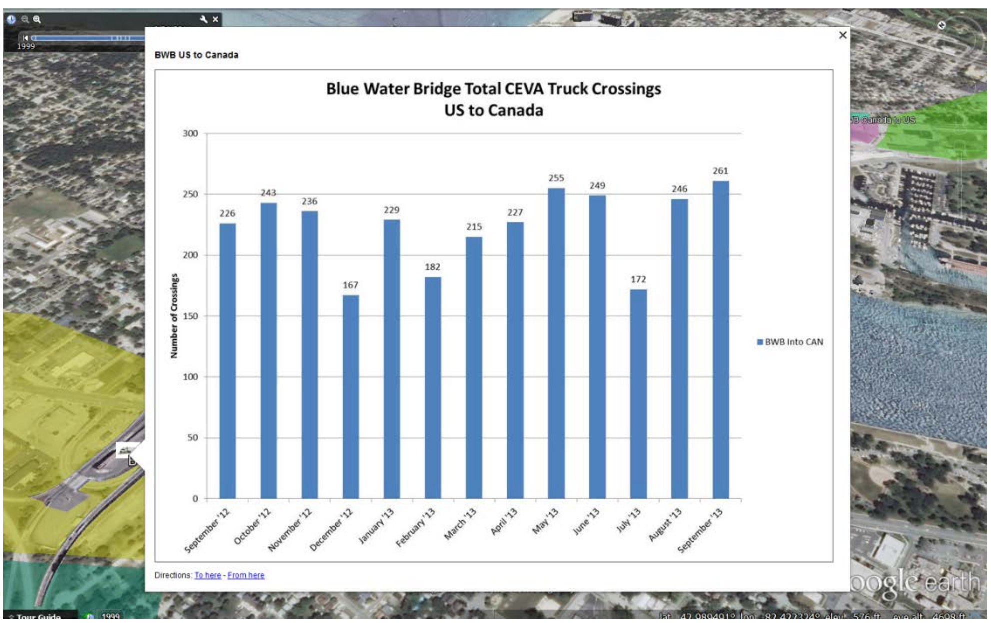


Figure 6-3. Graphs indicating the number of crossings are placed in the placemarkers on both sides of the Blue Water Bridge.

Additional visualizations within Google Earth can be created using other datasets. These additional visualizations may include animations similar to the ones located at Screencast.com, and animated graphs or charts, which would be similar to the ones that appear when a placemarker is selected.

Figure 6-4 through Figure 6-7 are frames from data animations created from a dataset containing example data from 2013. Each animation uses the same dataset but parses the data differently. They are designed to show how different representations and queries of the data can result in understanding patterns in the data that can reveal typical and unusual locations of the trucks sending the data.

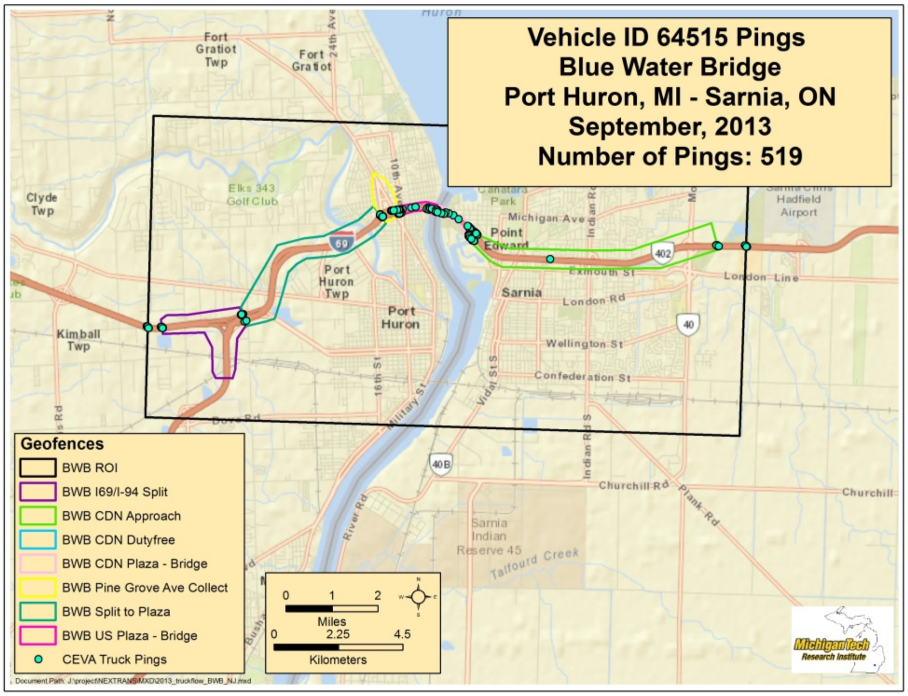


Figure 6-4: All the data "pings" (GPS records) for a single vehicle for September, 2013.

