FREIGHT PERFORMANCE MICRO ANALYSIS USING TRUCK GPS DATA

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1 Introduction

Transportation industry, comprising of freight transport and warehousing, contributes to around 4% of Canada's GDP, while trucking contributes to one-third of the industry GDP (Transport Canada, 2013; Statistics Canada, 2012). Also, trucking saw higher growth (25%) during the last decade, compared to 20% overall growth of the industry (Statistics Canada, 2012). It is, therefore, important to study how efficiently truck traffic is using the transport system. Analyzing freight performance involves, among other things, calculating congestion in the form of delays or speed, but unfortunately the availability of such data are limited at best (Gordon Proctor & Associates et al., 2011). Automatic speed recorders (dual loop vehicle detectors) on highways provide speed only at certain segments of the road network. The traditional sources of freight performance data are limited to large geographic scales and are not suitable for local planning purposes (Chase et al., 2013).

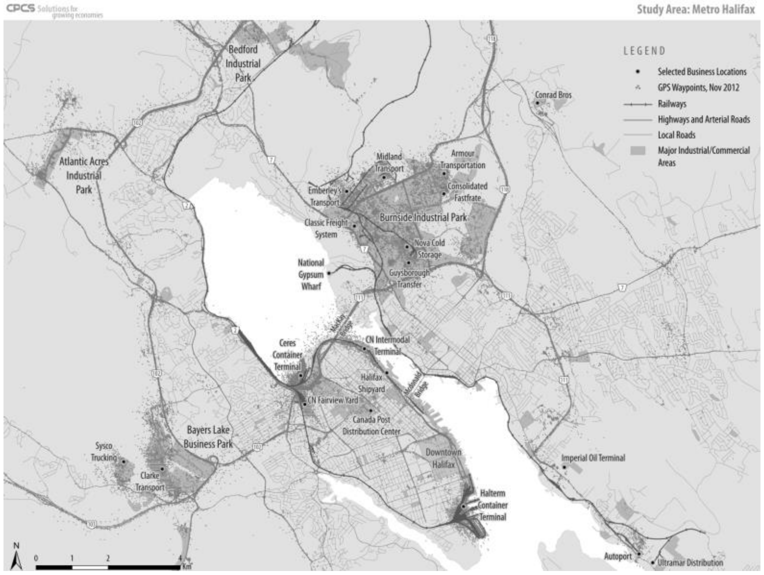
Global Positioning System (GPS) data, derived from trucks, has addressed many of these issues and data gaps, and has been increasingly used in freight analyses. Since 2002, Federal Highway Administration, in partnership with the American Transportation Research Institute, has been studying truck performance on major highways (Jones et al., 2005). Similar attempts have been made to study state level highways (Golias et al., 2012). However, there has been limited attempts, if any, in terms of looking at freight performance in urban areas. This study addresses the gap. Specifically, the study looks at how efficient the freight system is in Halifax. In this study, the focus is on both the road transport network and container operations at the Port of Halifax.

2 Study area and specific issues of interest

2.1 Study Area

The study is focused on the urban area around Halifax peninsula and Dartmouth. The major freight generators in the area are located within the Port of Halifax and across several industrial and business parks (Figure 2-1). Key generators in the port are two container terminals, Halterm and Fairview Cove (Ceres), which are served by both trucks and railways. Other important generators are the shipyard, CN's intermodal terminal, Imperial Oil's Terminal and Autoport.

