

## Road Congestion Measures Using Instantaneous Information From the Canadian Vehicle Use Study (CVUS)

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### Abstract

Traffic congestion is not limited to large cities but is also becoming a problem in medium-size cities and to roads going through cities. Among a large variety of congestion measures, six were selected for the ease of aggregation and their capacity to use the instantaneous information from CVUS-light component in 2014. From the selected measures, the Index of Congestion is potentially the only one not biased. This measure is used to illustrate different dimension of congestion on the road network.

Keywords: CVUS, province, cma, quarter, speed, speed limit, road network, day, hour, congestion, large data set.

### 1. Introduction

An urban transportation system includes private vehicle, public transportation, transportation of goods, cyclists and pedestrians. Congestion on road network, especially in urban area affects all the users of the transportation system. Congestion has important economic, environmental and health impacts. Winston and Langer (2006) evaluate that more than 25% of the cost of congestion is bare by the trucking firms and those receiving and shipping freight. The congestion impact the supply chain (McKinnon (1999), Konur and Geunes (2011), Weisbrod and Fitzroy (2011)) because more people are required to manage the congestion, larger warehouses are required to minimize the risks associated with congestion, relocation of warehouses and enterprises to minimize the cost of congestion and some enterprises could get out of business because they could not support the supplementary transportation costs. Taylor et al. (2012) found that in USA around 60% of the supplementary costs are transferred to the clients that have to pay higher prices. Congestion cost might reduce the competitiveness of Canadian firms.

Weisbrod et al. (2001) define congestion as “*a condition of traffic delay (i.e. when traffic flow is slowed below reasonable speeds) because the number of vehicles trying to use a road exceeds the design capacity of the traffic network to handle it*”.

Road congestion is the result of multidimensional choices like population density, where people live and work, their work schedules, the road network configuration and the presence of alternative transportation modes. It has four important dimensions:

- Spatial: could be local specific or apply to a whole network.
- Temporal: may vary by season, the time of the day and the day of the week.
- Stochastic: weather conditions, unexpected events like accidents or emergency road repairs.
- Predictable: repair to road or infrastructure, or special events.

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## 2. How do we Measure Road Congestion?

There are many measures of road congestion. Based on a table produced originally in FHWA (1994) and reproduced by Weisbrod et al. (2001) there are four families of congestion measures: time related measures, volume measures, delay measures and level of service. There are also some ad hoc measures like the one from the Urban Transportation Task Force (2012) based on 70% of speed limit, or California Department of Transportation for which the average speed on highways drop below 35 m/h (56.3 km/h) for 15 minutes or more in a typical day (Bertini(2006)).

From the information available in CVUS like the geo location, the instantaneous speed and the instantaneous fuel consumption, we derived six measures:

- Delay/km (minutes of delay on a road segment divided by the distance driven on the segment)
- Congestion/km (minutes of congestion on a road segment divided by the distance driven on the segment)
- Time/km (minutes driven on a road segment divided by the distance driven on the segment)
- Congestion Index (percentage of time below the free flow level)
- Km Congestion Index (percentage of the segment length below the free flow level)
- An indirect measure of GHG with the fuel ratio (L/100 km).

### 2.1 Concepts and Measures

If on a road segment 70% of speed limit is the **congestion level**, every second with a speed below that speed is **congestion (C)**. Every second where the speed is above the **congestion level** is considered as free flow time (**FF**). The total travel time on a segment (**TT**) is equal to the time in congestion and the free flow time (**C+FF**). On each segment, the **expected travel time (ET)** is given by the length of the segment, the speed limit and some mandatory stops on the segment. The **delay** (dark blue) is **the total travel time (TT)** less the **expected travel time**.

Each road segment on the road network has a different length, in order to compare the congestion measures we need to normalize the congestion measure by the distance driven – this is not require for the Congestion Index and Km Congestion Index. Another reason why we need to normalize the congestion measures is the fact that the users could enter or exit a road segment at more than one point. Any measure that do not adjust for this is biased.

