USDOT Region V Regional University Transportation Center Final Report

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TRUCK ACTIVITY AND WAIT TIMES AT INTERNATIONAL BORDER CROSSINGS

by

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TECHNICAL SUMMARY

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Truck Activity And Wait Times At International Border Crossings

Introduction

Documenting the times trucks incur when crossing an international border facility is valuable both to the private freight industry and to gateway facility operators and planners. Members of the project team previously developed and implemented an approach to document truck activity times associated with crossing an international border by using technologies that are already in use by truck fleets. The approach relies on position, navigation, and timing (PNT) systems in the form of on-board GPS-enabled data units, virtual perimeters called geo-fences that surround areas of interest, and a mechanism for data transmission. The project team has been teaming with a major freight hauler whose trucks regularly traverse two of the busiest North American freight border crossings – the privately owned Ambassador Bridge, connecting Detroit, MI, and Windsor, ON, and the publicly owned Blue Water Bridge, connecting Port Huron, MI, and Sarnia, ON– to determine times associated with the multiple activities associated with using the facilities at these border crossing sites.

In the study reported here, additional data were collected for future analysis, and previously collected data were processed to determine truck queuing times immediately upstream of the primary inspection facilities at the Ambassador Bridge (AMB) and Blue Water Bridge (BWB) facilities in both the Michigan-to-Ontario (MI-ON) and Ontario-to-Michigan (ON-MI) directions, the times trucks spent in inspection at the facilities in each direction, and the times trucks spent traversing surface streets in Windsor, ON, after exiting or before entering the Ambassador Bridge facility. (Little border crossing truck traffic uses surface streets in Detroit, Sarnia, or Port Huron, so these areas were not considered for surface street analysis.) These more recently estimated queuing, inspection, and surface street times were compared to times previously estimated in another project. Additionally, an approach to portray deseasonalized trends in queuing, inspection, and surface street times was applied to these unique historical data. Empirical investigations of the association between queuing and inspection times were conducted, and models relating queuing times to truck volumes and inspection times were developed.

Findings

An additional 35 months of geo-fence based data were collected from trucks using the Ambassador Bridge and Blue Water Bridge border crossing facilities. These data will be analyzed in the future.

Empirical results in this effort relate to processing and subsequent analysis of previously collected data. In a first effort to investigate changes over time, previously collected data were divided into a set of "old" data covering truck crossings between 09/29/2008 and 02/28/2010 and a set of "new" data covering truck crossings between 03/01/2010 and 07/24/2012. The queuing times derived from the "new" data were slightly higher than those in the "old" data for the MI-ON direction at both (AMB and BWB) bridges. Changes in the overall queuing time magnitudes did not seem as noticeable for the ON-MI direction. On the other hand, changes were observed in the times-of-day when queuing times peaked for both directions at both bridges. Of particular note was a long peak on Friday afternoons for the ON-MI directions at both bridges in the "new" data.

Slight increases in the Windsor, ON surface street times were observed in the "new" data, but the "new" and "old" time-of-day patterns were remarkably similar. Both the "new" and "old" data revealed strong time-of-day peaks that are consistent with expected overall vehicular peaking patterns on surface streets. In addition, larger surface street times were seen in the MI-ON (downstream) direction than in the ON-MI (upstream) direction.

Analysis of deseasonalized trends in queuing, inspection, and surface street times allowed a more continuous investigation of changes over time. Large changes in median monthly queuing times were seen across time for all but the BWB MI-ON traffic. Patterns in the trends were somewhat similar in the AMB and BWB ON-MI directions. All four bridge-directions demonstrated noticeable local minima in median monthly queuing times in January and July. Otherwise, there was little similarity across bridge-directions in monthly effects on median queuing times.

Appreciable decreases in the monthly median inspection times were seen at both bridges for the ON-MI directions, and a slight decrease was seen in the AMB MI-ON bridge-direction. No similarities were seen across bridge-directions in the monthly inspection time effects.

The changes in median monthly Windsor, ON surface street times were markedly lower than the changes in median monthly AMB MI-ON, AMB ON-MI, and BWB ON-MI queuing times. Moreover the patterns in the trends and monthly effects of median monthly surface street times in Windsor, ON, were very similar for the two directions of travel.

First-order analysis revealed a statistically significant, positive association between queuing and inspection times for the AMB MI-ON and BWB ON-MI traffic. A positive, but not statistically significant association was seen for the BWB MI-ON traffic. More detailed analysis revealed that, as expected, high queuing times for AMB ON-MI traffic were associated with high AMB ON-MI inspection times. However, the lowest values of inspection times for this bridge direction were associated with higher, rather than lower queuing times. This finding may reflect a speeding up of inspection times when AMB MI-ON queues are large. Regression models relating queuing times to inspection times and publically available, but very aggregate truck volume data demonstrated that meaningful, statistically significant relations can be produced using the unique data being collected with the geo-fence approach and judicious use of the publicly available truck volumes data.

Recommendations

The empirical results obtained using the unique data being collected with the geo-fence approach reveal changes over time in magnitudes and time-of-day patterns of queuing and inspection times at the AMB and BWB border crossing facilities. Therefore, it is recommended that monitoring program be established to document and update queuing and inspection time trends for planning purposes and causal investigations at these and other important international truck border crossings.

Little change was seen over time in the magnitudes or patterns of Windsor, ON surface street times. However, the ability to reveal meaningful time-of-day patterns indicates that geo-fences could be used with truck "probe" data to monitor surface street conditions for planning purposes and causal investigations.

The meaningful and generally statistically significant results obtained when pairing queuing and inspection times and when modeling queuing times as a function of inspection times and publicly available truck volumes motivate the use of these data to develop relationships that can be used for comparative purposes or to investigate the effects of infrastructure or operational changes at these international crossings.

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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.

Elsewhere (*1-3*), we described a geofence based approach we had previously developed to determine the times trucks incur in various activities when crossing international borders, as well as the implementation of the approach at two of the busiest and highest valued North American land border crossings – the Ambassador Bridge connecting Detroit, MI, and Windsor, ON, and the Blue Water Bridge connecting Port Huron, MI, and Sarnia, ON. 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 geofence, the coordinates of which are communicated remotely to the truck units. By designing the coordinates of the geofences so that the boundaries correspond to strategic locations, the truck times associated with multiple activities can be determined. Our implementation allowed us to produce unprecedented distributions of truck times at these border crossing facilities (*1,2*).

In the study reported here, we collected additional data for future analysis and processed previously collected data to determine truck queuing times immediately upstream of the primary inspection facilities at the Ambassador Bridge (AMB) and Blue Water Bridge (BWB) facilities in both the Michigan-to-Ontario (MI-ON) and Ontario-to-Michigan (ON-MI) directions, the times trucks spent in inspection at the facilities in each direction, and the times trucks spent traversing surface streets in Windsor, ON, after exiting or before entering the Ambassador Bridge facilities. (The geofences were not designed to capture surface street times in Detroit, MI, Port Huron, MI, or Sarnia, ON, where trucks using the border crossing facilities primarily travel on freeways.) Other data collected will be used in future efforts.

After briefly summarizing the data collection and data processing efforts in Section 2, in Section 3 we compare more recently estimated queuing, inspection, and surface street times to the corresponding times previously estimated. We then apply an approach to portray trends through time and determine seasonal effects in our unique historical data sets of queuing, inspection, and surface street times. We describe this effort and the results in Section 4. In Section 5, we investigate the association between queuing and inspection times and our efforts to develop models relating queuing times to truck volumes and inspection times. In Section 6, an overview of changes made to geofence boundaries and a prototype ongoing report are discussed provided.

2. Data Acquisition and Processing

We continued to collect and process truck location and timing data obtained from a fleet of private trucks using the Ambassador Bridge or Blue Water Bridge facilities with the geofences previously implemented and revised geofences. During this project's period, we collected 1,925,532 records between December 3, 2013 and October 31, 2016. Within these records, a total of 1,660,130 (~ 86% of the total) records corresponded to geofences within the Ambassador Bridge region of interest and 265,402 (~14% of the total) records within the Blue Water Bridge region of interest.

The data analyzed for this report were previously obtained between September 2008 and March 2012. These data were collected with the previously implemented geofences described in (*2*). The geofence boundaries related to the efforts reported here are the following:

- Geofence boundaries allowing a determination of the times trucks incur while traveling the roadway immediately upstream of primary inspection facilities. The distances between these geofence boundaries were approximately 0.8 miles upstream of the Canadian inspection facilities at the Ambassador Bridge (AMB MI-ON), 0.6 miles upstream of the American inspection facilities at the Ambassador Bridge (AMB ON-MI), 0.7 miles upstream of the Canadian inspection facilities at the Blue Water Bridge (BWB MI-ON), and 0.6 miles upstream of the American inspection facilities at the Blue Water Bridge (BWB ON-MI).
- Geofence boundaries immediately before and immediately after primary inspection facilities, which allow an approximation of times spent in inspection. The distances between these geofence boundaries were approximately 0.03 miles for the Canadian inspection facilities at the Ambassador Bridge (AMB MI-ON), 0.01 miles for the American inspection facilities at the Ambassador Bridge (AMB ON-MI), 0.02 miles for the Canadian inspection facilities at the Blue Water Bridge (BWB MI-ON), and 0.02 for the American Canadian inspection facilities at the Blue Water Bridge (BWB ON-MI).
- Geofence boundaries delimiting extensive travel on surface streets in Windsor, ON. The distances between these geofence boundaries were approximately 6.6 miles for trucks travelling on surface streets in both directions, *i.e.,* after departing (downstream of) the Ambassador Bridge (AMB MI-ON) and before entering (upstream of) the Ambassador Bridge (AMB ON-MI),

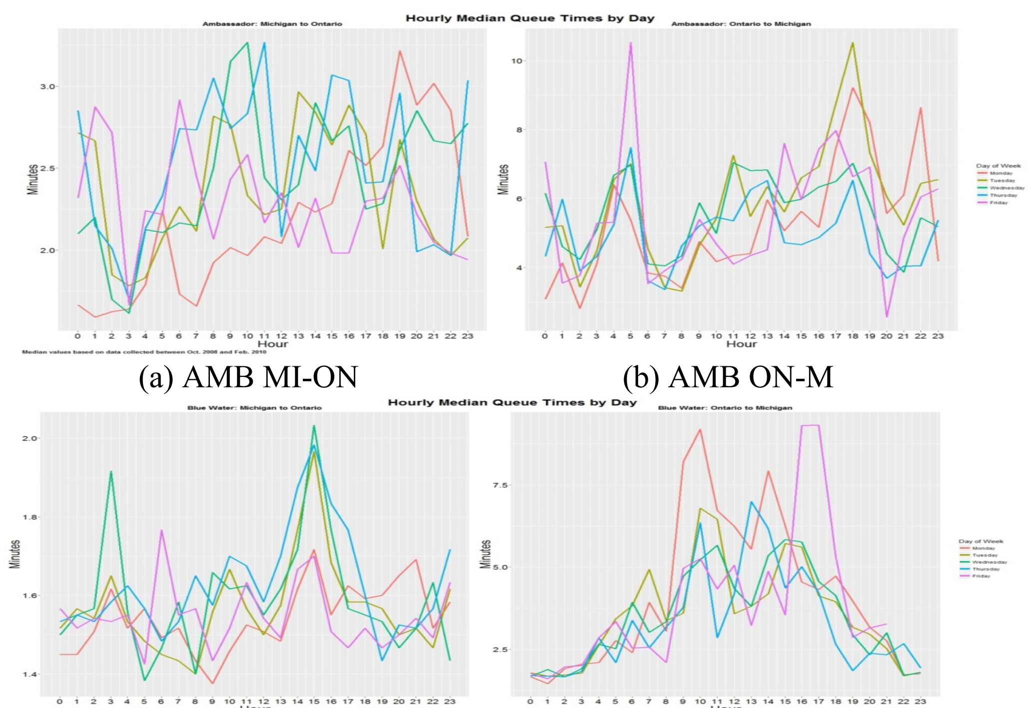
The procedure described in (*3*) was used to process the raw data into information that could be used for the analyses described in this report.

3. Comparison of Previous to More Recent Queuing and Surface Street Times

In this section, we compare queuing and surface street times determined from data we had previously processed to those determined from more recently collected data that we had not previously processed. Comparisons are made by time-of-day and day-of-week. We consider two sets of data: a set of "old" data, which covers truck crossings between 09/29/2008 and 02/28/2010 and which we previously processed, and a set of "new" data, which covers truck crossings between 03/01/2010 and 07/24/2012 and which we had not previously processed.

The medians of the "old" and "new" queuing time data are presented by bridge-direction in Figure 3-1 and Figure 3-2, respectively. In these figures, the median queuing times are plotted by hour-of-day and day-of-week.

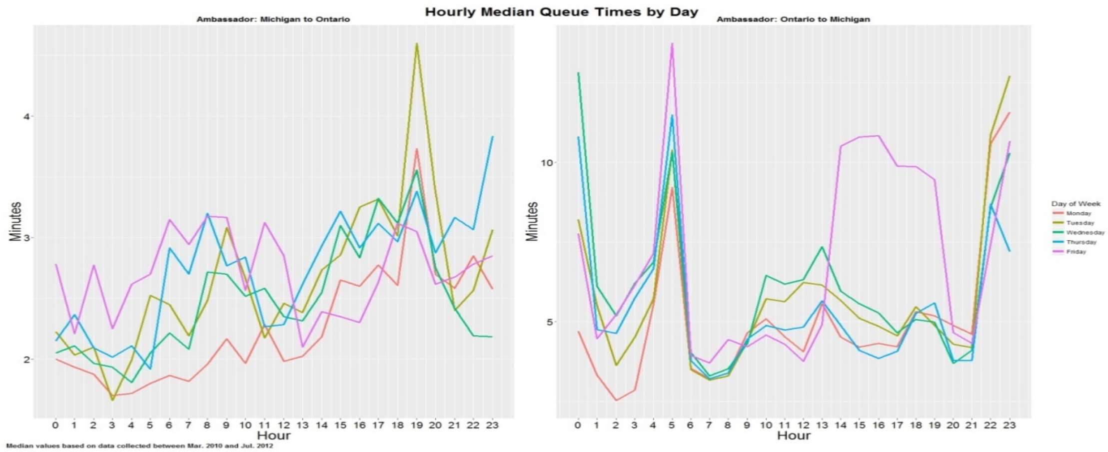
Changes in time-of-day patterns are apparent when comparing the bridge-direction plots in Figure 3-1 to the corresponding plots in Figure 3-2. Although the overall magnitudes of the queuing times are roughly the same, a much more peaked distribution is seen in the evening (19 h) in the new AMB MI-ON plots than in the old plots. On the other hand the peaks in the late afternoon (17 h) seen in the old AMB ON-MI plots are reduced in the new plots, and a noticeable long peak now appears on Friday afternoon (14-19 h). The early morning peaks at 3 h in the old BWB ON-MI plots are reduced, and peaking occurs at 8 h and 10 h in the new data. A peak at 9 h and 10 h in the old BWB ON-MI data is noticeable for Monday. In the new data, a noticeable morning peak occurs at 10 h and 12 h, and it occurs for all days. The long Friday afternoon peak that appears in the new AMB ON-MI direction also appears in the new BWB ON-MI results.