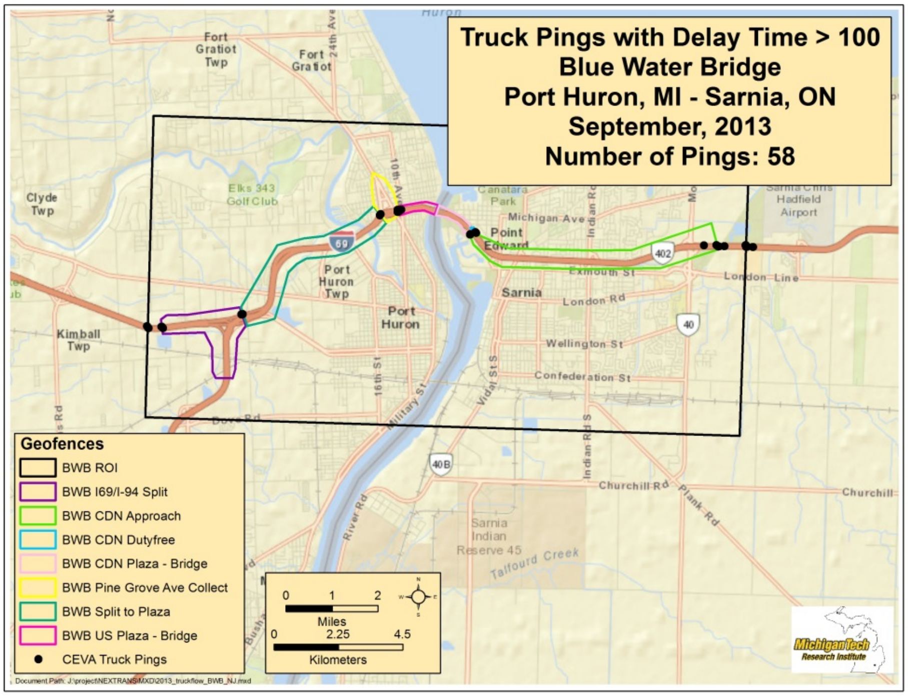


Figure 6-5: All the data pings with a "delay" field value > 100 (seconds) for September, 2013.

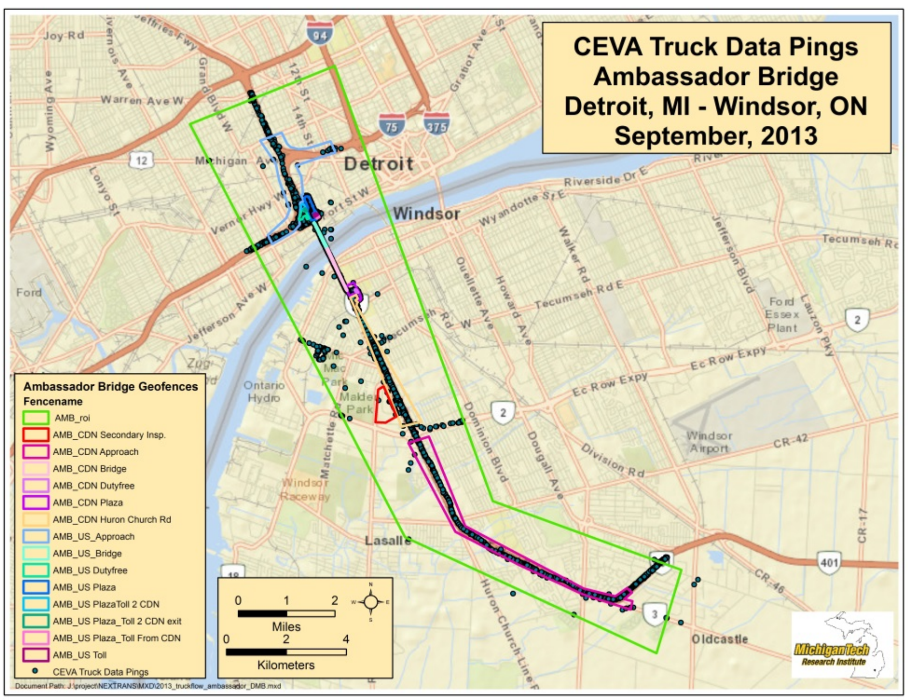


Figure 6-6: All the data pings for September, 2013 at the Ambassador Bridge.