Figure 2-1: Study Area



2.2 Key Issue Areas

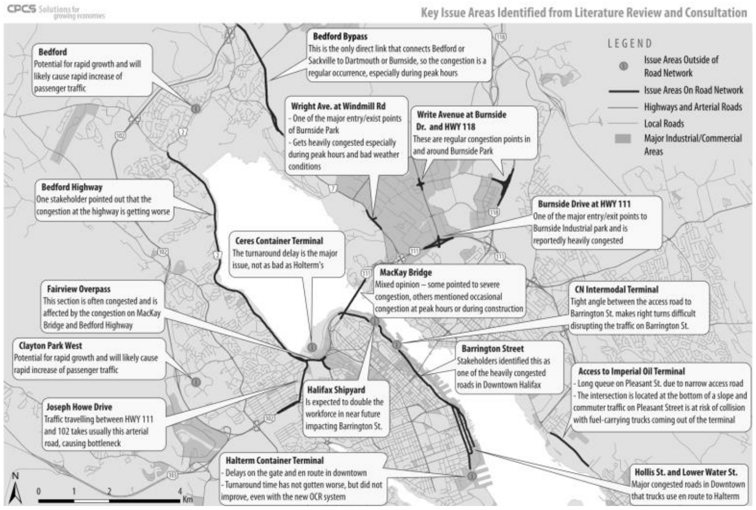
In order to gain a better understanding of the issues that have plagued truck fluidity in Halifax in recent years, we have conducted high-level consultations with industry stakeholders and did a review of studies on the subject, namely, Mary R. Brooks (2013), Opus International (2009) and MariNova (2008).

From these studies, along with stakeholder consultation, recurring issues were identified. In particular, truck fluidity issues noted centered on the following:

- Delays and slow turnaround time at the Halterm container terminal and on roads leading to it.
- Congestion on the following roads:
    - Barrington Street;
    - Bedford Bypass;
    - Mackay Bridge; and
    - the intersection of Wright Avenue and Windmill Road

While detailed results could be derived for other locations noted in Figure 2-2, we focused the analysis on the aforementioned issues.

Figure 2-2: Key Issues identified from Literature Review and Consultation



Bedford
Potential for rapid growth and will likely cause rapid increase of passenger traffic

Bedford Bypass
This is the only direct link that connects Bedford or Sackville to Dartmouth or Burnside, so the congestion is a regular occurrence, especially during peak hours

Wright Ave. at Windmill Rd
- One of the major entry/exist points of Burnside Park
- Gets heavily congested especially during peak hours and bad weather conditions

Write Avenue at Burnside Dr. and HWY 118
These are regular congestion points in and around Burnside Park

Bedford Highway
One stakeholder pointed out that the congestion at the highway is getting worse

Burnside Drive at HWY 111
One of the major entry/exit points to Burnside Industrial park and is reportedly heavily congested

Ceres Container Terminal
The turnaround delay is the major issue, not as bad as Holterm's

MacKay Bridge
Mixed opinion – some pointed to severe congestion, others mentioned occasional congestion at peak hours or during construction

Fairview Overpass
This section is often congested and is affected by the congestion on MacKay Bridge and Bedford Highway

CN Intermodal Terminal
Tight angle between the access road to Barrington St. makes right turns difficult disrupting the traffic on Barrington St.

Clayton Park West
Potential for rapid growth and will likely cause rapid increase of passenger traffic

Barrington Street
Stakeholders identified this as one of the heavily congested roads in Downtown Halifax

Access to Imperial Oil Terminal
- Long queue on Pleasant St. due to narrow access road
- The intersection is located at the bottom of a slope and commuter traffic on Pleasant Street is at risk of collision with fuel-carrying trucks coming out of the terminal

Halifax Shipyard
Is expected to double the workforce in near future impacting Barrington St.

Joseph Howe Drive
Traffic travelling between HWY 111 and 102 takes usually this arterial road, causing bottleneck

Halterm Container Terminal
- Delays on the gate and en route in downtown
- Turnaround time has not gotten worse, but did not improve, even with the new OCR system

Hollis St. and Lower Water St.
Major congested roads in Downtown that trucks use en route to Halterm

3 Methodology

3.1 Network Performance

The GPS datasets, obtained from Shaw, coordinates of trucks at different time intervals. Each record in the database contains a company ID, a truck ID, geographic coordinates and a time stamp. We call these records *waypoints*.