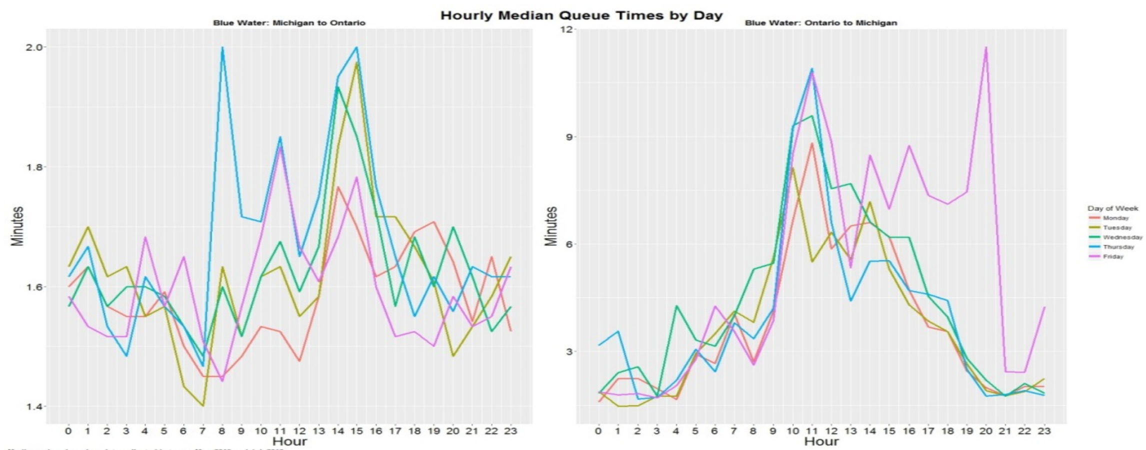
(a) AMB MI-ON (b) AMB ON-M

(c) BWB MI-ON (d) BWB ON-MI

Figure 3-1: Median queuing times by time-of-day day-of-week using “old” data (09/29/2008 - 02/28/2010) by bridge-crossing



(a) AMB MI-ON (b) AMB ON-MI

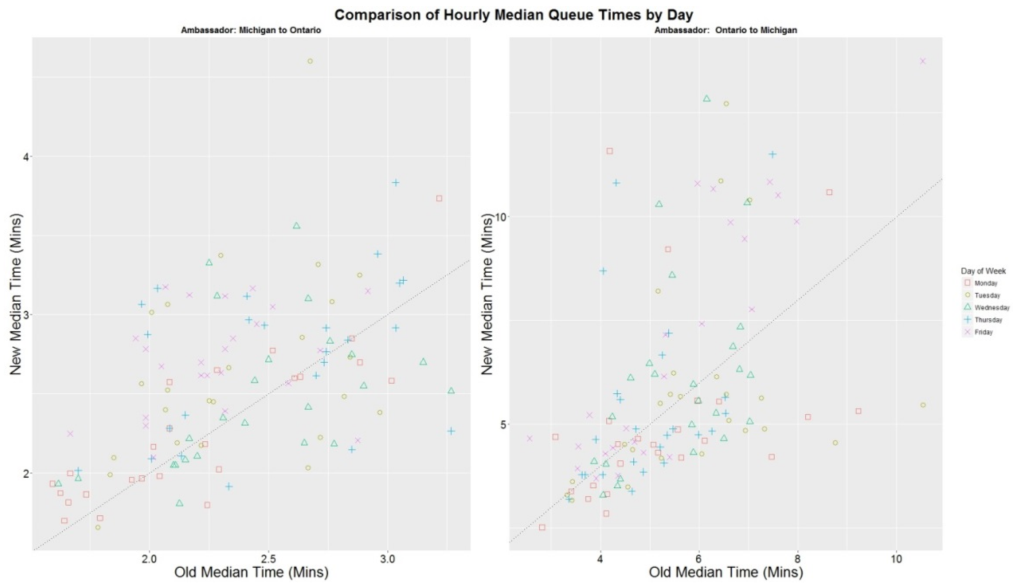


(c) BWB MI-ON (d) BWB ON-MI

Figure 3-2: Median queuing times by time-of-day day-of-week using “new” data (03/01/2010 - 07/24/2012) by bridge-crossing

To investigate changes in magnitudes, we developed scatterplots of the “old” versus “new” median queuing times, In Figure 3-3, we plot a point for each hour-of-the day that is colored according to day-of-week. There are slightly more hours where new median times are greater than old median times (above the 45^{o} line) for the MI-ON directions – 67% and 68% of “new hours” greater than “old hours” for the AMB MI-ON (Figure 3-3(a)) and BWB MI-ON (Figure 3-3(c)) bridge-directions, respectively. However, there are approximately the same number of hours where new median times are greater than old median times as hours where new median times are less than old median times for the ON-MI direction – 52% and 47% of “new hours” greater than “old hours” for the AMB ON-MI (Figure 3-3(b)) and BWB ON-MI (Figure 3-3(d)) bridge-directions, respectively. On the other hand, in the new data, there appear to be more hours with large increases in median times than hours with large decreases in median times.

We also investigated surface street times in Windsor, both because of the interest in improving truck times in this area and to illustrate the use of the geofence approach to document performance for general traffic analysis. (Our geofences were not designed to capture times on surface streets in Detroit, Port Huron, or Sarnia, since most truck traffic – and particularly the trucks in our study – approach and depart the bridges on freeways on these sides of the crossing.) Previous results (*1,2*) show that travel time on these streets can be an important component of the time associated with a truck using the Ambassador Bridge.

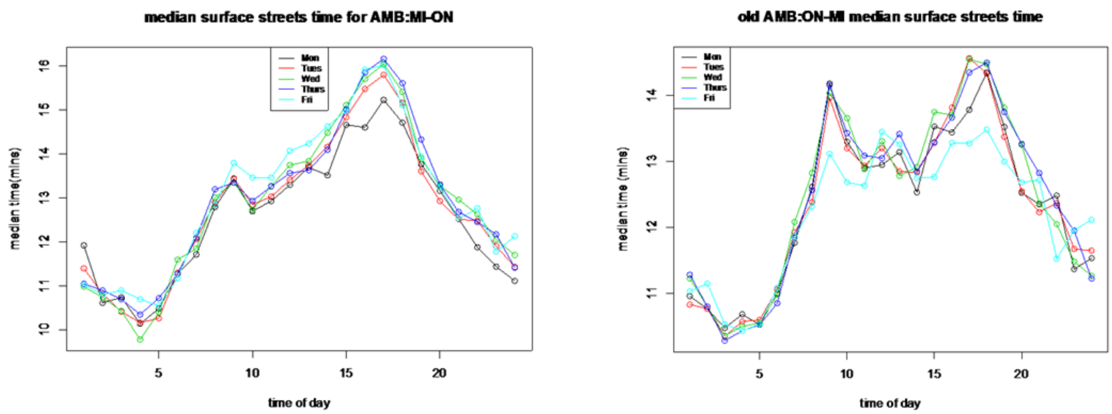


(a) AMB MI-ON (b) AMB ON-MI

(c) BWB MI-ON (d) BWB ON-MI

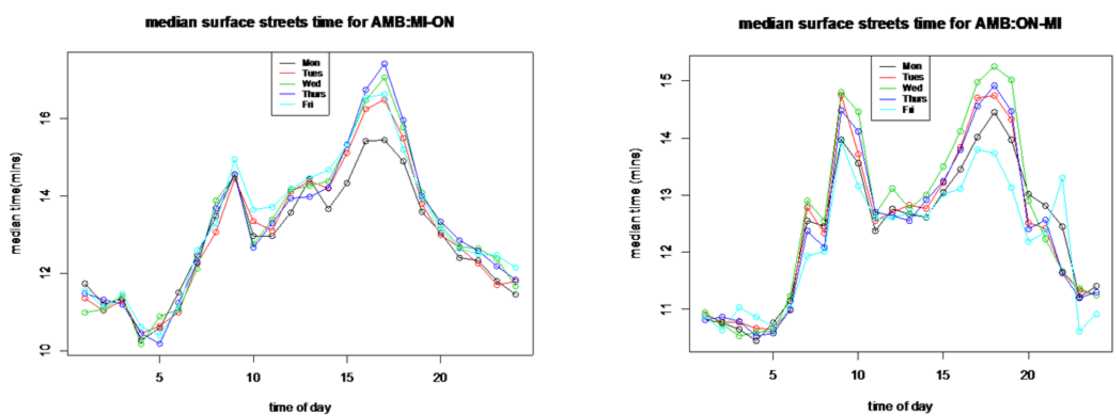
Figure 3-3: Scatter plot of "new" versus "old" median queuing times for hour-of-day and day-of-week

The medians of the “old” and “new” Windsor surface street times are presented by direction in Figure 3-4 and Figure 3-5, respectively. Again, the median queuing times are plotted by hour-of-day and day-of-week in these figures. There does not appear to be any appreciable change in the patterns between the “old” and “new” medians. Although the magnitudes of the “new” surface street medians appear slightly higher than the “old” medians, the same hour-of-day peaks and the more distinctive difference in the morning and afternoon peaks for the downstream direction occur in both data sets.



(a) Downstream (away from bridge) direction (b) Upstream (toward bridge) direction

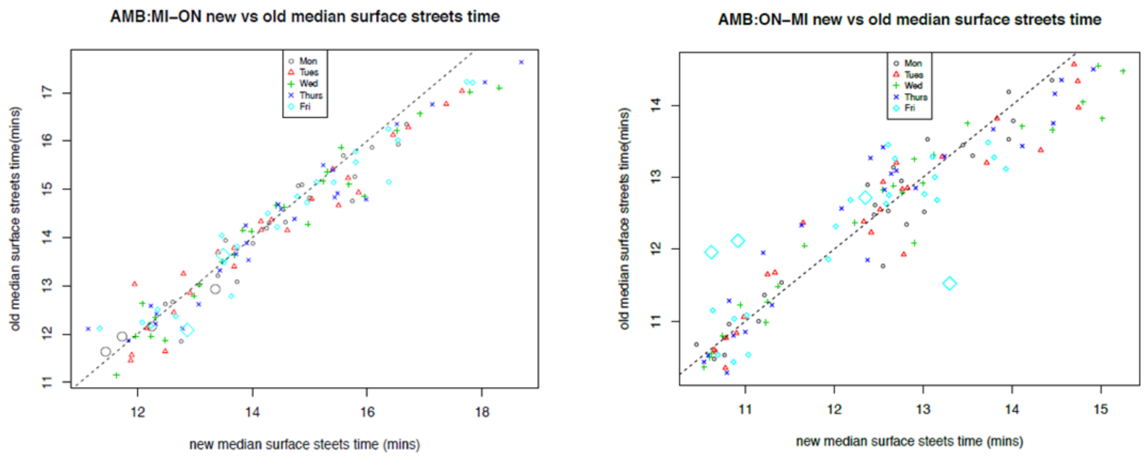
Figure 3-4: Median surface street times in Windsor, ON by time-of-day and day-of-week using “old” data (09/29/2008 - 02/28/2010) by direction



(a) Downstream (away from bridge) direction (b) Upstream (toward bridge) direction

Figure 3-5: Median surface street times in Windsor, ON by time-of-day and day-of-week using “new” data (03/01/2010 - 07/24/2012) by direction

Scatterplots of the “old” versus “new” surface street median times were also created to look at the changes between the time periods. Plots analogous to those in Figure 3-3 are presented in Figures 3-6 for the downstream and upstream directions. (It is noted that “old”/ “new” times are represented on the “x-axis”/“y-axis” in Figure 3-3 and on the “y-axis”/“x-axis” in Figure 3-6.) No marked increase or decrease in new surface street times is apparent from the plots, although the largest times appear to be associated with the new times, rather than the old times.



(a) Downstream (away from bridge) direction (b) Upstream (toward bridge) direction

Figure 3-6: Scatter plot of “new” versus “old” Windsor, ON surface street times for hour-of-day and day-of-week by direction

4. Trend and Seasonal Effect Analysis

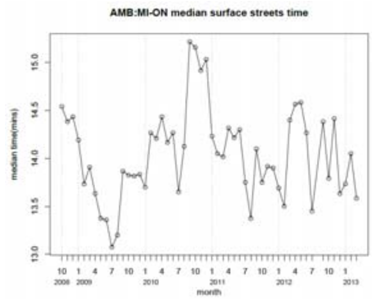
In the previous section, we looked at "snapshots" between "old" and "new" data to determine if there were noticeable changes in the queuing and surface street times. To investigate changes in a more continuous fashion, we also conducted trend analysis of the times of these activities and of inspection times between October 2008 and March 2013. This more continuous analysis was partially motivated by a discussion with Canadian officials who were interested in changes in truck times at the Ambassador Bridge (*3)*. In Figure 4-1(a), we plot the monthly median surface streets time for the downstream (AMB: MI-ON) direction. We noticed similar seasonal patterns throughout the time series, for example, lowest times in July and August. Therefore, we adopted commonly used smoothing methods to first estimate the pattern within the year (referred to as "seasonal effects") and then to eliminate these seasonal effects from the original data to produce an estimated trend that better represents changes over time. The procedure is described in the following steps, with application to the downstream direction surface street times for illustration.

Step 1. Smooth raw monthly medians with a Spencer 15-point filter, which calculates a moving average using 15 consecutive points with weights -3, -6, -5, 3, 21, 46, 67, 74, 67, 46, 21, 3, -5, -6, and -3. Figure 4-1(b) shows the raw median times and the resulting averages, referred to as the "initial trend," indicated by the red dotted curve.

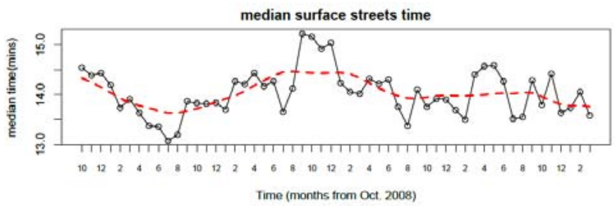
Step 2. Subtract the initial trend from the raw medians to obtain "initially detrended" data. The initially detrended results are shown in Figure 4-1(c).

Step 3. Estimate the seasonal effect by taking the mean values of the detrended medians for each month of the year. These seasonal effects are shown in Figure 4-1(d).

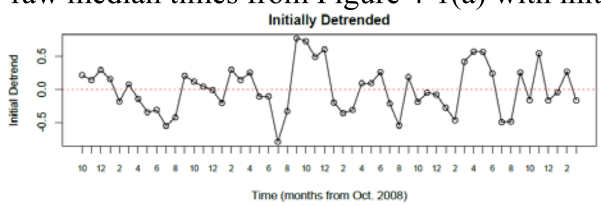
Step 4. Subtract estimated seasonal effects from the original data to obtain deseasonalized data, and repeat Step 1 one with the deseasonalized data to produce a more accurate estimated trend. The results are presented in Figure 4-1(e).



