MANAGING THE FLOW OF COMMERCIAL TRAFFIC AT A CANADA-US BORDER CROSSING

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1. Introduction

Underlying the well publicized concerns about inefficiencies at border crossings for truck-borne Canada-US trade (see, e.g., Table 1) is the notion that increased truck processing capacity might be a remedy. However, since capacity expansion entails heavy capital and operating expenses, less expensive initiatives deserve consideration. We present a computer simulation study of one such potential initiative: *managing the arrival flow of trucks to be more in line with capacity constraints*. The study quantifies the public benefit of traffic flow management. The specific benefit is that flow management yields resource savings that can be channeled towards enhancing border security. The savings result from the fact that, in order to achieve a given level of throughput at border crossings, greater levels of flow management will lower the required capital expenditure on truck processing capacity. Society at large is not the sole beneficiary of what flow management can offer: From a trucking company's perspective, a key benefit of better flow management (which is effectively an appointment system) is that it will enable more efficient trans-border logistics via shorter times spent at border checkpoints.

Table 1: Sample of articles citing the trade sector's concerns about Canada-US border crossings

1. "Canadian Border Crossings: From Bad to Worse?": *Land Line* article posted at I.E. Canada website, April 17, 2009
2. "Border U.S. Regulatory Barriers Mean Increased Costs for Canadian Industry and Its Customers": *NB Business Journal* article posted at I.E. Canada website, April 15, 2009
3. "Stuck at the Border": (*National Post* article posted at I.E. Canada website, April 6, 2009
4. "Overlapping Security Hurting Truckers At U.S. Border, Canadian Officials Say": *Transport Topics*, March 3, 2008. , Iss. 3782; p. 6
5. "Border Bottlenecks, Regulations Top Concerns for Ontario Shippers, Carriers": *Transport Topics*. November 5, 2007. Iss. 3766, p. 1,10 (2 pp.)
6. "We need harmony in U.S. border security": *The Ottawa Citizen*. May 23, 2007. p. A15
7. "Panel: U.S.-Canada Trade Profitable, but Difficult ": *Transport Topics*. April 16, 2007. Iss. 37, p. 43, 1 pg.
8. "Smart border vision blurred.": *Truck News*. March 2007. Vol. 27, Iss. 3; pg. 44, 2 pgs
9. "Security bottlenecks snarl U.S.-Canada trade": *Reuters*, March 5, 2007
10. "FAST needs to become more transparent.": *Truck News*. February 2007. Vol. 27, Iss. 2; pg. 70, 2 pgs
11. "Border boondoggle": *Truck News*, November 2006. Vol. 26, Iss. 11; pg. A20
12. "Border security is border absurdity.": Truck News, October 2006. Vol. 26, Iss. 10, p. 36.

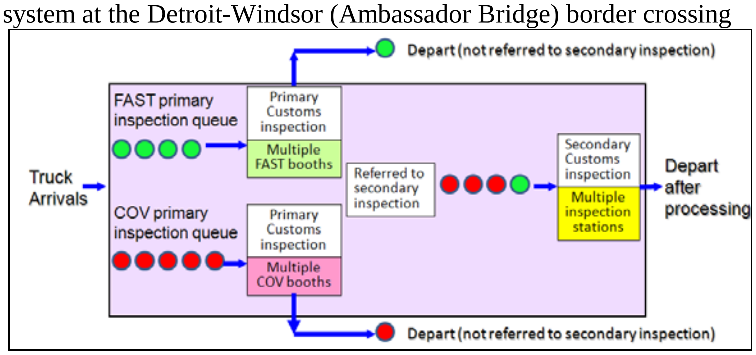
Research Context

The selected empirical context for the simulation was the Ambassador Bridge international trade corridor at the Detroit-Windsor border crossing for commercial trucks. This border crossing is of tremendous economic significance to Canada as it accounts for a third of Canada-

US trade and is the world's most active surface trade corridor. The basic structure of operations by the Customs department and other government departments (OGDs) with regulatory jurisdiction at the Detroit-Windsor border checkpoint conforms to the stylized depiction in Figure 1. An arriving truck will join one of two primary inspection queues. One queue is for trucks with shipments that the carrier, shipper, and other parties with custody or ownership of the shipment have been certified by Customs as compliant with sound supply chain security practices. North America's signature certification program is Free and Secure Trade (FAST), often dubbed FAST/C-TPAT to denote its inextricable ties to the Customs-Trade Partnership Against Terrorism (C-TPAT) initiative. The other queue (denoted in Figure 1 as COV for other commercial vehicles) is for shipments associated with at least one uncertified party; e.g., carrier, shipper, driver. On occasion, after exiting the primary queue, a truck is sent to secondary for further checks; e.g., detailed physical inspection of the cargo).