Transport Canada (TC) provided CPCS with GPS data for 13 months, from November 2012 to November 2013. Due to the bulk nature of the data and the necessary computation time to undertake any analysis, we focused our analysis on two months, November 2012 and November 2013. These also happen to be the only two months where seasonal factors were least likely to have an impact.

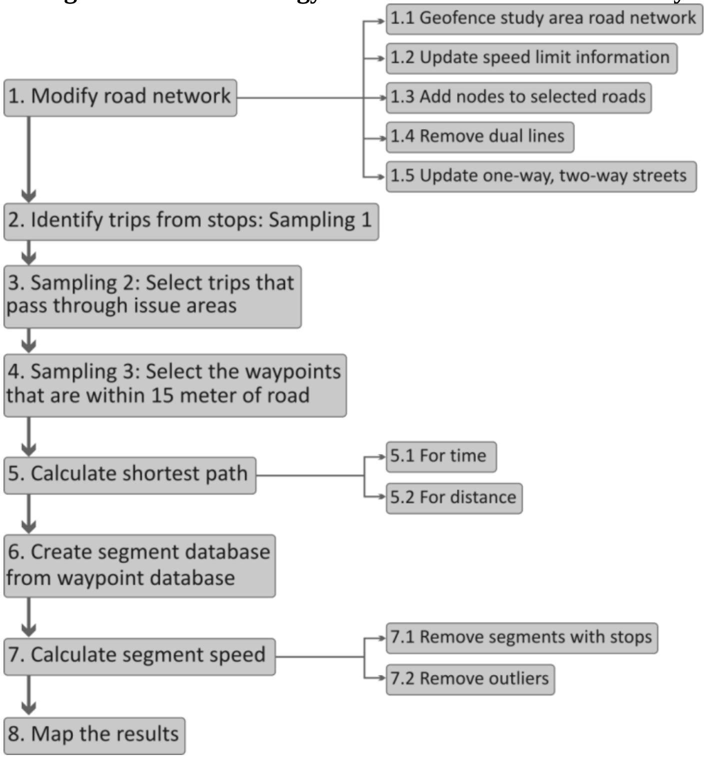
The dataset is plagued by two issues. First, the ping rate (i.e. time between two waypoints) is inconsistent and can vary from a fraction of a second to an hour. Second, some of the waypoints are far off the road network, sometimes in the middle of a lake. Both issues had to be taken into account in developing the analytical methodology (Figure 3-1) as illustrated in the following sections.

3.1.1 Modify Road Network

We used the National Road Network (NRN) file, tenth edition, obtained from the GeoBase portal[i] as the base road network. Since the analysis is at the scale of an urban area, we selected the road network for Halifax and its surrounding area only. In order to maximize sample size, however, we also included highways outside of the urban area.

The NRN does not contain speed limit information, information essential to our analysis. We thus had to derive a speed limit based on the NRN road hierarchy. For example, we used speeds of 100 kilometers per hour (kph) for expressways, 80 kph for secondary highways, 60 kph for arterial roads, 50 kph for local roads, and 10 kph for resource or recreational streets. For the most important segments, the speed limit was confirmed through a visual inspection using Google Map street view.

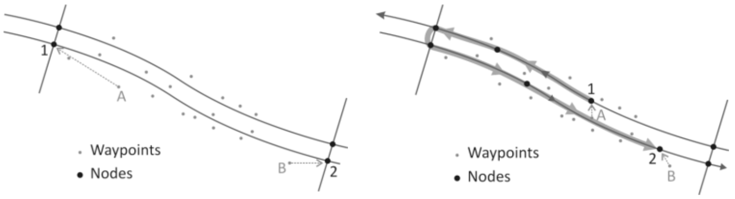
Figure 3-1: Methodology of Network Performance Analysis



In order to minimize errors, we increased the number of nodes to selected roads. The densification of nodes is quite important for any GPS micro analysis. In GIS, the shortest path is calculated between two nodes. A node is the intersection of two or more roads. Thus, if we were to estimate shortest path distance from waypoint A to B (Figure 3-2-A), TransCAD would tag these points to 1 and 2 and will overestimate the distance. To minimize the error, we inserted nodes on roads of particular interest, such as Barrington Street, Burnside Drive, etc.