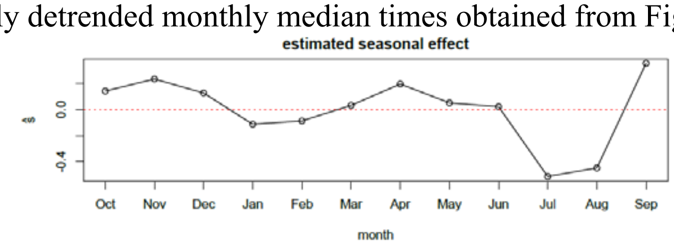
(a) Monthly raw median surface streets times



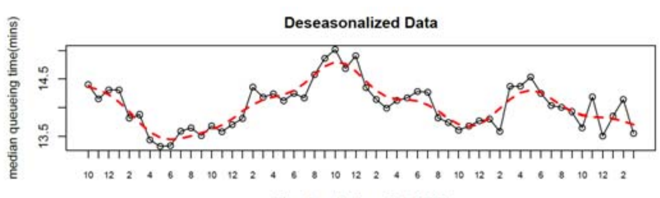
(b) Monthly raw median times from Figure 4-1(a) with initial trend curve



(c) Initially detrended monthly median times obtained from Figure 4-1(b)



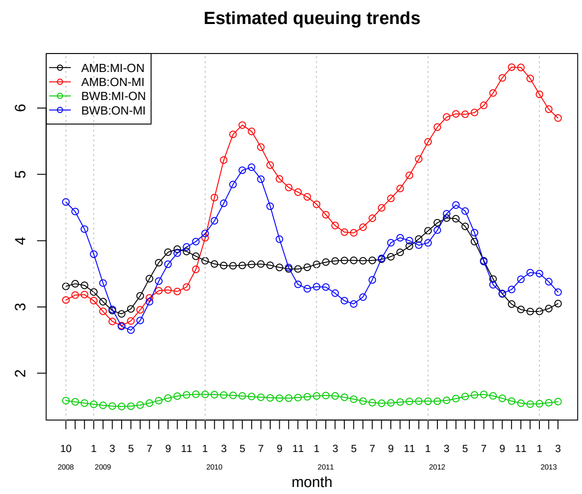
(d) Seasonal (month-of-year) effects obtained from initially detrended medians of Figure 4-1(c)



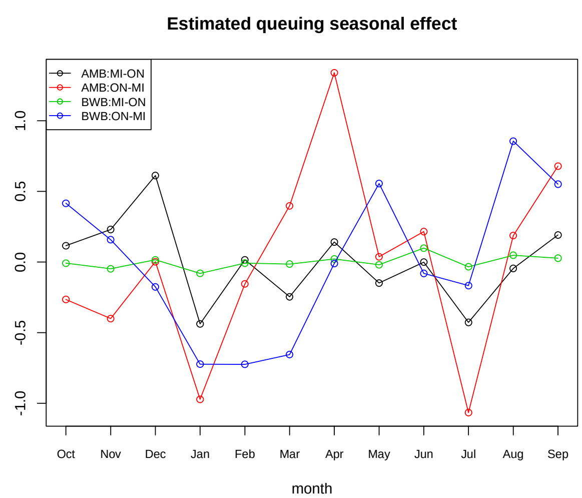
(e) Deseasonalized monthly data corresponding to data in Figure 4-1(a)

Figure 4-1: Illustration of procedure to determine trend and seasonal effects using median Windsor, ON surface streets times from Oct 2008 to Mar 2013 for downstream (AMB: MI-ON) directions; times on y-axis are in minutes

We applied this procedure to queuing time and inspection time data for the four crossing-directions. Figures 4-2(a) and 4-2(b) show, respectively, the estimated trends and seasonal effects for median queuing times for the four bridge-directions.



(a) Estimated trends of monthly median queuing times



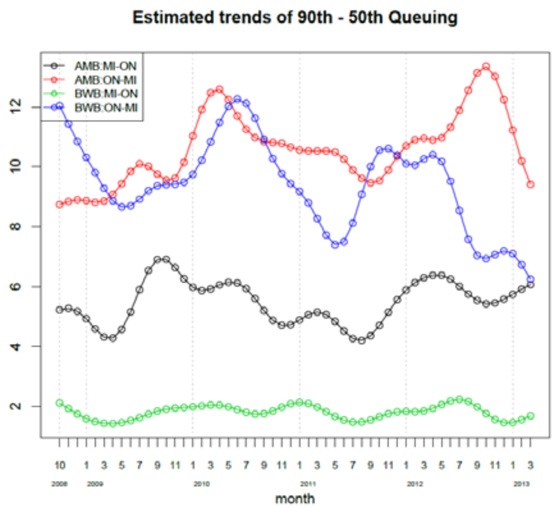
(b) Estimated seasonal (month-of-year) effects of monthly median queuing times

Figure 4-2: Estimated trends and seasonal (month-of-year) effects of monthly median queuing times for four crossing-directions; times on y-axis are in minutes

The trends in Figure 4-2(a) show important changes (more than four minutes for the AMB ON-MI bridge-direction) in median monthly queuing times over the period considered for all but the BWB MI-ON bridge-direction. Queuing times are appreciably greater in the recent months analyzed than in past months for the AMB ON-MI bridge-direction, but somewhat lower in recent months for the AMB MI-ON and BWB ON-MI bridge-directions. It is interesting to note that patterns in the AMB ON-MI and BWB ON-MI times are somewhat similar.

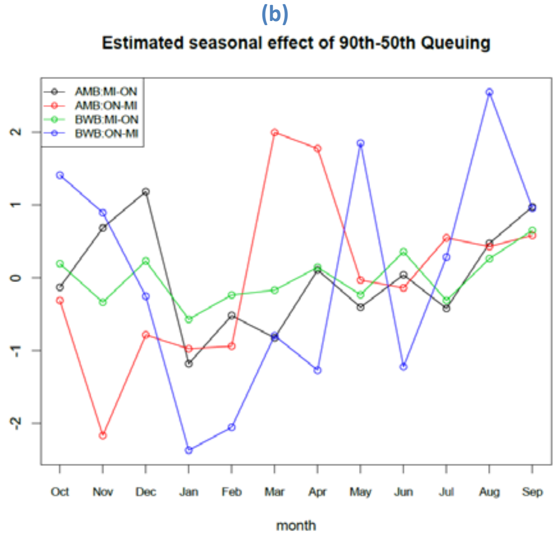
From Figure 4-2(b), it appears that all bridge-directions have local minimum times in January and July. Otherwise, there is little similarity in the patterns of the seasonal effects by bridge-direction, although there is slightly more similarity in the two sets of effects corresponding to the two AMB bridge directions than for any other pair.

The estimated trends in the monthly medians and seasonal (month-of-year) effects in the variability (90^{th} – 50^{th} percentiles) measure of the queuing times are shown in Figures 4-3(a) and 4-3(b), respectively.



(a) Estimated trends of monthly variability in queuing times

(b)

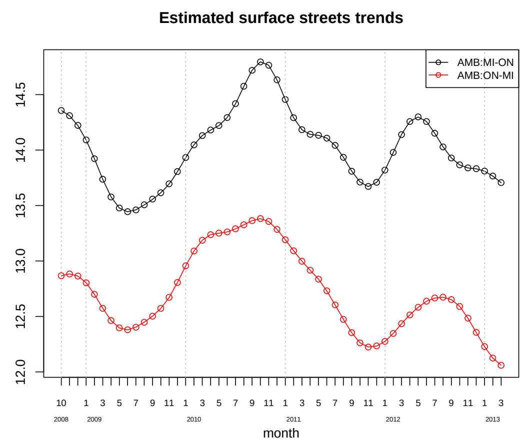


(b) Estimated seasonal (month-of-year) effects of monthly variability in queuing times

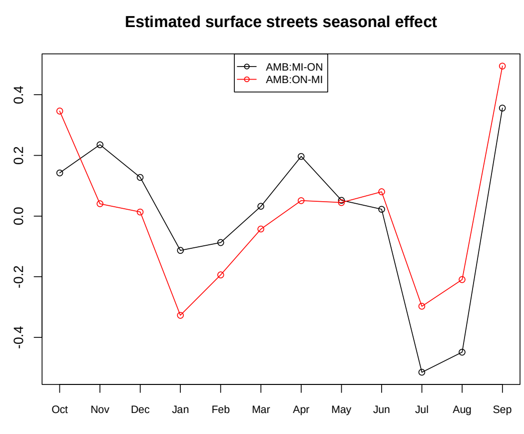
Figure 4-3: Estimated trends and seasonal (month-of-year) effects of monthly variability in queuing times for four crossing-directions; times on y-axis are in minutes

The magnitudes of the variability measures (90th-50th percentile values) seen in Figure 4-3(a) are generally greater than the medians in Figure 4-2(a) by a factor of two or more, implying that the 90th percentile queuing times are at least three times as large as the median queuing times. Variability measures vary over time, even for the BWB MI-ON bridge-direction. Although the magnitudes of the variability are different, the patterns of the variability seem more similar by bridge than by direction, until the four most recent months where the patterns seem more similar by direction than by bridge. It is also noteworthy that the BWB ON-MI variability in queuing times was appreciably greater than the AMB MI-ON variability for most of the time period, but the variabilities of these two bridge-directions became close to each other at the end of the period.

No consistency in the seasonal (month-of-year) effects across the bridge-directions is apparent in Figure 4-3(b). It is interesting, however, that the magnitudes appear much larger in the ON-MI direction than in the MI-ON direction, although this could in part be a result of the generally larger median times in the ON-MI direction.



(a) Estimated trends of monthly median surface street times



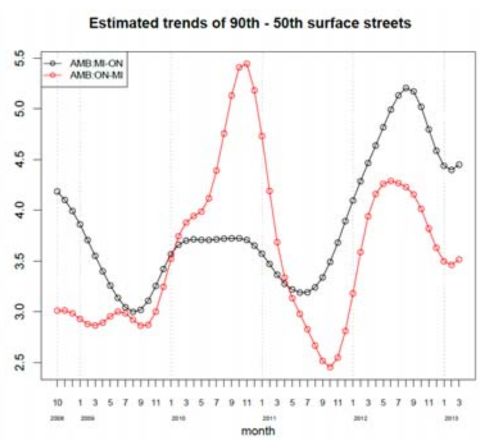
(b) Estimated seasonal (month-of-year) effects of monthly median surface street times

Figure 4-4: Estimated trends and seasonal (month-of-year) effects of monthly median surface street times in both directions in Windsor, ON; times on y-axis are in minutes

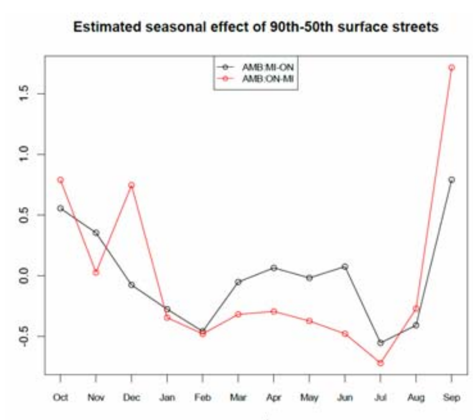
We also applied the smoothing procedure to the Windsor, ON surface street times. Figures 4-4(a) and 4-4(b), respectively, show the estimated trends and seasonal effects for median surface streets times in the two directions.

The patterns in the trend (Figure 4-4(a)) and seasonal (month-of-year) effects (Figure 4-4(b)) are very similar in the two directions, with larger surface street times seen in the MI-ON (downstream of the bridge) direction than in the ON-MI (upstream of the bridge) direction. It is also noteworthy that the magnitudes of the changes in the trends and the magnitudes of the seasonal (month-of-year) are much smaller for the surface streets (Figure 4-4) than for the queuing times (Figure 4-2).

The estimated trends in the variability (90^{th} – 50^{th} percentiles) measure of the surface street times are shown in Figures 4-5(a) and 4-5(b), respectively.



(a) Estimated trends of monthly variability in surface street times



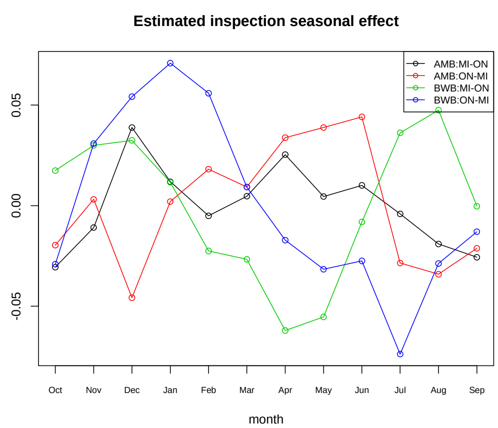
(b) Estimated seasonal (month-of-year) effects of monthly variability in surface street times

Figure 4-5: Estimated trends and seasonal (month-of-year) effects of monthly variability in surface street times in both directions in Windsor, ON; times on y-axis are in minutes

Unlike what was seen in the magnitudes of the variability measure for the queuing results, the magnitudes of the variability measure for the surface streets was much smaller than the median times, indicating much tighter distributions of times within a month. In addition, unlike what was seen when investigating the patterns for the variability in queuing times, the patterns in both the trends and seasonal (month-of-year) effects of the variability of surface street times are very similar in the two directions. It is interesting to note that the downstream (ON-MI) direction surface street variability was less than the upstream (MI-ON) direction variability except for most of 2010 and the beginning of 2011.

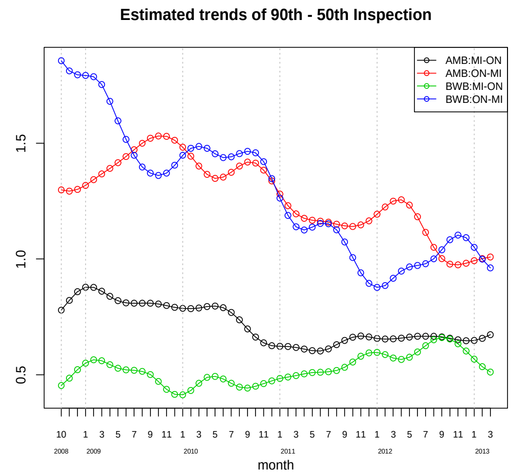
We also determined the trends and seasonal (month-of-year) effects for the medians and variability measures (90th-50th percentile) of monthly inspection times. The results for the medians are presented in Figure 4-6. The results for the variability are presented in Figure 4-7.

(a) Estimated trends of monthly median inspection times; BWB MI-ON times become artificially high beginning mid-2011 because of change in location of inspection facilities

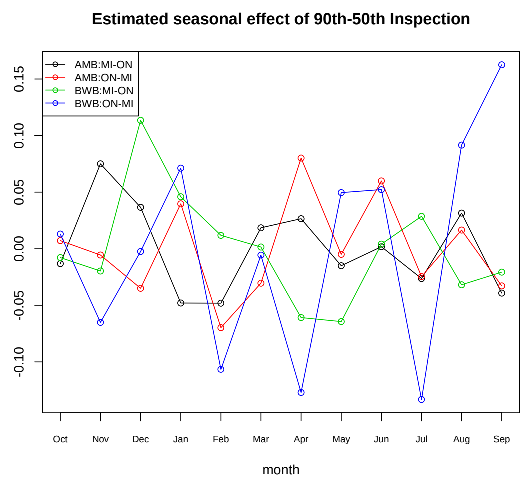


(b) Estimated seasonal (month-of-year) effects of monthly median inspection times

Figure 4-6: Estimated trends and seasonal (month-of-year) effects of monthly median inspection for four bridge-directions; times on y-axis are in minutes



(a) Estimated trends of monthly variability in inspection times



(b) Estimated seasonal (month-of-year) effects of monthly variability in inspection times

Figure 4-7: Estimated trends and seasonal (month-of-year) effects of monthly variability in inspection street times for four bridge-directions; times on y-axis are in minutes

From Figure 4-6(a), one can see appreciable decreases over time of the ON-MI (into the US) inspection time medians at the two bridges and a slight decrease in the AMB MI-ON inspection time medians between 03/10 and 06/11. The BWB MI-ON inspection time curve begins to increase appreciably in early to mid-2011. However, this increase is a result of the inspection facilities being moved on June 21, 2011 (see (*3*)). The location of the facilities resulted in a median increase of approximately 0.3 minutes to traverse the roadway before crossing the geofence boundary that determines the end of the inspection time estimation. The method used to smooth the data leads to a gradual increase in the trend data beginning before the June move date, rather than an abrupt change at that date. Subtracting the 0.3 minutes from the values after the times plateau (after 09/11) results in little change in inspection times for this bridge-direction. The trends in the variability measures (Figure 4-7(a)) are similar to the trends of the medians for the two ON-MI curves and the AMB MI-ON curve (Figure 4-6(a)). Note that the large increase in the trend of the BWB MI-ON median curve beginning 03/11 in Figure 4-6(a) is not apparent in the variability measure curve, since the effect of the changed location of the inspection facilities occurs in both the 50th and 90th percentile values and cancels out when performing the subtraction to determine the variability measure.