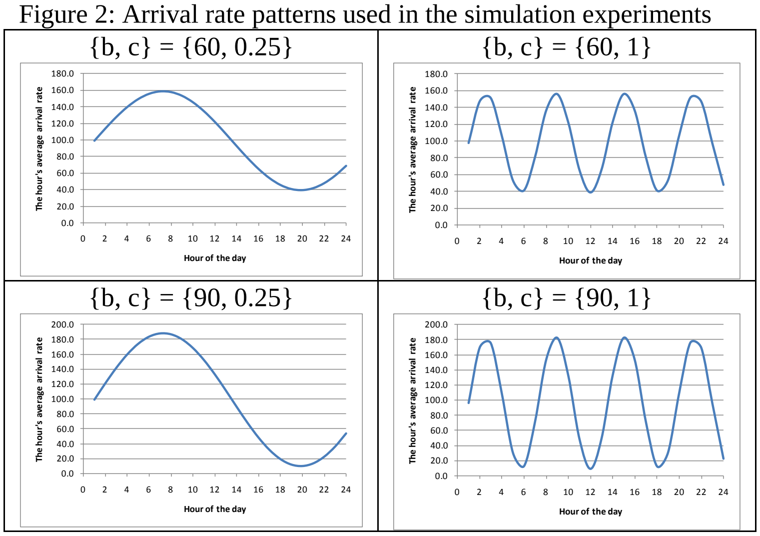
COV deliveries comprise the majority of trans-border trips and do not receive the privilege of fast-track treatment and shorter service times that are reserved for FAST trucks. Because of those particulars, traffic flow management is of much greater relevance for COV trucks. Our analysis is restricted to the first phase of checkpoint operations. That restricted analysis does not affect the insights presented here.

Figure 1: Stylized depiction of the commercial truck processing system at the Detroit-Windsor (Ambassador Bridge) border crossing



Based on data from the US Bureau of Transportation Statistics (BTS), direct observation, and anecdotal evidence, a phenomenon at border crossings is that the arrival rates of trucks vary wildly from hour to hour. To this end, we conducted the simulation by using four arrival daily (24-hour) profiles that capture that phenomenon. Specifically, we use a sinusoidal function to specify the Poisson distributed arrival rate for hour t as $\lambda_t = \lambda + b\sin\{c(t - 1)\}$, where λ is the overall average arrival rate across the 24 hours and b, $c \geq 0$. The parameters b and c depict, respectively, the function's amplitude (b = half the range between the highest and lowest arrival rate) and cycle (number of cycles $\approx 24 \times 0.5c/\lambda$ for 24 periods). The four (b, c) combinations used in the simulation were (b, c) = (60, 0.25), (60, 1), (90, 0.25), and (90, 1). The four patterns are shown in Figure 2. We used $\lambda = 100$ as the overall arrival rate for COV trucks and specify service times as Exponentially distributed with a mean of 5 minutes.

Figure 2: Arrival rate patterns used in the simulation experiments



Traffic flow management to account for capacity constraints

Implementing flow management involved first determining hourly capacity requirements (number of open primary inspection booths) subject to capacity constraint (number of primary booths available). The next step was then to revise the arrival rates to conform to the constraint. Assuming a desired utilization rate of 80% (i.e., the average percentage of time a primary inspection officer is busy should not exceed 80%) and given a processing rate of 12 trucks per hour (based on 5 minutes per truck) the required number of open booths in the t^{th} hour (s_t) is the integer rounded up value of as $\lambda_t \div (0.8 \times 12)$.