Tagging-related errors can be particularly problematic on dual-carriageway (Figure 3-2-B) which is why we modified the network to contain only single lines, except for downtown where the roads are dense enough to minimize dual line – related error.

Figure 3-2: Sources of Errors in Distance Calculation



A. Waypoints Tagging to Nodes

B. Erroneous Tagging of Waypoints for Dual Lines

3.1.2 *Identify Trips from Stops: Sampling 1*

We define a vehicle to have stopped if the speed is less than 4 kph between two consecutive pings or if it is less than 35 kph when the time between two consecutive pings is 4 hours or more. This speed is based on crow-fly distance.

Amongst stops, there are also two types: stops that are part of a trip origin or destination (O/D), and intermediary stops, such as stopping at a gas station. TC provided us with a stop file and a trip file that contains stops that were considered O/D stops. We used this information to relate trip IDs to the waypoint database so that all waypoints were assigned a trip ID. Many waypoints were not part of any trip according to the TC trip file. Those are part of the trips that extended outside Nova Scotia. Those waypoints were removed from our sample for further analysis.

3.1.3 *Sampling 2: Select Trips That Pass Through the Issue Areas (Nov, 2012 Only)*

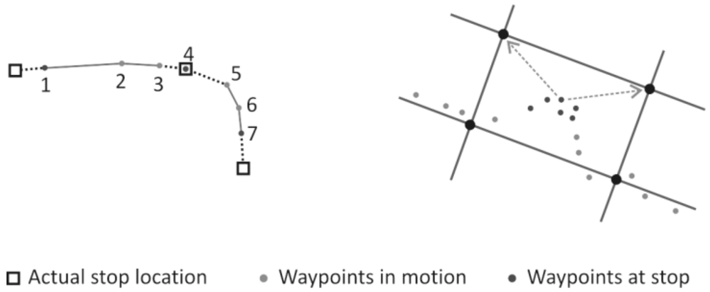
Our initial focus was to analyze congestion or delays around the issue areas identified in Figure 2-2. For that, we selected the *trips* that have at least one waypoint on any of these issue areas. Since the selection is based on trips, the geographic distribution of the sample is not only limited to the issue areas, but rather distributed across the region. For

November 2013 we did not use this sampling step since it unnecessarily limits the sample.

3.1.4 Sampling 3: Select Waypoints within 15 Meter of Roads

The next step of sampling involves removing waypoints more than 15 meters away from the road network. By doing this we removed two potential sources of error illustrated in Figure 3-3.

Figure 3-3: Sources of Error Regarding Waypoints Stops



A. Actual Stop vs Waypoint Stop

B. Stops Tagging to Wrong Nodes

Imagine a truck starts a journey from a truck yard and goes a certain distance, gets the satellite feed and pings (Figure 3-3-A). Since the ping rate in the Shaw dataset is inconsistent, it might ping within a few seconds or after 10 minutes of the truck's departure. Similarly, it is also possible that the truck came to a stop and a ping was recorded 5 minutes after the stop.

Another source of error is geographic inaccuracy. This is particularly problematic when a truck is parked away from the road network, where stop-related waypoints may be close to another road (Figure 3-3-B). During shortest path calculation, those stops will tag to the wrong nodes and distance or speed would be over- or under-estimated.

To minimize these errors we did not consider segments involving stops in our speed calculation. We also excluded waypoints located more than 15 meters away from the road. Removing these waypoints can minimize error by reducing the number of points tagged to inappropriate nodes (Figure 3-3-B).

3.1.5 Calculate Node-to-Node Shortest Path

Using sample 3, the shortest path distance was calculated between each waypoint pair. The shortest path routine was run in TransCAD using *time* which was calculated from distance and speed limit. Turn penalties of 24 seconds, 12 seconds and 5 minutes were specified for left turn, right turn and U-turn respectively.