No pattern is evident in the seasonal (month-of-year) effects for the median (Figure 4-6(b)) or variability (Figure 4-7(b)) curves.

5. Inspection Time and Queuing Time Relations

We also investigated the relationships between inspection and queuing times. We calculated the overall medians of the queuing and inspection times by bridge-direction and then assigned each truck-trip crossing the border into one of the following mutually exclusive and collectively exhaustive groups based on the trip's joint (*inspection time, queuing time*) value:

- Group 1: (inspection time in the pair ≤ overall median inspection time, queuing time in the pair ≤ overall median queuing time)
- Group 2: (inspection time in the pair > overall median inspection time, queuing time in the pair ≤ overall median queuing time)
- Group 3: (inspection time in the pair ≤ overall median inspection time, queuing time in the pair > overall median queuing time)
- Group 4: (inspection time in the pair > overall median inspection time, queuing time in the pair > overall median queuing time)

Table 5-1: Cross-tabulations of numbers of (*inspection time, queuing time*) observations in each of four categories defined by overall median times, by bridge-direction

(a) AMB MI-ON

		Queuing Time	
		Less than or equal to median	Greater than median
Inspection Time	Less than or equal to median	14312	12715
	Greater than median	12758	14257
X-squared = 177.1351, p-value < 2.2e-16			

(b) AMB ON-MI

		Queuing Time	
		Less than or equal to median	Greater than median
Inspection Time	Less than or equal to median	13593	13717
	Greater than median	13530	13264
X-squared = 2.8022, p-value = 0.09413			

(c) BWB MI-ON

		Queuing Time	
		Less than or equal to median	Greater than median
Inspection Time	Less than or equal to median	5675	5435
	Greater than median	5268	5133
X-squared = 0.3825, p-value = 0.5363			

(d) BWB ON-MI

		Queuing Time	
		Less than or equal to median	Greater than median
Inspection Time	Less than or equal to median	5742	5077
	Greater than median	4883	5513

X-squared = 78.7515, p-value < 2.2e-16

The numbers in each group are presented in Table 5-1(a)-(d), for the various bridge-directions. If there is no relationship between queuing and inspection times, the numbers of *(inspection time, queuing time)* pairs in the four groups should be approximately evenly distributed. We used Pearson's Chi-squared test with Yates' Continuity correction to test independence. The resulting p-values along with the Chi-square statistic are presented in the tables.

The low p-values for the AMB MI-ON and BWB ON-MI results lead to rejecting the null hypotheses of independence between the sets of queuing and inspection times in favor of strong associations between the sets. Given the larger number of counts on the diagonals, the associations are positive. Therefore, for these two crossing-directions, when inspection time are shorter, queuing times also tend to be shorter, and vice versa.

Although we did not see a strong statistical relationship in the BWB MI-ON results (p-values = 0.53), the probability of the queuing time being higher than median, conditional on the inspection time being higher than median is slightly larger than the marginal probability:

$$P(queuing\ time > median\ queuing\ time | inspection\ time\ > median\ inspection\ time) = \frac{5133}{5268+5133} = 0.4935 \quad (5.1a)$$

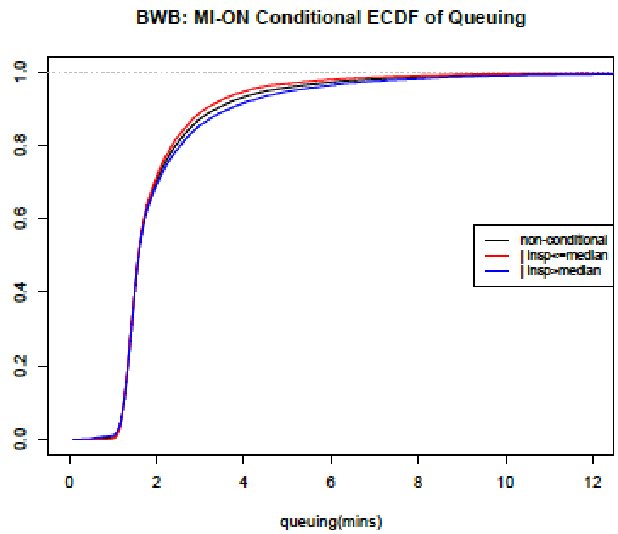
$$P(queuing\ time > median\ queing\ time) = \frac{5133+5435}{5133+5435+5268+5675} = 0.4912 \quad (5.1b)$$

However, the conditional probability was less than the marginal probability for the AMB ON-MI results:

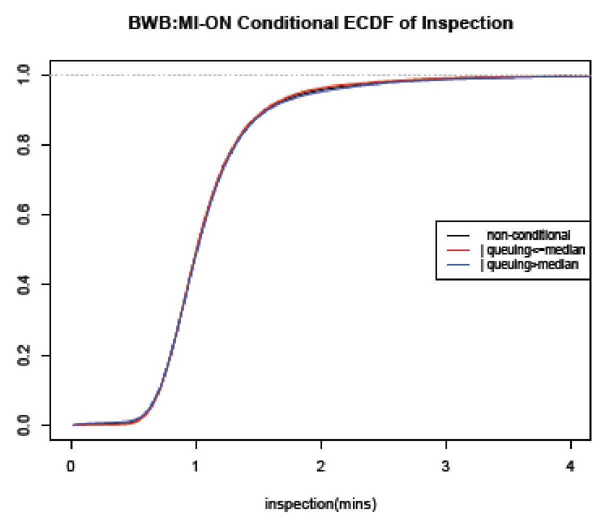
$$P(queuing\ time > median\ queuing\ time | inspection\ time > median\ inspection\ time) = \frac{13264}{13264+13530} = 0.4950 \quad (5.2a)$$

$$P(queuing\ time > median\ queuing\ time) = \frac{13264 + 13717}{13264 + 13717 + 13530 + 13593} = 0.4987 \quad (5.2b)$$

To further investigate the relationship between queuing and inspection times for the BWB MI-ON and AMB ON-MI bridge-directions, we plotted the empirical cumulative distribution functions (ECDFs) of inspection time conditional on queuing time being less than or equal to, or greater than, the median queuing time and of inspection time conditional on queuing time being less than or equal to, or greater than, the 90th percentile queuing time, and similarly for queuing time conditional on inspection time. The BWB MI-ON ECDFs are presented in Figures 5-1 and 5-2, with conditioning on the median in Figure 5-1 and conditioning on the 90th percentile values in Figure 5-2. The ECDFs of the queuing time, conditional on inspection time category are presented in Figures 5-1a) and 5-2(a). The ECDFs of inspection time, conditional on queuing time category are presented in Figures 5-1(b) and 5-2(b).

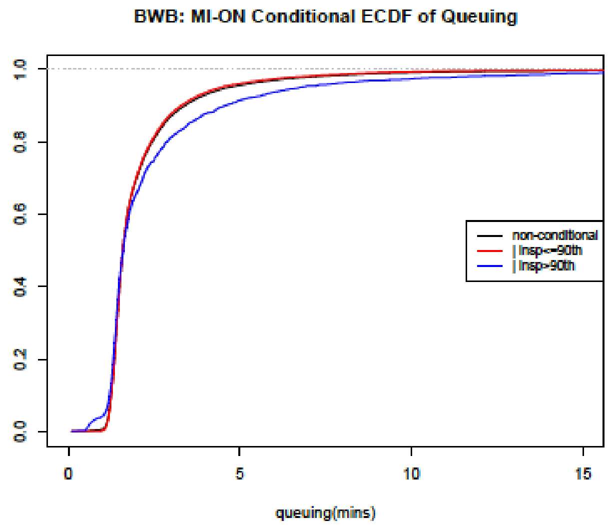


(a) ECDFs of queuing time conditional on median inspection time categories

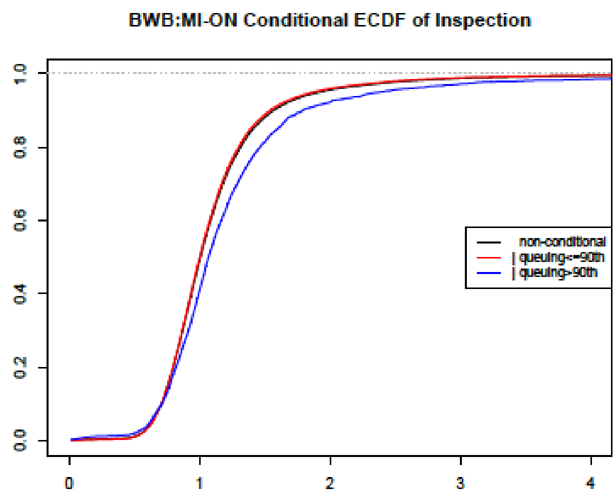


(b) ECDFs of inspection times conditional on median queuing time categories

Figure 5-1: Conditional queuing time-inspection time ECDFs based on median time categories for BWB MI-ON bridge-direction



(a) ECDFs of queuing times conditional on 90th percentile inspection time categories

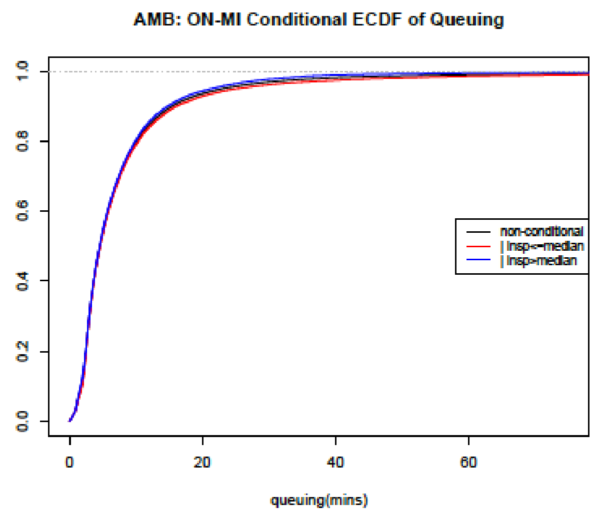


(b) ECDFs of inspection times conditional on 90th percentile queuing time categories

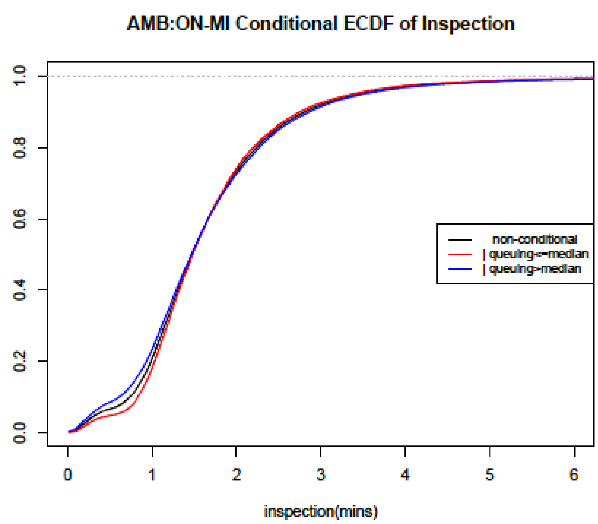
Figure 5-2: Conditional queuing time-inspection time ECDFs based on 90th percentile time categories for BWB MI-ON bridge-direction

Consistent with the numerical calculation of conditional and marginal probabilities presented in equations (5.1a) and (5.1b) above, the ECDFs in Figure 5-1(a) indicate a slight increase in queuing times when the inspection times are greater than the median. However, the effect is much more pronounced in Figure 5-2(a), where the conditioning is based on the 90th percentile inspection time. That it, the highest queuing times appear to be associated with the highest inspection times. The ECDFs of inspection times, conditional on queuing time category (Figures 5-1(b) and 5-2(b)) reinforce this association.

The ECDFs for the AMB ON-MI crossing-direction are presented in Figures 5-3 and 5-4 in a manner analogous to those presented in Figures 5-1 and 5-2 for the BWB MI-ON crossing direction.

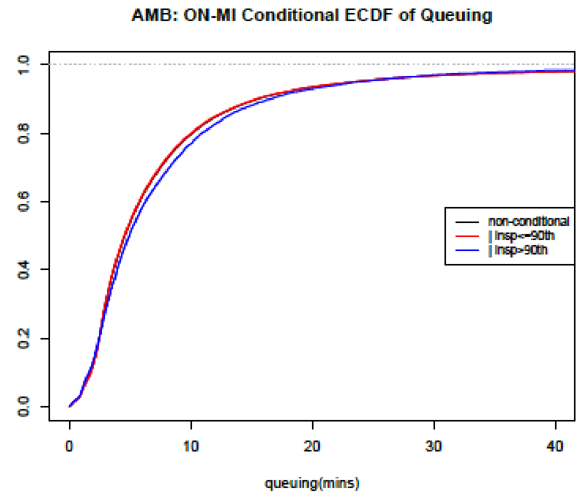


(a) ECDFs of queuing time conditional on median inspection time categories

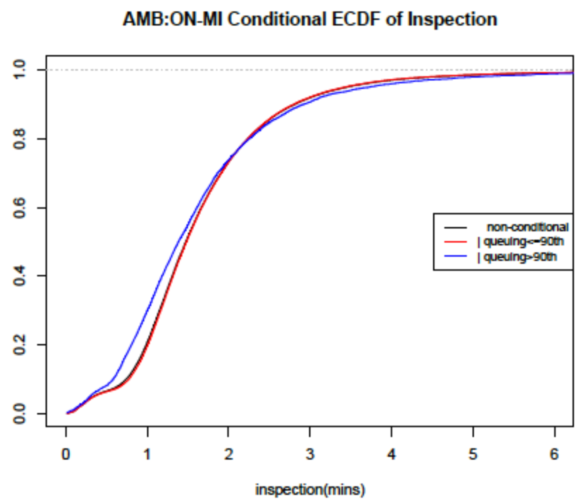


(b) ECDFs of inspection times conditional on median queuing time categories

Figure 5-3: Conditional queuing time-inspection time ECDFs based on median time categories for AMB ON-MI bridge-direction



(a) ECDFs of queuing times conditional on 90th percentile inspection time categories



(b) ECDFs of inspection times conditional on 90th percentile queuing time categories

Figure 5-4: Conditional queuing time-inspection time ECDFs based on 90th percentile time categories for AMB ON-MI crossing-direction

The ECDF of queuing time, conditional on inspection time being greater than the median inspection time, is shifted slightly to the left in Figure 5-3(a), a finding that is counterintuitive but consistent with the numerical calculation of conditional and marginal probabilities presented in equations (5.2a) and (5.2b) above for the AMB ON-MI crossing direction. On the other hand, the ECDF of queuing time, conditional on inspection time being greater than the 90th percentile inspection time is shifted slightly to the right in Figure 5-4(a), indicating that, as expected, the highest queuing times are, indeed, associated with the highest inspection times, although only slightly.