Modifying s_t to account for the number of available booths being Q, while assuring that the desired level of utilization is met involves reallocating the positive differences ($s_t - Q$) to periods having $s_t < Q$. The modification proceeds as follows. Rank each period having $Q > s_t$ in non-increasing order of period-specific utilization (approximated as $\rho_t = \lambda_t \div s_t$) then add one open primary inspection booth to each period with the R largest ρ_t values (R is calculated in (1) as the amount to be re-allocated). If fewer than R periods have $Q > s_t$ then perform another round of additions. Each subsequent round is performed using revised values for R (previous round's R minus its number of booth additions), for ρ_t, and for the number of periods with $Q > s_t$.

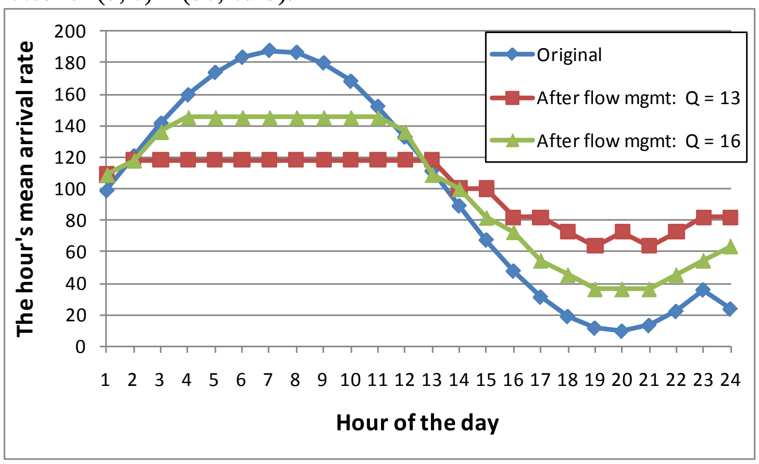
$$R = \sum_{t:s_t > Q} \left(s_t - Q \right) \qquad (1)$$

To bring the arrival rate in line with the capacity constraints involved calculating the revised period t arrival rate $\left(\hat{\lambda}_t \right)$ as:

$$\hat{\lambda}_t = \sum_{t=1}^{24} \lambda_t \times \left[\hat{s}_t \div \sum_{t=1}^{24} \hat{s}_t \right] \qquad (2)$$

This can be viewed as equivalent to using an appointment system for arriving customers, with the added feature that a customer is expected to arrive within an agreed appointment *time window* instead of at a specific appointment time. Equivalently, the number of scheduled trucks for appointment time window t is Poisson distribution with a mean of $\hat{\lambda}_t$. To assess the effect of capacity constraint for each (b, c) combination we considered values of Q ranging from a low denoted Q_{min} = to the average hourly capacity requirements (i.e., the mean of $s_1, s_2, \ldots, s_{24}$) = 11 inspection booths to high denoted Q_{max} and equal to max{s_1, s_2, …, s_{24}} in increments of 1. Figure 3 illustrates how the pattern of revised arrival rates compares with the pattern of the original arrival rates for Q = 13 and Q = 16 with (b, c) = (90, 0.25).

Figure 3: Impact of traffic flow management on hourly mean arrival rates for (b, c) = (90, 0.25).



Experiments and Results

For each (b, c, Q) combination, the COV primary inspection operation was simulated with the Arena simulation program for 200 days and replicated 30 times. The 200-day run length was found to be sufficient to yield steady state results as it was well beyond the point at which mean waiting time began to level off. Table 2 summarizes the results with respect to the effect of capacity constraint on queue time for selected factor combinations. Two inter-related observations are conspicuous in this table. First, moderate capacity constraints (Q close to Q_{max}) yield waiting time results that are just marginally worse than what would be attained without capacity constraints. For example, the mean queue times if $Q \geq 15$ are all less than two minutes greater than the mean queue time if $Q = Q_{max}$. Second, and more importantly, capacity constraints have much greater influence on system performance when the arrival pattern is highly non-stationary (high b values) and there are few cycles (low c values). This stems form the fact that fewer cycles equate to longer duration of arrival rates that are well above average. Therefore, under highly constrained capacity, primary stage inspectors cannot benefit from having frequent periods of low arrival rates (i.e., as breaks or rest periods from preceding periods of high arrival rates). The inevitable outcome is that if capacity is tightly constrained, there will be queue build-ups and longer wait times; e.g., at (*b*, *c*) = (90, 0.25) for the lowest capacity level of *Q* = 11 inspection booths.