3.1.6 Create Segment Database from the Waypoint Database

From the shortest path routine, we obtained free flow time as well as distance between each waypoint-pair. We can imagine each of these pairs as a segment. Segment-based analysis is more granular and thus more accurate than O-D based analysis, since the latter may include highways and local roads thereby overestimating local road speed and underestimating highway speed. We call this error *smoothing effect*.

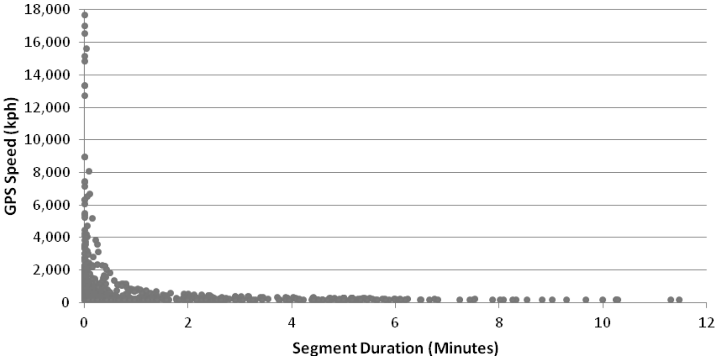
3.1.7 Calculate Segment Speed

The average speed over a segment can be easily calculated from shortest path distance between the two waypoints and the GPS time interval. However, if we have a waypoint-pair (i.e. segment) extending across roads of different speed limit, (distance ÷ time) would give us the same speed for the both roads, as explained above. To address this issue, we calculated a ratio of GPS time to free flow time (i.e. shortest path time) and then divided the speed limit by the ratio.

In a final step, we removed outliers that have speed of 150 kph and above. This was done because a truck does not move at those speeds and a probable source of this type of error is erroneous tagging of waypoints to nodes. For a short-duration segment, the waypoints could tag to nodes located further away, resulting in higher speed. A scatterplot of speed outliers versus duration confirms this error (Figure 3-4). Most of the extreme speeds (1,104 out of 1,473) occur for segments with GPS durations of 1 minute or less.

Removing segments with stops and outliers was the last step of data cleaning, after which we mapped the results. To allocate various measures of speed and congestion, we used all or nothing assignment in TransCAD.

Figure 3-4: Imputed Speed Distribution (150 kph or More) for November, 2012



3.2 Port Terminal Performance

To analyze terminal turnaround delays, we adopted an approach very similar to that generally used to estimate border delays using GPS data. The following steps were taken:

- A polygon (geofence) covering the terminal and the gate area is used to identify waypoints which are considered to be ‘in the terminal’.
- All waypoints immediately before or immediately after a block of observations ‘in the terminal’ are also identified.
- *Trips* are then built from these waypoints based on having an outside-inside-outside pattern. Trips with more than one hour between two waypoints and trips with a total time over six hours are eliminated assuming those are not delays, rather parking in the terminal. Trips with only one ping in the terminal were excluded because they displayed very low times and may reflect erroneous ping of a truck parked outside.
- The straight-line distance between the outside-inside waypoints (last waypoint before entering Halterm to first waypoint in Halterm) and the inside-outside waypoints (last waypoint in Halterm to first waypoint outside Halterm) is

computed. A ‘free flow’ time is estimated for these straight-line distances using a speed of 50 km/h.

- Finally, Halterm delays are defined as the elapsed time from the last waypoint before a trip enters the Halterm geofence to the first waypoint that exits, to which the ‘free flow’ time outside the terminal is removed. These delays thus combine terminal, gate and, potentially, some road delays on the way to/from the terminal.