Investigating the ECDFs of inspection times, conditional on queuing times (Figures 5-3(b) and 5-4(b)) indicates that the lowest values of inspection times are associated with higher values of queuing times. This finding may reflect a speeding up of inspection times when queues are large at the AMB ON-MI direction. Additional numerical support for this association is presented in (*4*).

More detailed investigations of the relations between queuing times and inspection times, while controlling for truck volumes can be found in (*4*) and (*5*), where the latter is reproduced as Appendix A. These investigations, which were undertaken as part of this project, demonstrated that meaningful, statistically significant relations can be produced using the unique data being collected with the geofence approach and judicious use of publicly available, very aggregate (average daily, two-way) truck volumes.

6. Geofence Changes and Prototype Report Preparation

Geofence Boundary Modifications

On August 25th, 2014, modifications to certain geofence boundaries at the Ambassador Bridge were implemented to reflect the updated traffic patterns, which were changed due to the completion of the I-75 Ambassador Bridge Gateway Project. The Gateway Project made substantial changes in the approach to the Ambassador Bridge on the US side by reconfiguring traffic flow from I-75 and I-96 for all vehicles crossing into Canada. Two geofences, the “wtw-amb-usplaza-toll2CA” and “wtw-amb-usplaza-toll2CAexit,” were completely removed from the analysis as traffic did not pass through these areas any longer, as evident in Figure 6-1. Additionally, two geofences, the “wtw-amb-usplaza” and “wtw-amb-usdutyfree” were modified and renamed to “wtw-amb-usplaza-20141021” and “wtw-amb-usdutyfree-20141021”, respectively (Figure 6-1). These changes were made to capture a better representation of traffic patterns near the duty free shop and inspection booths on the US side.

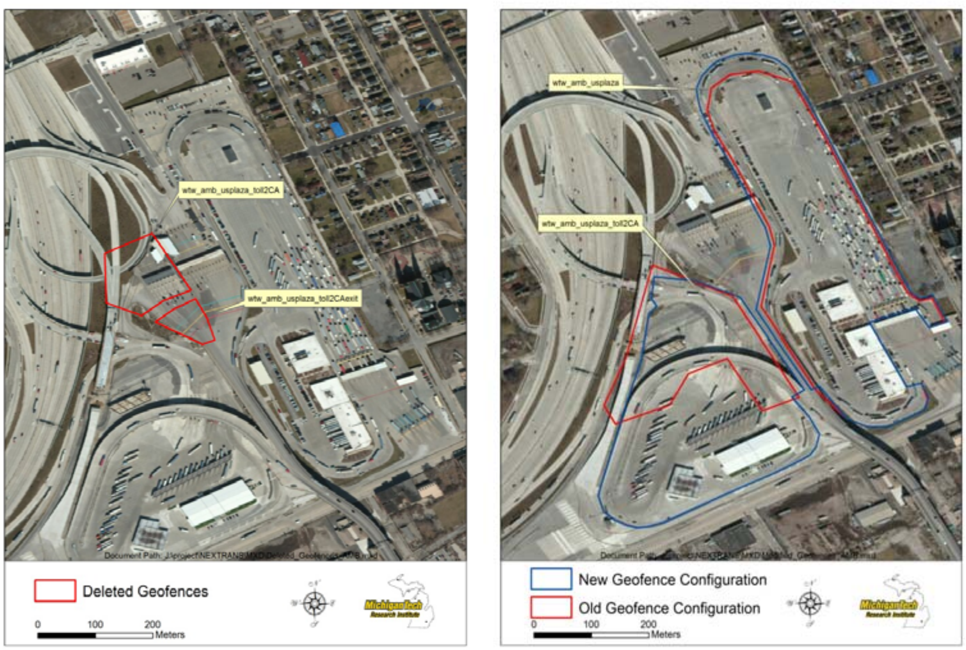


Figure 6-1: Geofence modifications at the US Ambassador plaza

Similarly, three geofences at the Blue Water Bridge were modified on the Canadian side and include “wtw-bwb-rte25-collect”, “wtw-bwb-caplazabridge”, and “wtw-bwb-caapproach”, which were changed to “wtw_bwb_rte25_collect_20141021”, “wtw_bwb_caplazabridge_20141021”, and “wtw_bwb_caapproach_20141021”, respectively (Figure 6-2).

Figure 6-2: Geofence modifications at the Canadian Blue Water Bridge plaza

Adjustments were also made to reflect changes in ramp alignments and the location of the primary inspections booth. The change in the location of the inspection booth was pin-pointed to June 20th – 22nd, 2011 by creating a shapefile based on the GPS locations of truck pings on those days. As Figure 6-3 illustrates, on June 20th, trucks entering Canada are using the old primary inspection booths. On June 21st, some trucks are seen using the old primary inspection booths as well as the new booths. Finally, on June 22nd, all trucks are seen using the new primary inspection booths, with virtually none using the now closed booths.

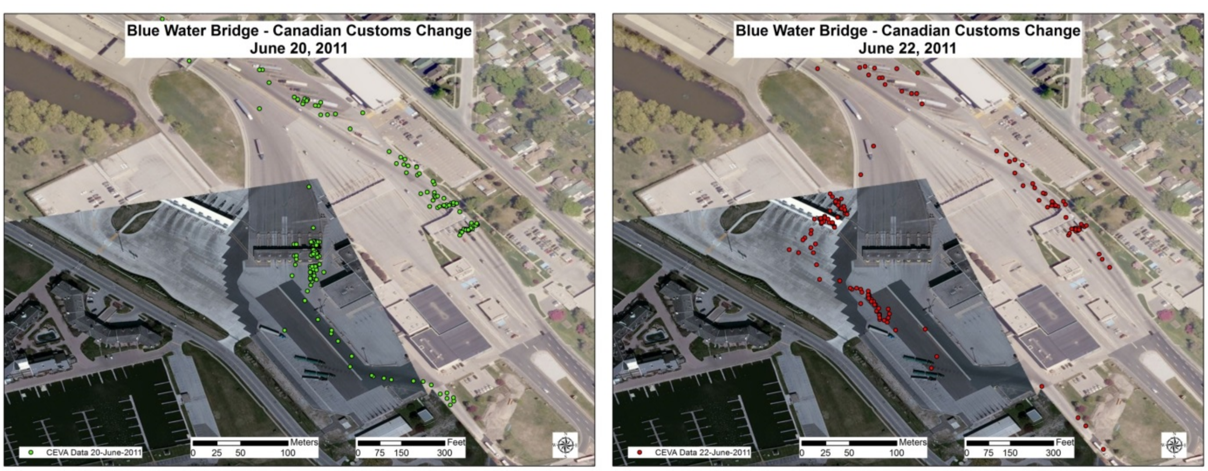
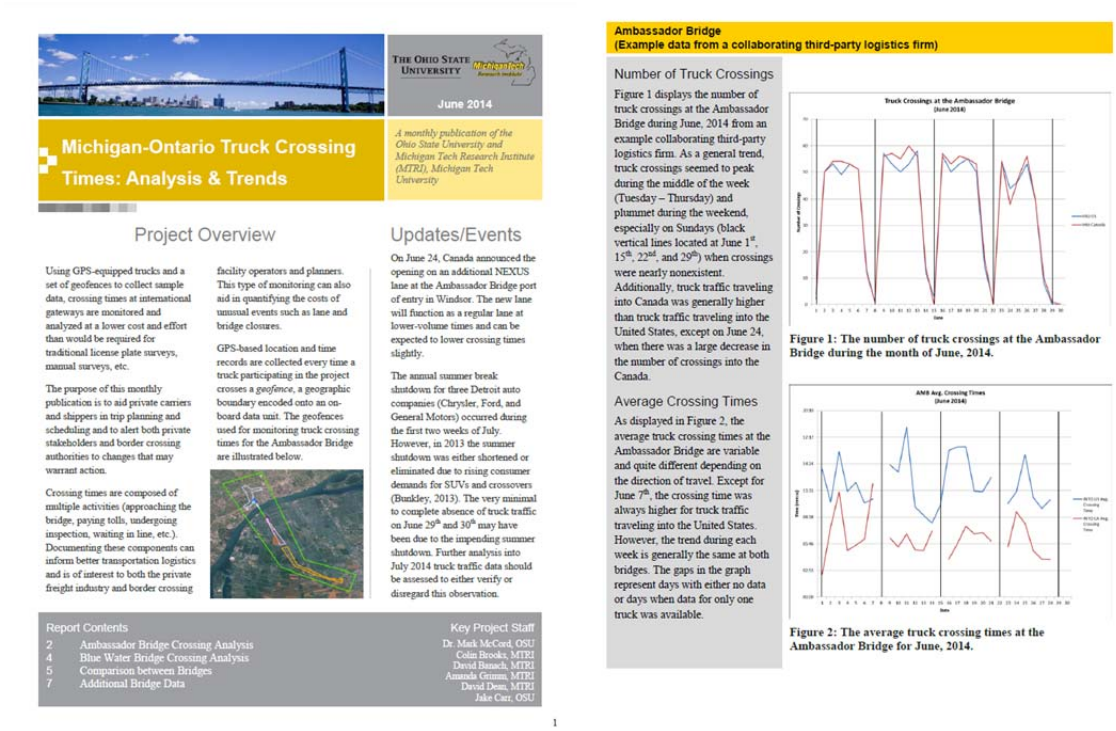


Figure 6-3: Canadian customs venue change was tracked via truck GPS data

Although the geofence changes mentioned above were made on August 25, 2014, a majority of the trucks did not implement the changes until September 25, 2014, when all trucks were issued the updated geofence boundaries. However, some trucks were using both the old and new geofence boundaries. As of November 7th, 2014 all issues were resolved, but truck data between August 25th and November 7th, 2014 were treated with caution due to the geofence transition issues experienced.

Periodic Reports

In order to provide an overview of truck crossing data and delay events at both international crossings, the project team began to develop a period report (Figure 6-4). This report highlighted truck crossing patterns and events for June 2014, including graphs and charts overviewing the number of truck crossings, average crossing times, and inspection times for both bridges. It is important to stress that the data and graphs presented in the report only reflected the small percentage (approximately 1%) of total daily freight flow traffic across both the Ambassador and Blue Water bridges. The report also served as an overview of the analyses and results created under this project for other logistic groups which may be interested in having this type of analysis conducted for their company. For example, the project team met with General Motors (GM) in Warren, Michigan on February 4, 2015 to discuss how GM could potentially implement this type of analysis to help track their freight patterns across international. The periodic report will be further developed during the following phase of the project.



The Ohio State University
Michigan Tech Research Institute
June 2014

Michigan-Ontario Truck Crossing Times: Analysis & Trends

A monthly publication of the Ohio State University and Michigan Tech Research Institute (MTRI), Michigan Tech University

Project Overview

Using GPS-equipped trucks and a set of geofences to collect sample data, crossing times at international gateways are monitored and analyzed at a lower cost and effort than would be required for traditional license plate surveys, manual surveys, etc.

The purpose of this monthly publication is to aid private carriers and shippers in trip planning and scheduling and to alert both private stakeholders and border crossing authorities to changes that may warrant action.

Crossing times are composed of multiple activities (approaching the bridge, paying tolls, undergoing inspection, waiting in line, etc.). Documenting these components can inform better transportation logistics and is of interest to both the private freight industry and border crossing facility operators and planners. This type of monitoring can also aid in quantifying the costs of unusual events such as lane and bridge closures.

GPS-based location and time records are collected every time a truck participating in the project crosses a *geofence*, a geographic boundary encoded onto an on-board data unit. The geofences used for monitoring truck crossing times for the Ambassador Bridge are illustrated below.

Updates/Events

On June 24, Canada announced the opening on an additional NEXUS lane at the Ambassador Bridge port of entry in Windsor. The new lane will function as a regular lane at lower-volume times and can be expected to lower crossing times slightly.

The annual summer break shutdown for three Detroit auto companies (Chrysler, Ford, and General Motors) occurred during the first two weeks of July. However, in 2013 the summer shutdown was either shortened or eliminated due to rising consumer demands for SUVs and crossovers (Bunkley, 2013). The very minimal to complete absence of truck traffic on June 29th and 30th may have been due to the impending summer shutdown. Further analysis into July 2014 truck traffic data should be assessed to either verify or disregard this observation.

Report Contents

2 Ambassador Bridge Crossing Analysis
4 Blue Water Bridge Crossing Analysis
5 Comparison between Bridges
7 Additional Bridge Data

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Ambassador Bridge
(Example data from a collaborating third-party logistics firm)

Number of Truck Crossings

Figure 1 displays the number of truck crossings at the Ambassador Bridge during June, 2014 from an example collaborating third-party logistics firm. As a general trend, truck crossings seemed to peak during the middle of the week (Tuesday – Thursday) and plummet during the weekend, especially on Sundays (black vertical lines located at June 1st, 15th, 22nd, and 29th) when crossings were nearly nonexistent. Additionally, truck traffic traveling into Canada was generally higher than truck traffic traveling into the United States, except on June 24, when there was a large decrease in the number of crossings into the Canada.

Truck Crossings at the Ambassador Bridge
(June 2014)

Figure 1: The number of truck crossings at the Ambassador Bridge during the month of June, 2014.

Average Crossing Times

As displayed in Figure 2, the average truck crossing times at the Ambassador Bridge are variable and quite different depending on the direction of travel. Except for June 7th, the crossing time was always higher for truck traffic traveling into the United States. However, the trend during each week is generally the same at both bridges. The gaps in the graph represent days with either no data or days when data for only one truck was available.

AMB Avg. Crossing Times
(June 2014)

Figure 2: The average truck crossing times at the Ambassador Bridge for June, 2014.

2

Figure 6-4: Samples from the example periodic mock report

7. Summary and Conclusions

We successfully collected new geofence data from trucks crossing the US-Canada border at the Ambassador Bridge and Blue Water Bridge facilities and processed a subset of these newly collected data to compare more recent queuing times at the facilities and surface street times in Windsor, ON, to corresponding times determined in the past. Slight increases in queuing times were found or the Michigan-to-Ontario directions, but peak time-of-day and day-of week periods changed more noticeably. Little systematic change in magnitudes or time-of-day and day-of-week patterns was found in the surface street time comparisons.

We also integrated the older and more recent queuing, inspection, and surface street times to conduct temporal analysis over the time span of the entire dataset. We applied commonly used methods to determine seasonal (month-of-year) effects and to smooth trends over time. Important differences were seen in the magnitudes of queuing and inspection times for most of the bridge-directions over the time period analyzed. In addition, all bridge-directions exhibited strong, negative seasonal queuing time effects in January and July. There was much less difference in magnitudes of surface street times over the time period analyzed, but the similarity in the temporal trends and seasonal effects was much greater for the surface street times than for the queuing or inspection times.

In addition, we investigated associations of queuing times with inspection times and publicly available, very aggregate truck volume data. Strong, statistically significant associations were found with meaningful directions, namely, larger queuing times were positively associated with larger inspection times and truck volumes. These results indicate the potential of using the geofence based times collected to derive meaningful, quantitative models.

Taken together, the multiple quantitative analyses undertaken in this study demonstrate the potential of using the geofence based data to develop previously unobtainable quantitative understandings of truck queuing and inspection time patterns and relations at international border crossing facilities.

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(4) Sell, N.L. *Empirical Investigations of Queuing and Surface Street Times using Truck Probe Data around International Border Crossings.* M.S. Thesis, The Ohio State University, Columbus, OH 2014.

(5) McCord, M.R., N.L. Sell, J. Zaetz, Aggregate Truck Queuing Time Relations at the Ambassador Bridge and Blue Water Bridge Border Crossing Facilities. *Compendium of the 93rd Annual Meeting of the Transportation Research Board,* 2014.