#### Free Flow Speed and Congestion Level

There are many definitions of free flow speed. One is based on the average speed at night when the segment is mostly empty. This could be higher than the speed limit. In CVUS we observed that 15% of the time people exceed the speed limit. The free flow speed could vary between adjacent segments subject to the same speed limit and could result in inconsistent comparison of congestion between segments.

On an economic point of view, the congestion arose when the number of vehicles on a road segment exceeds the road capacity. When the demand on a segment take into account all the costs linked to the use of a segment private cost plus pollution and negative externalities on travel time of the other users), the equilibrium define an optimal level of congestion. There are no means to define an optimal level of congestion – or free flow speed. One approach to the problem is to use a range of values defined in proportion of the speed limit on the segment: **60%, 70% and 80% of speed limit**.

#### Delay/km

At each second on a road segment we know the **congestion level (FF)** and the actual speed ( $s$ ). When the actual speed is below the free flow speed we can estimate the delay in seconds as  $[1 - \frac{s}{FF}]$ . If the free flow speed is 40 km/h and the current speed is 20 km/h then the delay associate to that second of observation is half a second.

Each road segment does not have the same length and this is why the measure is normalized by the total distance driven on the segment (D) for all the users of a segment. Because there is always the possibility to enter or exit a road segment, we need to adjust the measure to the proportion of the distance driven on the segment.

We assume that there are n seconds of observation on a road segment. If  $\delta_i$  is an indicator that speed is below the congestion level FF and 0 otherwise, and  $k_i$  the percentage of distance driven on a road segment related to observation i, then the total minutes of delay per km is measure as

$$\frac{delay}{km} = \sum_{i=1}^n \left[ 1 - \frac{s_i}{FF_i} \right] \frac{k_i * \delta_i}{D * 60}$$

This measure is potentially biased because it does not take into account the driving time on the segment.

#### Congestion/km (min/km)

The time in congestion is the total time spent at speed below the congestion level divided by the total distance driven on the segment (D). Each observation in congestion ( $c_i$ ) is adjusted for the proportion of the distance driven on a road segment. The measure is the minutes in congestion per km:

$$\frac{congestion}{km} = \sum_{i=1}^n c_i \frac{k_i * \delta_i}{D * 60}$$

This measure is potentially biased because it does not take into account the driving time on the segment.

#### Time/km

This measure is the inverse of the speed measured in km/min. This measure is potentially biased because it does not take into account the speed limit on the segment.

#### Congestion Index

The Congestion Index could be defined as the percentage of congestion time on a road segment, where TT is the total travel time on the segment. Because we can observe only the distance  $x_i$  over a segment of length  $y_i$ , we need to adjust for the percentage of distance driven on the segment and to the number of users, n, on the segment.

$$\frac{\sum_{i=1}^n \frac{C_i}{TT_i} * k_i}{n} * 100$$

The measure is biased because it does not take into account the congestion time and the driving time on the road segment

#### Km Congestion Index

The concept is similar to the Congestion Index except that we measure the percentage of a road segment subject to congestion. This measure is not biased but it does not provide any information on time in congestion.

#### Fuel Ratio (L/100 Km)

The quantity of fuel (L) consumed on a road segment normalized by the distance driven on the segment and express for 100 km to get the usual fuel ratio.

For the remaining of this paper we will focus only on the Congestion Index.

### 3. CVUS Data

The light component of the Canadian Vehicle Use Study (CVUS) includes vehicles like passenger cars, minivans, pickup trucks and SUV with gross weight less than 4.5 tonnes. The Heavy component include vehicles with gross weight of 4.5 tonnes or more.

The sample of each component is stratified by vehicle characteristic, age class and province. The participating provinces for the whole 2014 are Québec, Ontario, Manitoba and Saskatchewan. When the owner of a vehicle agree to participate, he has to install a logger in the vehicle ODB port. At the beginning of each trip a minimum of information is required and all the remaining information is automatically collected every second including the geographic location, the instantaneous speed and the instantaneous fuel consumption.