4 Results

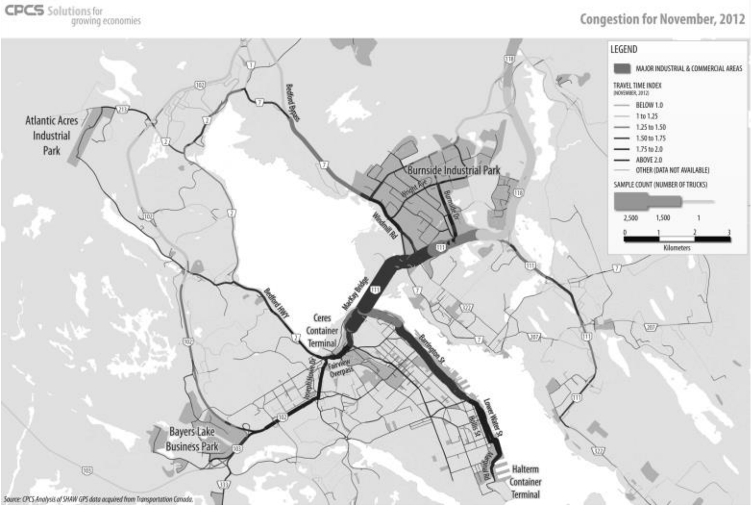
4.1 Overall Congestion

We measured congestion using the Travel Time Index (TTI) which is the ratio of GPS time to free flow time, the latter being estimated from the speed limit. Key congestion points are, unsurprisingly, centered on the roads where issued were identified from the literature and consultations. Most heavily congested segments are the Fairview Overpass, the intersection of Windmill Road and Wright Avenue in Burnside Park, and Marginal Road which is the entrance and exit road for Halterm.

For both months (Figure 4-1 and Figure 4-2), downtown Halifax route gets more and more congested as one gets closer to Halterm. One interesting pattern for this route in November 2013 (Figure 4-2) is that southbound Hollis Street is more congested than northbound Lower Water Street. It means that trucks coming into the terminal are facing more delays than the trucks going out, a fairly intuitive result.

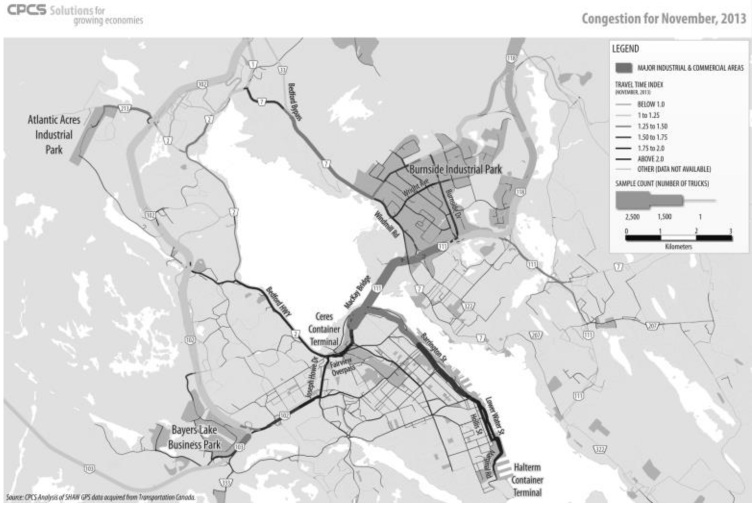
Outside the Halifax peninsula, we see notable congestion on the route between Bayers Lake and Fairview Overpass i.e. Joseph Howe Drive and part of Highway 102. Joseph Howe Drive links Highway 111 and 102, so it is likely to be busy with passenger traffic and the trucks generated by Bayers Lake increase the pressure. Bedford Highway is heavily congested as well. Both roads get worse in terms of congestion in November 2013 (Figure 4-2) than at the same time previous year.

Figure 4-1: Congestion Based on Travel Time Index, November 2012



Source: CPCS Analysis of SHAW GPS data acquired from Transportation Canada.

Figure 4-2: Congestion Based on Travel Time Index, November 2013



Source: CPCS Analysis of SHAW GPS data acquired from Transportation Canada.