Appendix A Technical Paper Associated with this Project

Aggregate Truck Queuing Time Relations at the Ambassador Bridge and Blue Water Bridge Border Crossing Facilities

Paper presented at the 93rd Transportation Research Board Annual Meeting (2014)

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ABSTRACT

Relationships between truck queuing times immediately upstream of primary inspection stations and truck volumes and inspection times are estimated at the Ambassador Bridge and Blue Water Bridge international crossing facilities. The estimations are possible because of the recent availability of queuing and inspection time data obtained through the deployment of new technologies. Since truck volumes are available only at the monthly level, truck-level queuing and inspection time data are converted to monthly values, and aggregate relationships are estimated.

Relationships are estimated for each crossing facility when using a set of 54 months of data and when dividing the data into subsets that represent a past and a recent period. Despite the aggregate nature of the data, strong relationships are produced that exhibit increased queuing times with increased monthly truck volumes and queuing time-to-volume elasticities greater than one. Differences in estimated elasticities, depending on crossing facility and direction, are consistent with different roadway characteristics upstream of the inspection stations. Relations exhibiting increased queuing times with increasing inspection times are produced, and the estimated coefficients are large enough to reflect the impacts on queuing times of differences in U.S. and Canadian inspection times. Changes in estimated relations from past to recent periods are consistent with infrastructure projects and improvements at the crossing facilities.

INTRODUCTION

The need to ensure the security of freight entering a country and the limited infrastructure that can be constructed at international border crossings lead to truck queues at border inspection facilities. The added trip time and variability in the time associated with the queuing upstream of the inspection facilities are important components of planned trip times.

Obtaining extensive data on truck queuing at international border crossings has been prohibitively difficult in the past, but recent deployment of various technologies (*1-4*) is now producing what were previously unavailable data. However, to the authors' knowledge no relations have been estimated between queuing times and the underlying demand and service rates traditionally considered in queuing systems. Such relations would be helpful in benchmarking the performance of facilities, monitoring changes in performance over time, and supporting planning and policy decisions.

In this paper, relations between truck queuing times and demand and service rates are estimated at the Ambassador Bridge and Blue Water Bridge international crossings, two of the busiest and highest valued international commercial vehicle crossings in North America. The Ambassador Bridge is a privately owned and operated facility that connects Windsor, Ontario, and Detroit, Michigan. The Blue Water Bridge is a publicly owned and operated facility that connects Sarnia, Ontario, and Port Huron, Michigan. Truck trip-level queuing and inspection time data are obtained, but only monthly truck volumes are available. The aggregate nature of the truck volume data necessitates aggregate modeling.

The aggregate modeling structure is developed in the next section. The third section describes the truck-trip level queuing time and inspection time data obtained over a 54-month period and the aggregation of these data to make them compatible with the available monthly volume data used in the empirical study. Aggregate models for the Ambassador Bridge and Blue Water Bridge crossings are estimated in the fourth section for the entire 54-month period and for subsets of the period representing recent and past conditions. In the fifth section, results of the models are interpreted in terms of elasticity of queuing times to the aggregate volumes and the importance of inspection rates. The results also show differences consistent with different roadway characteristics and temporal changes in infrastructure. General conclusions and future work are discussed in the final section.

AGGEGRATE QUEUING MODELS

Traditional queuing functions (e.g., (*5*)) represent the time t above free-flow time, or delay, as an increasing function of arrival rate λ and as a decreasing function of capacity, which in queuing systems is related to number of service channels C and service rate μ – *i.e.,* $t \sim \lambda/(C\mu) = \lambda(1/\mu)(1/C)$. In the context of truck queuing at customs inspection stations, λ corresponds to the truck volume per time period, and C corresponds to the number of inspection booths open. The service rate μ corresponds to the truck inspection rate, and $1/\mu$, therefore, corresponds to the inspection time. Changing arrival rates, opening and closing of inspection booths, and varying inspection rates make steady–state queuing conditions unlikely. In addition, in this study, aggregate empirical data are used. Therefore, rather than using a theoretically derived queuing formula, a common power function is used, so that the queuing time relation can be written:

$$t = k\, \lambda^{\beta 1}\, (1/\mu)^{\beta 2}\, (1/C)^{\beta c} \qquad (1)$$

where β_1, β_2, and β_c are parameters of the aggregate function for their corresponding variables, and k is a parameter that incorporates factors other than arrival rate, service rate, and number of service channels. In the empirical study, only bi-directional, average daily data, which will be denoted VOL, are available for truck volumes. One can consider an unknown factor f^{vol} that scales the bi-directional VOL to an arrival rate λ during the time period of interest:

$$\lambda = f^{\mathrm{vol}}\ \mathrm{VOL} \qquad (2)$$

Given the monthly nature of the volume data, a summary measure (namely, the monthly median) of the distribution of truck trip queuing times (defined below), denoted QUE, will be used for t. Similarly, the monthly median of the distribution of individual trip inspection times, denoted INS, will be used for $1/\mu$. Equation (1) can then be rewritten:

$$\mathrm{QUE} = k\, (f^{\mathrm{vol}}\ \mathrm{VOL}\,)^{\beta 1} \mathrm{INS}^{\beta 2}\, (1/C)^{\beta c} = k\, (f^{\mathrm{vol}})^{\beta 1}\, (1/C)^{\beta c}\, \mathrm{VOL}^{\beta 1}\, \mathrm{INS}^{\beta 2} \qquad (3)$$

No data were available to determine the factor f^{vol} that converts the aggregate VOL to an arrival rate for the time-of-day period considered. Similarly, no data were available for the number of inspection booths open for the data set constructed. Therefore, (3) is rewritten as:

$$\mathrm{QUE} = k'\, \mathrm{VOL}^{\beta 1}\, \mathrm{INS}^{\beta 2} \qquad (4)$$

where $k' \equiv k\, (\mathrm{f}^{vol})^{\beta l} (1/C)^{\beta c}$ is now a constant incorporating the effects of f^{vol} and $(1/C)$, in addition to accounting for the unmodeled factors affecting the more fundamental relation in equation (1).

Equation (4) forms the basis of the empirical study. It is well known (*e.g., (6)*) that exponents in power function representations correspond to the elasticities, *i.e.,* the percent change in response variable (queuing time, here) for a percent change of the corresponding explanatory variable (volume will be of interest here). The β_1 exponent will be of interest in this paper.

EMPIRICAL DATA

Queuing models of the form presented in equation (4) were estimated at the Ambassador Bridge and Blue Water Bridge crossing facilities. Queuing and inspection times were produced from vehicle location and timing data collected with the “geo-fence approach.” Details of this approach to measuring truck times at international border crossings can be found in *(3)*, but in short, the approach relies on data records that are triggered when a truck’s Onboard Data Unit

(OBDU) crosses an electronic geo-fence segment. A geo-fence is a virtual perimeter of a physical area that defines a region of interest. The coordinates of the points that define the geo-fence are digitized and remotely transmitted to a truck's OBDU. The unit continuously checks GPS location signals against the electronic geo-fence boundary to determine if the truck has crossed a geo-fence segment. Once it is determined that the truck has crossed a segment, a data record is transmitted to a central database with the location, time, and accompanying descriptive information. A unique identifier of the truck's OBDU in the data records and additional logic are used to match records of the various geo-fence segment crossings during an individual truck trip. The time taken to traverse a roadway section can be determined by taking the difference in crossing times for the pair of geo-fence segments delineating the section.

One of the authors previously worked with a large freight hauler to specify and digitize geo-fences that allowed determination of the times trucks incurred in multiple activities associated with crossing the border at the Ambassador Bridge and Blue Water Bridge facilities *(3)*. Of interest to this study are three geo-fence segments for each of the four "crossing-directions": Ambassador US-to-Canada (AMB US-CAN), Ambassador Canada-to-US (AMB CAN-US), Blue Water US-to-Canada (BWB US-CAN), and Blue Water Canada-to-US (BWB CAN-US).

One geo-fence segment had been placed upstream of the primary customs inspection station for each of these crossing-directions at distances of, respectively, 1.0 km (0.62 mi), 1.3 km (0.81 mi), 1.0 km (0.61 mi), and 1.1 km (0.71 mi). A second segment had been placed a few meters before the primary inspection facility. Most truck queues would be contained in the roadway sections between these pairs of geo-fence segments. The differences in the recorded times when the truck crossed the geo-fences would be the times the trucks spent traversing the roadway section in these "queuing sections."

Free-flow truck times associated with traversing the queuing sections were subtracted from the difference in geo-fence crossing times to produce estimated delays, which would mostly be caused by queuing over the section. These times will be referred to as "queuing times," although the time a truck spent in a queue could be longer if the queue extended farther upstream than the segments used in this study. The free-flow time for a crossing-direction was determined from information available in the data records (*3*).

A third fence segment had been placed several meters downstream of the inspection stations. The differences in recorded times between this third fence segment and the second segment (immediately upstream of the inspection station) described above would be the times the trucks spent in the section of roadway that contained the inspection station. Because these fence segments were close together, most of the time in this section would be attributable to the time spent in inspection. To produce a refined estimate of the "inspection times," free-flow times to traverse the section of roadway between the second and third fence segments could be subtracted from the times obtained as the difference between recorded times in the geo-fence data records.

However, the free-flow time would only be a few seconds, and the times between the second and third geo-fence segments were directly used in this study as approximations of the inspection times. (The location of the Canadian BWB inspection station was changed in July 2011, which was within the time period considered for the empirical study below. This change affected the time between the second and third geo-fence segments at this bridge-direction, and the additional free-flow time resulting from this change in location was subtracted after July 2011 to maintain consistency in the inspection time approximation.)

Geo-fence data were collected on a continuous basis from a private fleet of trucks crossing the Ambassador and Blue Water bridges. The trucks were all FAST (Free and Secure Trade) approved (*7*). From 54 months of archived data (10/2008 – 3/2013), individual truck trip queuing and inspection times were produced as described above for each of the four crossing-directions. Median queuing times were determined for each hour of the day and each weekday. The AMB CAN-US median queuing times by hour-of-day and day-of-week are graphed in Figure 1.

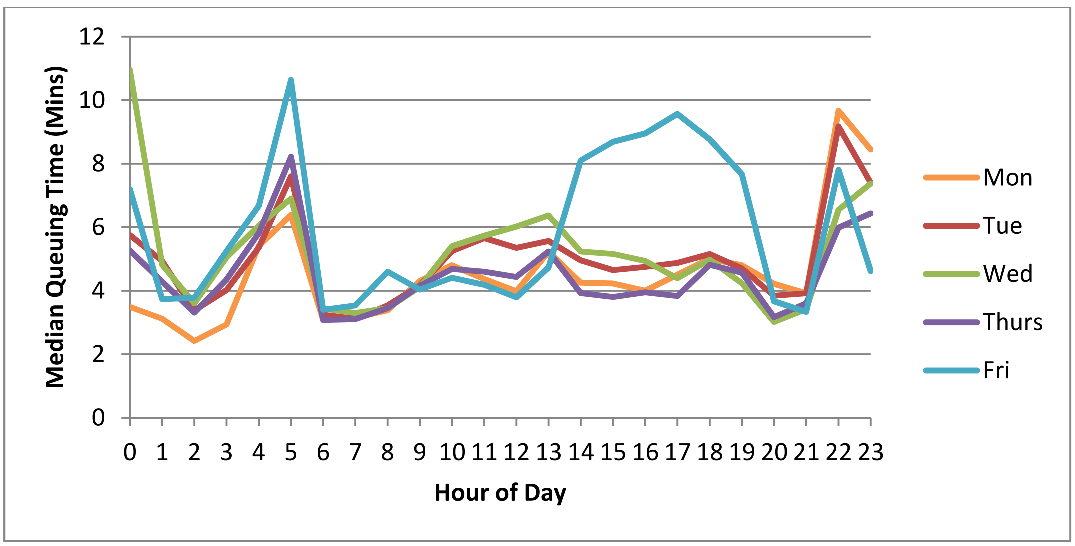


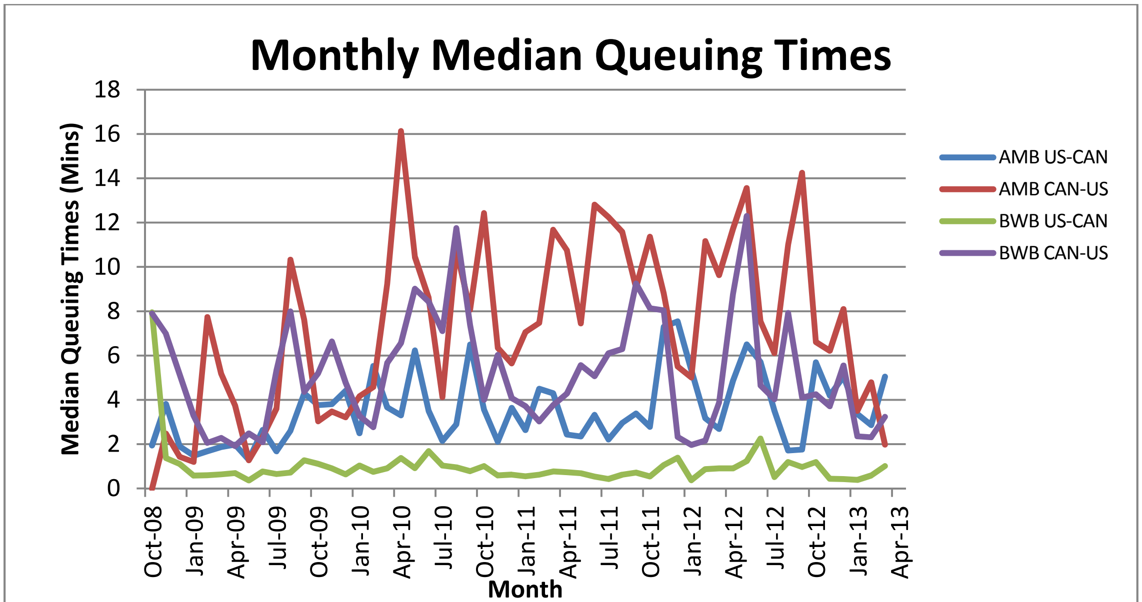
FIGURE 1 Median queuing times at Ambassador Bridge crossing for US-bound trucks by hour-of-day and day-of-week; Hour of Day represents queuing times for trucks entering inspection during that hour

In this study, queuing times in "worst" time-of-day periods were considered for analysis. In Figure 1, a peak in the queuing times is seen in hour 5 (5:00-6:00 AM), and this hour was chosen as the "worst" time-of-day period for the AMB CAN-US crossing-direction. (Late night and early morning hours had fewer observations and were not considered for analysis.) In some crossing-directions, the "peak" encompassed a few hours. Based on the time-of-day queuing patterns, the following were determined as "worst" time-of-day periods to be analyzed:

- AMB US-CAN: Monday-Thursday, 7:00-8:00 PM

- AMB CAN-US: Monday-Friday, 5:00-6:00 AM
- BWB US-CAN: Tuesday-Thursday, 2:00-4:00 PM
- BWB CAN-US: Monday-Friday, 10:00 AM–3:00 PM

From the truck trip-level queuing times, median queuing times in each of these crossing-direction periods were determined for each of the 54 months of archived data. Median monthly inspection times for the same crossing-direction periods were similarly determined. The monthly queuing and inspection medians for the analysis periods are presented in Figure 2.