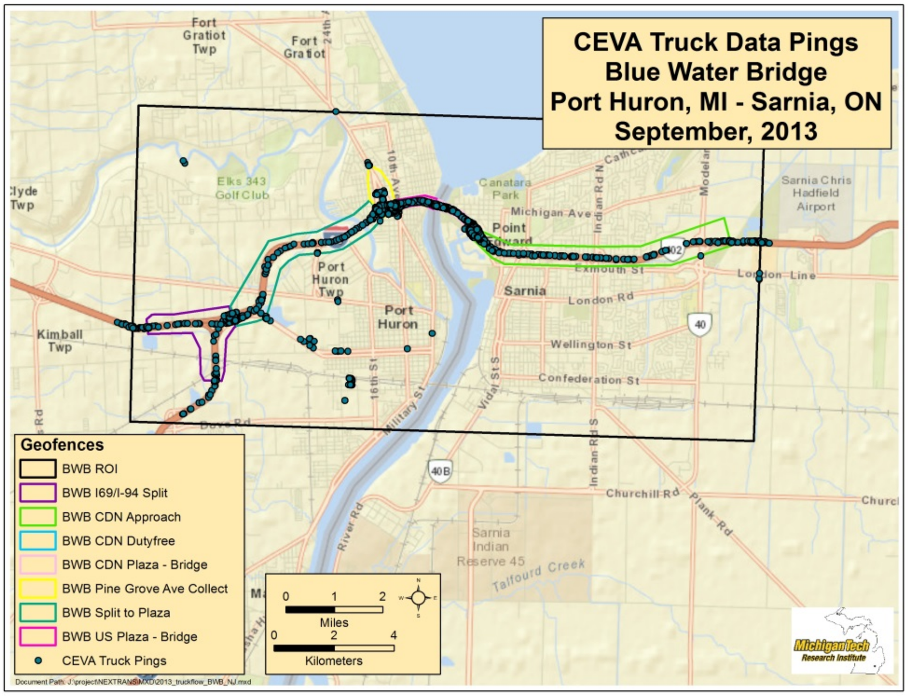


Figure 6-7: All the data pings for September, 2013 at the Blue Water Bridge.

7. Expressed Stakeholder Interest

The former Economic Relations and Regulatory Affairs Officer at the Consulate General of Canada-Detroit, who had previously expressed interest in the activity times we had been producing (1), invited one the project investigators to a social event hosted by the Consul General of Canada for Ohio and the Columbus Council on World Affairs in Columbus, OH. After being introduced to the project investigator, the Consul General stated that he had been informed of our our work and specifically asked about changes in border crossing times entering the U.S. at the Ambassador Bridge and Blue Water Bridge facilities. A brief discussion indicated that ours were now the only archived quantitative information that could provide such information. The specific questions asked by the Consul General also motivated us to consider longitudinal analysis in the future.

Members of the project team also met with Michigan Department of Transportation (MDOT) staff member Michele Mueller at the end of the project timeframe. Ms. Mueller, who is located in Detroit, MI, is responsible for MDOT’s border-crossing-related data programs to help ensure efficient border crossing experiences. She expressed interest in the results of our analyses and capabilities of our team, including potentially using the team’s crossing time component data as part of her management efforts. The project team will continue discussions with Ms. Mueller in the future.

8. Summary and Conclusions

We successfully collected new geo-fence data from trucks crossing the US-Canada border at the Ambassador Bridge and Blue Water Bridge facilities and processed these newly collected data and previously collected but unprocessed data to produce truck activity times at these facilities. We use the newly produced activity times in several targeted empirical studies. We documented the effect of a change in the location of the Blue Water Bridge inspection facilities on inspection and downstream-of-inspection time estimates produced from data collected with presently implemented geo-fences. We also used the activity times to demonstrate that the Black River Bridge construction project near the western side of the Blue Water Bridge increased truck times in the vicinity of the project, but only slightly. We saw a dramatic lowering of upper percentile duty-free times at both facilities beginning in the same month. Finally, we used the activity times to demonstrate time-of-day patterns and peaking in travel times incurred on surface streets in Windsor.

We also refined and expanded previously conducted comparisons between crossing times produced from our geo-fence data and crossing times obtained from Transport Canada, which were determined using a Bluetooth-based approach. Our investigations showed strong positive associations between the crossing times produced from the two datasets in both directions at the Ambassador Bridge facility and in the Ontario-to-Michigan direction at the Blue Water Bridge facility. A positive association was also seen for the Michigan-to-Ontario direction at the Blue Water Bridge facility, but the association was not statistically significant. We note that this weaker association is consistent with the relatively low variability in crossing times and low magnitude of queuing times exhibited for this crossing-direction.

In addition, we noted changes in infrastructure at the crossing facilities, proposed that such changes motivate implementation of new geo-fences, and developed preliminary procedures to visualize the data and activity times for better communication and analysis. We also received interest in our results from a high ranking Canadian official, who enquired about changes in crossing times over time, and from a Michigan DOT border crossing data manager, who expressed potential interest in receiving our results.

In the future, it would be helpful to conduct additional empirical investigations with the geo-fence data. The interest in our results from individuals directly interested in border operations motivates us to investigate time trends in crossing and activity times at the border crossing facilities. We now have data acquired over a sufficiently long time span to investigate such trends. It would also be valuable to investigate the ability to estimate meaningful relations between the crossing or queuing times we have recorded and explanatory variables such as traffic volumes or inspection times.

We have been comparing crossing times produced from geo-fence based data and from the Transport Canada Bluetooth-based data to determine if the two datasets are redundant of if they can somehow be combined to produce a more complete picture of activity times at these border crossing facilities. During the timeframe of this project, we discovered that the Canadian efforts to collect Bluetooth-based data at these facilities had ceased. This makes efforts to combine the two datasets less pressing, but motivates continued collection of our geo-fence data, since this now appears to be the only sustained data collection effort underway at these two important international freight facilities.

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