4.2 Analysis of Specific Issue Areas

Figure 4-3 summarizes average TTI and speed on key issues areas of the road network. In all cases, the GPS time is higher than free flow time. The average speed is around half the speed limit for Barrington Street, Fairview Overpass, Hollis Street, Marginal Road, Windsor Street at Highway 111, which is located closed to Fairview Overpass, and Wright Avenue at Windmill Road. There is no general improvement or decline of speed from 2012 to 2013 at problematic locations.

There is one odd observation, Wright Avenue at Highway 111, where congestion is less during peak hours in November 2013. This is most likely due to the smoothing effect pointed out in the previous section.

Figure 4-3: Congestion and Speed at All Issue Areas

	Average Travel Time Index				**Average Speed (kph)**			
	All		**Peak**		**All**		**Peak**	
Issue Area	**Nov 2012**	**Nov 2013**	**Nov 2012**	**Nov 2013**	**Nov 2012**	**Nov 2013**	**Nov 2012**	**Nov 2013**
Barrington St	2.06	1.81	2.61	1.78	32.6	34.0	29.4	35.2
Bedford Bypass	1.20	1.13	1.23	1.17	81.4	85.7	79.5	84.1
Bedford HWY	1.54	1.86	1.55	1.60	51.9	47.2	53.1	56.8
Burnside Dr at HWY 111	1.61	1.50	1.86	1.85	37.0	40.2	32.6	37.4
Fairview Overpass	2.05	2.22	2.38	2.40	38.3	35.6	32.9	32.6
Hollis St	1.93	2.05	2.16	2.69	31.2	29.6	28.6	22.5
Imperial Oil Access at Pleasant St	1.31	1.11	1.39	1.07	45.9	54.0	43.1	56.2
Joseph Howe Dr	1.88	1.95	1.99	2.43	30.6	29.4	29.0	25.2
Lower Water St	1.75	1.87	1.87	1.74	34.6	32.6	32.3	35.4
MacKay Bridge	1.63	1.47	1.79	1.47	61.4	68.1	55.9	68.1
Marginal Rd	2.05	2.30	2.10	2.05	24.6	22.5	23.9	24.5
Windsor St at HWY 111	1.94	1.96	2.26	2.33	32.3	29.4	30.9	23.9
Wright Ave at Burnside Dr	1.63	1.60	1.76	1.61	29.8	31.4	27.0	28.4
Wright Ave at HWY 111	1.33	1.14	1.03	0.99	32.7	33.1	30.4	35.8
Wright Ave at Windmill Rd	1.98	1.76	2.14	1.87	39.4	44.5	48.6	50.9

TTI below 1	TTI 1 to 2	TTI above 2

4.3 Port Terminal Performance

The average turnaround time at the Halterm terminal, including delays on roads to/from the terminal, at the gate and within the terminal, was estimated at 70.9 minutes in November 2012. Estimates for November 2013 point to a significant increase in average time, of the order of about 15 minutes, or 20 percent.

Figure 4-4: Average Truck Turnaround Time for Trips to Halterm Terminal

	Average Delay (Min) Nov. 2012	Sample Size (Trips) Nov. 2012	Average Delay (Min) Nov. 2013	Sample Size (Trips) Nov. 2013
Day of Week (Origin of the Trip)				
Monday	79.5	63	84.9	45
Tuesday	75.9	138	73.7	107
Wednesday	75.6	84	89.3	78
Thursday	81.5	142	92.4	93
Friday	72.4	121	92.0	133
Time of Day (Origin of the Trip)				
0:00 AM to 7:59AM	182.2	27	133.2	17
8:00 AM to 9:59 AM	61.2	122	83.6	163
10:00 AM to 12:59 PM	77.1	157	95.6	111
1:00 PM to 3:59 PM	60.5	226	79.5	155
4:00 PM to 11:59 PM	41.7	16	63.8	11

In terms of the time of the day, there are more differences, with the longest estimated times for trucks early in the day as they line up before the gate opens (at 8AM). Longer delays are observed in the middle of the day, which includes the closure of the gate for the lunch hour, with much lower delays observed for after hour shipments (the gate closes at 5PM).