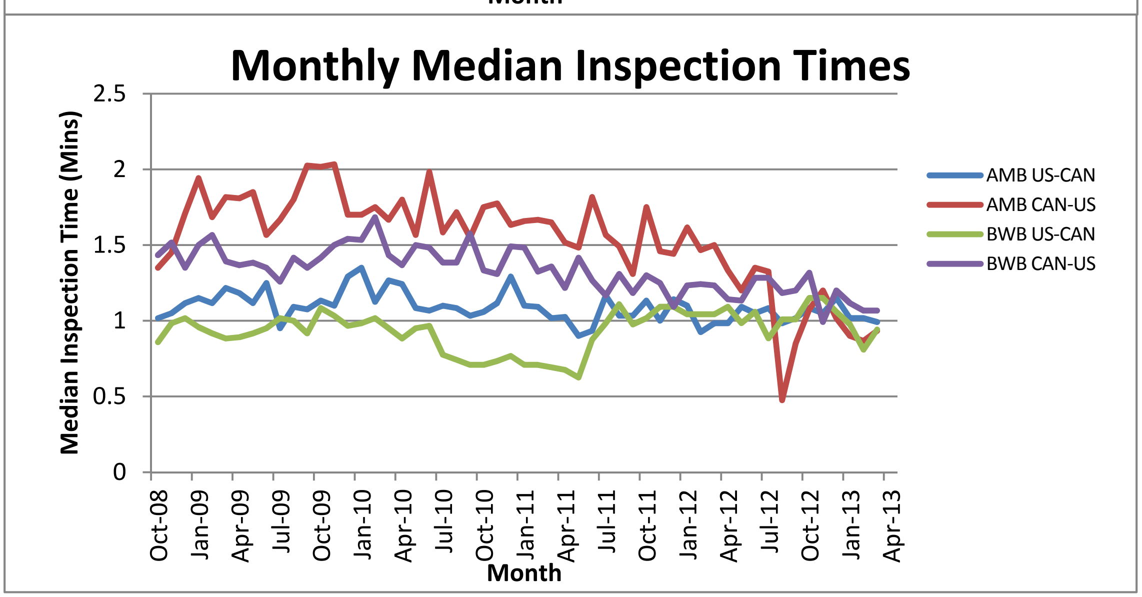


FIGURE 2: Monthly median queuing and inspection times for four

crossing-directions used in empirical study; Queuing and inspection times are based on times trucks spent in sections upstream of inspection facilities and surrounding the facilities, respectively, using the geo-fence approach described in text

Monthly truck volumes crossing the Ambassador and Blue Water Bridges for the same 54 months were available from (*8*) as two-way volumes. The monthly data were divided by the number of days in the month to produce monthly average daily truck volumes, which are depicted in Figure 3. At the monthly level, one would expect the directional split in truck traffic to be approximately 50%, but the effect of any strong deviations from this expectation, as well as the scaling of average daily volumes to the flow rate applicable to the time-of-day period analyzed, would be manifested in the constant *k'* in equation (4).

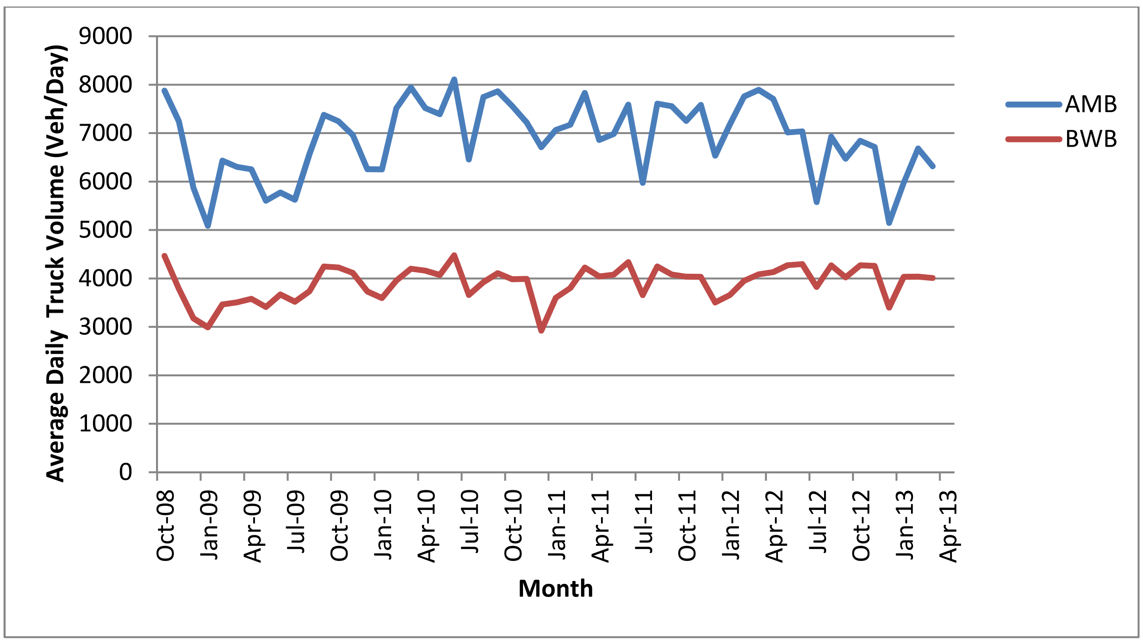


FIGURE 3: Average daily truck volume by month at Ambassador Bridge and Blue Water Bridge crossings

EMPIRICAL ESTIMATION RESULTS

Aggregate models relating the monthly median queuing times (*i.e.,* the times above free-flow times incurred in the "queuing sections" described above) during the "worst" time-of-day periods determined in the previous section to the average daily, bi-directional truck volumes for the month and monthly median inspection times for the same time-of-day periods were estimated for the AMB and BWB crossings using linear regression. The estimations were based on the structure of the aggregate queuing model presented in equation (4) and the monthly records

($QUE_{i,j}$, VOL_i, $INS_{i,j}$), $i = 1,2,\ldots,54, j = 1,2,$ where the variables are described above, subscript i indexes the month, and subscript j indexes the direction. In the following $j=1$ will be used for the US-to-Canada direction, and $j=2$ will be used for the Canada-to-US direction. (VOL is only subscripted by i, since only bi-directional volume data were available.) Taking the (natural) logarithm of both sides of equation (4) produces the linear-in-parameters specification:

$$\ln(QUE) = \ln(k')+\beta_1\ln(VOL)+\beta_2\ln(INS) = \beta_0+\beta_1\ln(VOL)+\beta_2 \ln(INS) \qquad (5)$$

where $\beta_o \equiv ln(k')$. Following typical least squares estimation notation, one can write:

$$\ln (QUE_{i,j}) = \beta_0+\beta_1\ln(VOL_i)+\beta_2\ln(INS_{i,j})+\varepsilon_{i,j} \qquad i=1,2,\ldots,54, j=1,2 \qquad (6)$$

where $\varepsilon_{i,j}$ is the "error term" representing the difference between the observed $ln(QUE_{i,j})$ and the modeled $\beta_0+\beta_1\ln(VOL_i)+\beta_2 \ln(INS_{i,j})$. Results obtained using the Equation (6)-specification revealed large temporal correlation among the error terms. To address this problem frequently encountered when using time series data, a "lag-1" $ln(QUE)$ variable was added to the specification:

$$\ln (QUE_{i,j}) = \beta_0 + \beta_1 \ln(VOL_i) + \beta_2 \ln(INS_{i,j}) + \beta_3 \ln(QUE_{i-1,j}) + \varepsilon_{i,j} \qquad i=2,\ldots,54, j=1,2 \qquad (7)$$

where the parameter β_3 reflects the association between the value of the dependent variable $ln(QUE_{i-1,j})$ in month $i-1$ and direction j on the value of $ln(QUE_{i,j})$ in the following month i and the same direction j. Based on t-test of error terms, no further temporal correlation was evidenced when using Equation (7)-specifications and similar specifications described below. Moreover, as will be seen in the empirical results, the estimated values of β_3 obtained when using these specifications were consistently positive and significantly different from zero. (No statistical significance was found on the coefficients estimated when adding $ln(QUE_{i-1,j})$ as an independent variable in additional specifications.)

As defined in equation (5), the "intercept" term β_0 equals $ln(k')$, where, as described when deriving equation (4), k' incorporates the factor that translates the bi-directional aggregate (average daily) volume to an arrival rate (units of vehicles per minute are compatible with the units of queuing time used in the study) for the direction-specific time-of-day periods considered in the empirical data and the effect of the number of inspection booths in operation The factor and number of booths would be different, depending on the trip direction. Therefore, separate "intercepts" were originally considered for the US-CAN and CAN-US directions, so that Eq. (7) is rewritten as:

$$\ln (QUE_{i,j}) = \beta_0+\beta'_0DUM_j+\beta_1\ln(VOL_i)+\beta_2\ln(INS_{i,j})+\beta_3\ln(QUE_{i-1,j})+\varepsilon_{i,j}$$

$$i=2,3,\ldots,54, \quad j=1,2 \tag{8}$$

where DUM_j is a dummy variable indicating direction, specifically, $DUM_1 \equiv 0$ and $DUM_2 \equiv 1$. In this way, β_0 is the intercept (the $ln(k')$ term) for US-to-Canada trips, and $\beta_0+\beta'_0$ is the intercept for Canada-to-US trips.

Estimation results using the Equation (8)-specification for the AMB and BWB crossings are presented in Table 1. As seen in the table, the magnitudes of the estimated intercepts are significantly less than zero. (Recall that the point estimates of the intercepts for US-CAN and CAN-US trips are, respectively, β_0 and $\beta_0 + \beta'_0$. (The t-statistic and the corresponding p-value on the β'_0 term are associated with the null hypothesis $\beta'_0 = 0$, which is equivalent to there being no difference in the US-CAN and CAN-US intercepts.) Since the intercept is equal to $ln(k')$, the large negative intercept values indicate that the k' values are much less than 1. Referring to equation (4), k' values much less than one are reasonable when β_1 values are close to one or greater, since the volumes have magnitudes in the thousands, whereas the queuing times are on the order of a few minutes.

TABLE 1 Estimation results for Ambassador Bridge and Blue Water Bridge crossings using specification in Equation (8) and observations from all 54 months

Equation (8) Results						
	Ambassador Bridge Crossing			Blue Water Bridge Crossing		
Coeff	Est Val	t-Stat	P-value	Est Val	t-Stat	P-value
β_0	-14.57	-4.38	2.9E-05	-11.13	-2.71	8.0E-03
β'_0	0.56	4.54	1.6E-05	0.95	4.09	8.7E-05
β_1	1.73	4.56	1.5E-05	1.34	2.69	8.4E-03
β_2	-0.38	-1.77	7.9E-02	0.26	0.80	4.2E-01
β_3	0.39	4.74	7.1E-06	0.40	3.80	2.5E-04
R^2	0.59			0.82		

The β_1 coefficients are positive, indicating an increase in queuing time with an increase in volume, and significantly different from zero for both crossings. The estimated β_2 coefficient for the BWB crossing is positive, indicating a positive effect of inspection time on queuing time. The corresponding t-statistic is not large, and one cannot reject the null hypothesis that the value of the coefficient is zero with confidence. However, not rejecting does not imply accepting the null hypothesis, and the positive sign of the estimated coefficient is noteworthy, given the very aggregate relationship that would be expected between median monthly queuing times and median monthly inspection times. The estimated β_2 value is negative for the AMB crossing model, which is counterintuitive. However, the estimate is not significantly different from zero, and as will be seen, subsequent estimations produce positive coefficients and also indicate that using all 54 months of data in one AMB model would be inappropriate. Finally, as mentioned above, the β_3 estimates are significantly positive, indicating strong association among month *i-1* and month *i* queuing times.

Additional estimations were conducted to investigate possible differences in the effect of volume and inspection times on the queuing times, depending on direction of the trip. Equation (8) was revised to form the following specification:

$$\ln(QUE_{i,j}) = \beta_0 + \beta'_0 DUM_j + \beta_1 \ln(VOL_i) + \beta'_1 \ln(VOL_i \mathrm{x} DUM_j) + \beta_2 \ln(INS_{i,j}) + \beta'_2 \ln(INS_{i,j} \mathrm{x} DUM_j) + \beta_3 \ln(QUE_{i-1,j}) + \varepsilon_{i,j} \quad i=2,3,\ldots,54, \quad j=1,2 \qquad (9)$$

where the variables have been defined above. The additional use of the dummy variable DUM_j (again, with $DUM_1 \equiv 0$ and $DUM_2 \equiv 1$), results in β_1 (β_2) representing the effect of volume (inspection time) on queuing time in the US-CAN direction and $\beta_1+\beta'_1$ ($\beta_2+\beta'_2$) representing the effect of volume (inspection time) on queuing time in the CAN-US direction. Better results – in terms of significance of the estimated coefficient – were produced when restricting the “lag variable” $\ln(QUE_{i-1,j})$ to have the same coefficient β_3 for both directions. To focus the analysis on the effects of volume and inspection times, only results of specifications restricting the value of the β_3-coefficent to be the same for each direction are presented.

Equation (9)-specifications were estimated for both crossings. Multiple other specifications were estimated. For example, specifications were considered that restricted the β_1 coefficient to be the same for both directions but allowed different β_2 coefficients for the two directions, and vice-versa; eliminated the *INS* variable; and restricted the intercept to be the same for each direction. Based on the results of estimating these specifications, as well as the Equation (8)- and Equation (9)-specifications, a “best” specification was identified for each of the AMB and BWB crossings. When determining the best specifications, having a single β_1 or β_2 coefficient that did not depend on the direction was desired, unless the t-statistics indicated a significant difference in the coefficients, depending on the direction.

The results of the Equation (9)-specifications and the “best” specifications for the AMB and BWB crossings are presented in Table 2. A shaded cell with no entry in the “best” specification results indicates that the variable relating to the corresponding coefficient was not used in the specification considered to be best. The results show important differences in the effects of volumes on queuing times (through the magnitude and statistical significance of the β'_1 estimate) at the AMB crossing, but not at the BWB crossing. The β'_2 estimates are not statistically different from zero at either crossing, indicating no statistically different effect of inspection time, depending on the direction. The counterintuitive negative value seen in the AMB Equation (8)-specification seems to result from the magnitude of the negative β'_2 value being greater than that of the positive β_2 value. However, neither estimate is significantly different from zero, and the estimated effects are such that the corresponding *INS* variable does not appear in the best specification for the AMB crossing.