Each quarter we collect the information about 1000 vehicles for the light component which result in 380 million of records. From those record we selected only those that could be linked to a segment of the national road network (highways, provincial roads and local roads that are part of those roads). This left us with 180 million of records

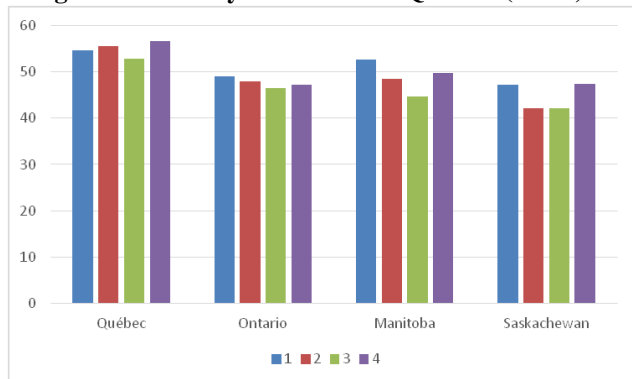
Each province define its road network and the length of the road network vary by province:

- QUÉBEC : 24,100 KM
- ONTARIO: 60,396 KM
- MANITOBA: 18,343 KM
- SASKATCHEWAN: 33,661 KM

### 4. Visual Presentation of Congestion Index

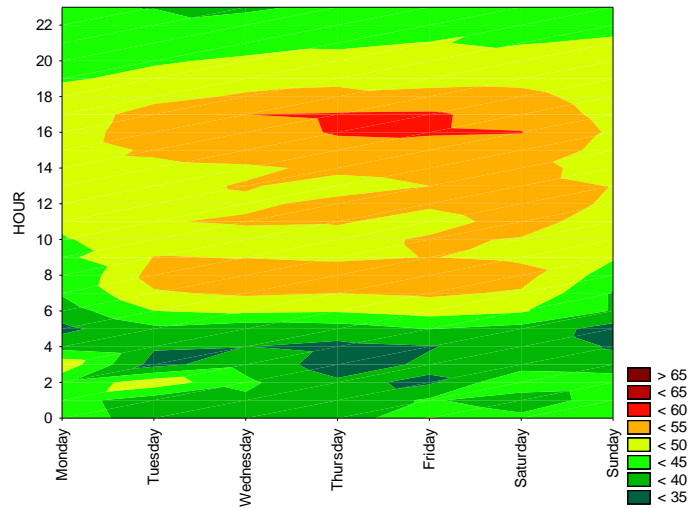
The visual presentation of Congestion Index is based on a congestion speed of 80% of speed limit. We explore various ways to present the information on congestion: by geographic area, by time period and on the road network.

**Figure 4-1**  
**Congestion Index by Province and Quarter (1 to 4) - 2014**



The congestion seems to be higher in Québec than in Ontario. One factor explaining this result is the length of the road network that biases the results, the longer the road network the lower the probability of observing congestion on all the segments of the road network. In Ontario the road network is more than 2 times the length of the road network in Quebec. The same argument apply to the congestion level in Manitoba compared to Saskatchewan. Summer (quarter three) is the less congested in all provinces. Another factor is that in Québec especially in Montréal and Québec City, there were extensive works on the road network in 2014.

**Figure 4-2**  
**Congestion Index by Hour and Day - 2014**



In the morning people are experiencing congestion (orange) between 7 and 9, at noon there is a slight increase in congestion but the longest period of congestion is between 14:30 and 17:30 hour, the worst period (red) is around 16:00 hour Thursday and Friday. The surprise is the congestion level people experience in Saturday afternoon.

One of the most useful way to present the congestion information is by linking the congestion information to the road network. The highest congestion is in orange and red in Figure 4-3. In Toronto area we can see that the downtown area is one of the most congested followed by highway 401 from east to west.

**Figure 4-3**  
**Congestion Index in Toronto Area - 2014**



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