Table 2: Mean queue time without traffic flow management

	Capacity (*Q*)				
(*b*, *c*) values	Q_{max} **= 17**	**16**	**15**	**12**	Q_{min} **= 11**
(60, 0.25)	0.67	0.78	0.86	13.36	28.57
(60, 1)	0.64	0.62	0.71	2.46	2.91

	Capacity (*Q*)				
(*b*, *c*) values	Q_{max} **= 20**	**18**	**16**	**13**	Q_{min} **= 11**
(90, 0.25)	0.55	0.64	1.91	25.20	78.88
(90, 1)	0.57	0.60	1.57	5.91	15.74

Impact of Traffic Flow Management on trucking companies

Table 3 shows how the proposed traffic flow management policy might affect queue performance for all (*b*, *c*) combinations at the lowest capacity level of *Q* = 11 inspection booths. The table shows that the policy can yield the same performance that would have been attainable in the absence of capacity constraints. Surely, the question of whether the policy would have the necessary support for its deployment would have to be considered. Ultimately, it is an empirical question because it rests heavily on the question of the extent to which arrivals are willing to shift from what might be preferred arrival periods to other periods. Table 2 presents the calculated values for the traffic shift. Table 2 shows that at (*b*, *c*, *Q*) = (90, 0.25, 11), if flow management is to achieve the stated system performance, then 36.8% of the total average volume in periods that end up with the reduced arrival rates would have to be moved to periods with lower arrival rates.

Table 3: Mean queue time and shift percentage with traffic flow management at the lowest capacity of $Q = 11$

(*b*, *c*) values	**Queue time using flow management**	**% shifted from periods of high arrival rates**
(60, 0.25)	0.66*	27.7%
(60, 1)	0.69*	26.9%
(90, 0.25)	0.64*	36.8%
(90, 1)	0.66*	34.7%

*Statistically less than or within a minute above the queue time for $Q = Q_{min}$ (using a 0.0001 significance level for the *t*-tests to compare mean wait times)

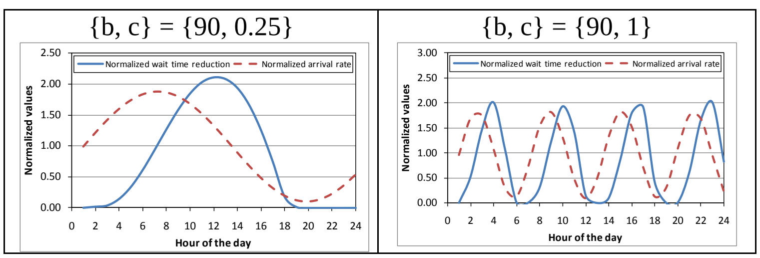
The transferred volume is not the only dimension of the change that traffic flow management requires of arrivals. Consider that, for (*b*, *c*) = (90, 0.25), there are 12 consecutive periods of above average arrival rates. Therefore, shifting arrivals from those periods to periods with smaller arrival rates could span six or more periods (note that since we assume a continuously operating system, transferring from, say, period 6 to period 24 is considered as arriving 6 hours earlier instead of 18 hours later). For (*b*, *c*) = (90, 1), the required shifting would not be as drastic as for (*b*, *c*) = (90, 0.25), even though the data are similarly non-stationary (in terms of the amplitude = 2*b*) for both scenarios. That is because (*b*, *c*) = (90, 1) has no more than three consecutive periods of above average arrival rates. Those periods are followed by and preceded by three consecutive periods of below average arrival rates. This affords more opportunity for shifting no more than one period before or after one's usual period. The inference from this is that for highly non-stationary arrival patterns with few cycles between periods of above average and below average arrival rates garnering truckers' support for flow management will require greater effort.