TABLE 2 Estimation results for Ambassador Bridge and Blue Water Bridge crossings using Equation (9)- and "best" specifications and observations from all 54 months

Equation 9 Results						
	Ambassador Bridge Crossing			Blue Water Bridge Crossing		
Coeff	Est Val	t-Stat	P-value	Est Val	t-Stat	P-value
β_0	-9.42	-2.04	4.4E-02	-13.00	-2.39	1.9E-02
β'_0	-13.16	-2.10	3.8E-02	4.29	0.56	5.8E-01
β_1	1.15	2.19	3.1E-02	1.56	2.38	1.9E-02
β'_1	1.57	2.22	2.9E-02	-0.41	-0.44	6.6E-01
β_2	0.56	0.82	4.2E-01	0.13	0.33	7.5E-01
β'_2	-1.13	-1.57	1.2E-01	0.32	0.47	6.4E-01
β_3	0.36	4.53	1.7E-05	0.41	3.77	2.7E-04
R^2	0.63			0.83		
Best Model Results						
	Ambassador Bridge Crossing			Blue Water Bridge Crossing		
Coeff	Est Val	t-Stat	P-value	Est Val	t-Stat	P-value
β_0	-7.79	-1.75	8.4E-02	-11.13	-2.71	8.0E-03
β'_0	-13.07	-2.10	3.8E-02	0.95	4.09	8.7E-05
β_1	0.96	1.90	6.1E-02	1.34	2.69	8.4E-03
β'_1	1.53	2.17	3.3E-02			
β_2				0.26	0.80	4.2E-01
β'_2						
β_3	0.39	4.89	3.9E-06	0.40	3.80	2.5E-04
R^2	0.60			0.82		

To investigate possible temporal changes in the volume-inspection time-queuing time relations, specifications were estimated as above for a "recent" period and for a "past" period. The recent period consisted of the most recent 24 months for which data were available (04/2011 to

03/2013, *i.e., i=31,32,…54)*, and the past period consisted of the first 30 months for which data were available (10/2008 to 03/2011, *i.e., i=1,2,…,30*). (Choosing 24 as the number of months to constitute recent conditions was done somewhat arbitrarily but in an effort to provide a sufficient number of observations for estimation. In the final section, investigating results with other subsets of months is proposed for future work.) It is noted that the "worst" queuing time-of-day periods determined above for the crossing and direction did not change when considering recent and past conditions.

Estimated results from the Equation (8)-, Equation (9)-, and best specifications for the recent and past periods at the AMB and BWB crossings are presented in Table 3. Observations based on these results are presented in the following section.

TABLE 3 Estimation results for Ambassador Bridge and Blue Water Bridge crossings using Equation (8)-, Equation (9)-, and "best" specifications for "recent" (04/2011-03/2013) and "past" (10/2008-03/2011) periods

Equation 8 Results												
	Ambassador Bridge Crossing						Blue Water Bridge Crossing					
	Past			Recent			Past			Recent		
Coeff	Est Val	t-Stat	P-value	Est Val	t-Stat	P-value	Est Val	t-Stat	P-value	Est Val	t-Stat	P-value
β_0	-24.50	-5.97	2.1E-07	-0.44	-0.09	9.3E-01	-11.96	-2.23	3.0E-02	-16.94	-1.86	7.0E-02
β'_0	0.19	0.62	5.4E-01	0.57	3.70	6.4E-04	0.72	1.84	7.1E-02	1.28	4.06	2.2E-04
β_1	2.85	6.09	1.4E-07	0.14	0.26	8.0E-01	1.45	2.24	2.9E-02	2.01	1.84	7.3E-02
β_2	0.48	0.76	4.5E-01	0.11	0.39	7.0E-01	0.24	0.46	6.5E-01	0.64	1.14	2.6E-01
β_3	0.29	2.89	5.6E-03	0.36	2.63	1.2E-02	0.48	2.93	5.0E-03	0.25	1.69	9.9E-02
R^2	0.65			0.62			0.83			0.83		
Equation 9 Results												
	Ambassador Bridge Crossing						Blue Water Bridge Crossing					
	Past			Recent			Past			Recent		
Coeff	Est Val	t-Stat	P-value	Est Val	t-Stat	P-value	Est Val	t-Stat	P-value	Est Val	t-Stat	P-value
β_0	-16.85	-3.06	3.6E-03	-4.20	-0.52	6.0E-01	-15.50	-2.31	2.5E-02	-18.82	-1.49	1.4E-01
β'_0	-15.92	-2.12	3.9E-02	-1.13	-0.11	9.1E-01	9.06	1.04	3.1E-01	5.35	0.30	7.7E-01
β_1	1.99	3.18	2.6E-03	0.57	0.62	5.4E-01	1.88	2.31	2.5E-02	2.24	1.48	1.5E-01
β'_1	1.86	2.20	3.3E-02	0.21	0.18	8.6E-01	-1.04	-0.97	3.4E-01	-0.49	-0.23	8.2E-01
β_2	0.73	0.81	4.2E-01	2.29	1.61	1.2E-01	0.14	0.23	8.2E-01	0.60	0.94	3.5E-01
β'_2	-0.72	-0.58	5.7E-01	-2.33	-1.62	1.1E-01	0.50	0.36	7.2E-01	0.21	0.15	8.9E-01
β_3	0.27	2.82	6.9E-03	0.30	2.15	3.8E-02	0.52	3.00	4.1E-03	0.25	1.64	1.1E-01
R^2	0.68			0.65			0.83			0.83		
Best Model Results												
	Ambassador Bridge Crossing						Blue Water Bridge Crossing					
	Past			Recent			Past			Recent		
Coeff	Est Val	t-Stat	P-value	Est Val	t-Stat	P-value	Est Val	t-Stat	P-value	Est Val	t-Stat	P-value
β_0	-16.18	-3.02	3.9E-03	-0.19	-0.04	0.97	-11.96	-2.23	3.0E-02	-16.94	-1.86	7.0E-02
β'_0	-16.69	-2.27	2.7E-02				0.72	1.84	7.1E-02	1.28	4.06	2.2E-04
β_1	1.91	3.15	2.8E-03	0.11	0.20	0.84	1.45	2.24	2.9E-02	2.01	1.84	7.3E-02
β'_1	1.92	2.30	2.6E-02	0.06	3.71	0.00						
β_2	0.35	0.57	5.7E-01	0.10	0.37	0.71	0.24	0.46	6.5E-01	0.64	1.14	2.6E-01
β'_2												
β_3	0.28	2.98	4.4E-03	0.36	2.62	0.01	0.48	2.93	5.0E-03	0.25	1.69	9.9E-02
R^2	0.68			0.63			0.83			0.83		

DISCUSSION OF EMPIRICAL RESULTS

As seen from the results in Table 3, differences between past and recent estimation results are much greater for the Ambassador Bridge crossing than for the Blue Water Bridge crossing. The larger differences in the best AMB specifications could be a result of the redecking project undertaken on the Ambassador Bridge between June 2010 and May 2012 (*9*). This period would have affected over half the months considered in the recent period, but only one third of the months considered in the past period. Approximately half the bridge is included in the roadway segments upstream of the US and Canadian inspection stations over which queuing times were determined. Moreover, the changes in traffic control that would accompany a major infrastructure project would likely induce changes in the volume-queuing time relations. Indeed, the magnitudes of the AMB β_1 and $\beta_1+\beta'_1$ estimates, which relate queuing times to traffic volumes, are practically zero in the recent period. Conversely, the estimated volume-queuing time association is seen to be strong in the past period. On the other hand, the AMB intercepts β_0 and $\beta_0+\beta'_0$ increase markedly from the past to recent period; specifically, they change from -16.1 and -33.0 in the past period to -0.2 in the recent period (no distinction among intercepts appears in the recent period best specification). The increases in the intercepts are apparently compensating for the lack of a modeled effect on queuing times from truck volumes.

Even though the increased AMB intercept values in the recent period are compensating for the decreased effect of volume (and inspection time), AMB queuing conditions seem to be worse in the present period than in the past period. Queuing times based on best past and present specifications were calculated using estimated coefficients and common, independently determined combinations of *VOL, INS,* and QUE_{i-1} values in the data set. Present AMB queuing times were greater than calculated past AMB queuing times in both directions except when using extreme data combinations that would favor queuing times calculated with the recent specification, namely, combinations with very high VOL_i and INS_i values (which exploit the decreased contribution to queuing time resulting from lower β_1 and β_2 coefficients in the recent period) and very low QUE_{i-1} value (which would diminish the increased contribution resulting from the β_3 coefficient in the recent period). It would be unlikely that a low QUE_{i-1} value would precede the higher QUE_i value associated with high VOL_i and INS_i values because of the significant positive value of the β_3 coefficient. The implication is that queuing conditions, as represented by calculated times for same volumes and inspection rates, would be worse during the recent period than the past period except for very rare conditions. Such deterioration of queuing conditions is consistent with the existence of a long-lasting redecking project.

Although the best BWB specifications did not change between the past and recent periods, the β_0 and $\beta_0+\beta'_0$ values are much lower in the recent period than in the past period. The estimated β_1 and β_2 values are greater in the recent than in the past period, but a similar analysis to that conducted when comparing past and recent AMB conditions showed that queuing times calculated using best specifications and common *VOL, INS,* and QUE_{i-1} values are lower for recent conditions than for past conditions. As described previously, the intercepts account for the number of inspection booths operated, in addition to other factors. Additional Canadian inspection booths were installed near the end of the past period (*10*), (*11*), and additional US booths were installed near the beginning of the recent period (*12*). Such changes are consistent with recent intercepts being much lower than past intercepts.

The estimated β_1 and $\beta_1+\beta'_1$ coefficients are positive in all the best specifications, a finding consistent with the underlying behavior that increased arrival rates (volume) would lead to increased queuing times. Other than in the recent AMB results, which as discussed above would likely be influenced by temporally varying traffic control patterns associated with the bridge redecking project, the β_1 and $\beta_1+\beta'_1$ estimates are all also significantly different from zero. That is, estimations are indicating strong associations consistent with queuing-based expectations between the variations in median monthly queuing times in the worst time-of-day periods and variations in monthly average daily truck volumes. Moreover, all the BWB β_1 and $\beta_1+\beta'_1$ estimates, and the past AMB β_1 and $\beta_1+\beta'_1$ estimates are greater than one and, in some cases, significantly greater than one. As mentioned above, these coefficients represent the elasticity of the queuing times with respect to volumes. Elasticity values greater than one are consistent with the "greater than linear" response of queuing times to arrival rates seen in steady-state, individual vehicle queuing models. Here, the phenomenon is evidenced using aggregate data.

It is also of note that the best BWB specifications use a single β_1 value for both directions, whereas the AMB specifications show significantly different values, depending on the direction. The geometrics of the roadway upstream of the inspection stations, where the queuing times were determined, are more similar across directions at the BWB than at the AMB crossing. The roadway segment upstream of US inspection booths exhibits much more curvature than the segment upstream of the Canadian inspection station. The (significantly) positive β'_1 estimate in the past AMB specification implies a larger elasticity of queuing times with respect to volume in the CAN-US direction than in the US-CAN direction, which may be reflecting this more restricted geometry.

The t-statistics on the β_2 values are not large in any of the estimated specifications, implying that one would not be confident in rejecting the null hypothesis that the values are different from zero. However, not rejecting the null hypothesis does not imply accepting the hypothesis, and it is noteworthy that the estimated β_2 values are positive in all the specification results except for the AMB Equation (8)- and best specification results produced when using all 54 months of data in one model. In the 54-month best specification, the corresponding *INS* variable was eliminated, and in both cases, the large difference between past and present results at the Ambassador Bridge crossing would argue against using a specification including all 54 months of data. A positive β_2 is consistent with increased inspection times causing increased queuing times. Once again, considering that very aggregate data were used in the estimations, repeatedly finding a positive association is noteworthy. The estimated magnitudes are also large enough to affect calculated queuing times. Specifically, when using the estimated coefficients, the larger

US inspection times (see Figure 2) lead to calculated median queuing times that are 10-25% (depending on the crossing and period) larger in the CAN-US direction than in the US-CAN direction.

The β_3 values were all positive and statistically significant, indicating the strong positive association between queuing times in consecutive months. Specifications estimated without including the lagged *ln(QUE)* variable produced most of the same general results as those presented above – namely, stability through time of the best BWB specifications; BWB β_1 and β_2 coefficients not depending on direction; large differences in past and present best AMB specification; worse AMB queuing conditions in the recent period than in the past period; estimated β_1 values greater than one except for the recent AMB specification; a markedly larger AMB β_1 in the past period when going into the US than when going into Canada; and positive values of the β_2 estimates. However, both the magnitudes and t-statistics of the β_1 and β_2 estimates tended to be greater when not controlling for the correlation in the error terms through the use of the lagged *ln(QUE)* variable, indicating the influence of the this temporal correlation. As mentioned above, temporal correlation among the error terms was essentially eliminated after incorporating the lagged *ln(QUE)* variable.

CONCLUSIONS AND FUTURE WORK

Aggregate truck queuing time relationships have been estimated as a function of monthly average daily truck volumes and aggregate inspection times for peak queuing time-of-day periods at the Ambassador Bridge and Blue Water Bridge international border crossings, two of the busiest and highest valued crossings in North American. The reasonableness of the signs of the estimated coefficients, the correspondence of changes seen between past and recent estimates with known changes at the facilities, and the large magnitudes of the coefficients associated with truck volumes support the validity of the empirically estimated results. The ability to produce reasonable results using aggregate data is of methodological interest.

Although the very aggregate nature of the estimated models would make them inappropriate for quantitative forecasting, the empirical results are of applied interest for understanding queuing times at international border crossings. Queuing time elasticities with respect to volume are seen to be greater than one, even when using such aggregate data, indicating that median queuing times at the two international crossings, and in both directions, increased more than linearly with increases in average daily volumes. The large differences in the estimates depending on direction at the Ambassador Bridge and the similar estimates produced at the Blue Water Bridge indicate the effect of roadway characteristics upstream of the queuing facilities on the volume-queuing time relation. Although not statistically significant, the repeatedly positive estimates of the coefficient relating inspection times to queuing times obtained using the very aggregate data support the belief that the greater inspection times incurred when entering the US, compared to those incurred when entering Canada, have an effect on queuing times. The estimated relations also allowed a comparison of the deterioration in conditions likely caused by the bridge redecking project at the Ambassador Bridge crossing, while controlling for truck volume and inspection times.

This study produced reasonable truck queuing relationships at two major crossings. However, additional investigations are warranted. A $ln(QUE_{i-1,j})$ variable was used in the specification to control for correlation among the error terms in the time series data. The estimated values of the corresponding coefficient were positive and significantly different from zero, the resulting correlations in error terms were very small and not statistically different from zero when using this "lag-1" variable, and coefficients of a "lag-2" variable were found to be insignificant. Moreover, although the magnitudes of the other coefficients and their corresponding t-statistics were reduced when using the $ln(QUE_{i-1,j})$ variable, the implications of the results were the same when the variable was omitted. Nevertheless, it would be valuable to see if the implications are insensitive to other approaches that address correlation among the error terms (*13*).

Given the apparent influence of the Ambassador Bridge redecking project, it would be useful to estimate specifications using data from months not included in the project and compare results to estimated specifications using data from months included in the project. (Preliminary analysis indicates that "bridge redecking period" relations are stronger than "recent" period relations, but weaker than "pre-redecking period" relations, and that "pre-redecking period" relations were similar to "past period" relations.) It would also be valuable to conduct similar empirical studies at other border crossing facilities, both to allow comparative analyses at the facilities and to examine the stability of the results seen in this study (*e.g.,* volume elasticities greater than one, impact of differences in US and Canadian inspection times).

The queuing times used as the response variable in this study were monthly median times in time-of-day periods with greatest queuing times. It would be interesting to examine the effects of volumes and inspection times on other measures of the queuing time distributions – *e.g.,* the variability of queuing times or the upper percentile values of the distribution, which can be of equal or greater importance to timely shipping of freight – and to the effects during off-peak time-of-day periods. Finally, more meaningful results could be obtained if more disaggregate data were used in the estimations and if data on the number of inspection booths in service were available. Truck-level data were available for queuing and inspection times, but only monthly truck volume data were available.

Despite a need for further investigation, the success of the empirical estimations seen in this study is noteworthy. Estimating these relationships was possible because of the availability of queuing and inspection time data produced through the recent use of advanced technologies at border crossing facilities. With the expected continued availability of such data, additional empirical studies are expected to lead to a better understanding of truck queuing at international border crossings.

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