Comparing November 2012 and November 2013 suggests that, as noted in the consultations, the reservation system seemingly did not improve turnaround times at the terminal. The only improvement seems to be for trips beginning early in the morning, where delays decreased from 180 minutes to 130 minutes. Indeed, the scheduling system may reduce the tendency for trucks to line up early at the gate to secure a prime spot. This would in turn reduce the delay observed in that early portion of the day.

5 Key Findings and Next Steps

The analysis of GPS truck flow data largely confirms the issues identified by stakeholders and from previous reports. Congestion is heavy in a number of areas and in particular on the road leading to the Halterm container terminal. The situation did not improve in the area in 2012-13, with many congested areas worsening. In Halterm terminal, the new scheduling system appeared to have reduced morning line-ups but increased wait times across the board.

While the method applied seems largely successful, there are room for further refinements:

- Automated node densification using *Add Centroid Connector* procedure in TransCAD would minimize errors. It was attempted, but failed due to insufficient computational memory.
- Developing detailed road network with more accurate and complete speed limit information.
- Finally, better GPS data would definitely improve the quality of the analysis. Data collection initiatives, such as CargoM's project in Montreal, which installed loggers with higher ping frequency and which gather some information on engine status, would provide higher quality GPS data and allow for more detailed analyses.

Notwithstanding current limitations, GPS data seems to be the most promising source of freight data at the moment. With the ever increasing pace of technology, data accuracy will improve in the future and increasing numbers of truckers will be using GPS because of its operational usefulness and cheaper cost. There will be more surveys and more use of such data to answer more complex questions.

In the meantime, though, we can make better use of GPS data by combining it with other conventional data, such as Statistics Canada Truck Commodity Origin Destination (TCOD) or Ministry of Transport Ontario Commercial Vehicle Survey (CVS). Using commodity information, along with land use data, we could come up with reasonable estimate of how different industries are affected by congestion.

In addition to freight system performance, studies could look into system reliability, that is, how variable and unpredictable the congestion is and what affects reliability. Such analysis would require other data, in addition to GPS, such as port vessel call, weather condition, road construction, accidents, etc. These are some of the examples of how GPS freight data may very well be the next frontier of freight transport research.

Acknowledgement

The authors thank Transport Canada for providing the GPS and other necessary data as well as for their valuable comments during the course of the project.

Reference

Chase, K. M., Anater, P. & Phelan T. (2013). Freight Demand Modeling and Data Improvement Strategic Plan. SHRP 2 Report, S2-C20-RW-2. Transportation Research Board.

Golias, M., Dobbins, J., Shorts, J. & Johnson, Z. (2012). GPS/GIS Analysis of Tennessee Truck Trips. Tennessee Department of Transportation.

Gordon Proctor & Associates, Cambridge Systematics, American Transportation Research Institute, StarIsis Corporation & Council of Supply Chain Management Professionals. (2011). Performance Measures for Freight Transportation (Vol. 10). NCFRP. Transportation Research Board.

Jones, C., Murray, D. and Short, J., (2005). Methods of Travel Time Measurement in Freight-Significant Corridors. TRB 84th annual meeting, Compendium of Papers, Washington D.C.

MariNova Consulting (2008). Atlantic Gateway Distripark Plan, Final Report for Halifax Regional Municipality.

Mary R. Brooks Transportation Consulting (2013). Situational Analysis of the Container Trucking Sector at the Port of Halifax for Transport Canada, Final Report Prepared for Transport Canada.

Statistics Canada (2012). Canada Year Book. Retrieved from http://www.statcan.gc.ca/pub/11-402-x/2012000/pdf/transport-eng.pdf.

Transport Canada (2013). Transportation in Canada: Statistical Addendum, Preliminary Estimates

Notes

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[i] Geobase has now moved to Geogratis: http://geogratis.cgdi.gc.ca/geogratis/