In reality, the efficacy of such efforts would have to be assessed with the resulting incentive in mind; i.e., the incentive of reduced wait times. In the case of (*b*, *c*) = (90, 0.25), Table 2 shows that mean wait time under extremely tight capacity constraints is 78.88 minutes (the 95th percentile was found to be 164.45 minutes) but would fall precipitously to less than a minute (0.65) under the flow management policy. Thus, the tradeoff for a trucking company would be whether the incentive of a 78-minute reduction in queue time is worth a 6-hour deviation from its usual arrival period. It is reasonable to surmise that if a trucking company is serving a just-in-time supply chain (e.g., as is typical in automobile manufacturing) such a change in its delivery schedule might be a challenging proposition. Still, it is surely possible that there are trucking companies (and the supply chains they support) with the flexibility to easily accommodate revised delivery schedules.

Figure 4 provides some insights on the incentives that different groups of arrivals might have for conforming to the requirements of traffic flow management. It considers the case of Q = 11 for (b, c) = (90, 0.25) and (b, c) = (90, 1). For each combination, the graph shows the waiting time changes that each group of arrivals would experience as a result of traffic flow management. For standardization of the findings, the wait time changes (all reductions) on the vertical axis of the graph for each scenario are normalized as multiples of that scenario's mean overall wait time reduction across all customers. Thus, a value of 2 for particular period means that trucks arriving in that period will experience a mean wait time reduction that is twice the overall mean reduction. Note that in all scenarios covered in the graphs, the mean wait time with flow management is statistically identical across all time periods. Therefore, the specific new arrival period to which a truck switches does not affect the truck's mean wait time reduction. Each graph also plots a normalized arrival rate (calculated as $\lambda_t \div \lambda$) as a dotted line to depict the connection between the hour's arrival rate and its mean wait time reduction.

Three consistent observations can be made from these graphs. First, none of the arrivals would experience an increase in waiting time: even arrivals in periods that experience increases in the average number of arrivals are not worse off because flow management helped to lower the queue backlog that they encountered in the absence of flow management. Second, trucks that originally arrived during or close to the peak periods would experience the greatest reductions in wait times: generally those that arrived immediately after the peak benefit more through the reduction in the backlog of customers from the peak periods. Third, the largest reductions are always close to 2: mostly above or just slightly under. By way of further illustration of what this third observation means, consider the factor combination of in the left panel of Figure 4. For that scenario, overall waiting time reduction was 78 minutes and the largest normalized reduction was 2.11 so some arrivals could experience a wait time reduction of approximately 165 minutes (= 78 x 2.11) or 2 hours and 45 minutes. Again, we note the tradeoff that those arrivals would have to grapple with: by how much would they be willing to adjust the schedule of their trans-border freight deliveries to avoid the unproductive outcome of being stuck in a queue for nearly three hours?

Figure 4: Hourly breakdowns of wait time reductions resulting from traffic flow management for the lowest capacity level (Q = 11)



Impact of Traffic Flow Management on the government

As Table 3 shows, the performance attainable with maximum capacity can be attained with minimum capacity *if traffic flow management can be deployed*. This is beneficial at two levels. First, this makes it possible to operate with a smaller investment in physical infrastructure because the number of inspection booths need not be as high as Q_{max}. Second, the resulting savings in spending on infrastructure expansion can be directed to support spending facilities could become available to supporting one of the government's high priorities: minimizing the risks of trans-border supply chains being conduits for or targets of harm to national security. Initiatives to which such funds could be redirected are those that are directly and unambiguously correlated with security. These include, but are not limited to training inspectors in specialized areas (biohazards, agricultural products, etc.) and investment in technologies that are effective in detecting security risks.

Conclusion

Through a queue simulation study based on the Detroit-Windsor border crossing for truck-borne trade flows, we demonstrate the benefit of traffic flow management in situations of considerable hour-to-hour variation in mean arrival rates. We quantify the benefits for trucking companies (and, by extension, their supply chain partners) and the government (border administration personnel and institutions). Notwithstanding the benefits, there are obvious challenges to making the required behavioral change. E.g., the change required of a trucking company to schedule trans-border deliveries at times that conform to traffic flow management instead of at times that reflect its current practices and/or preferences. Whether such changes are worthwhile in order to attain the benefits reported herein will require a comparison of those benefits with the sacrifices of deviating from current delivery schedules.

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