MEASURING FREIGHT PRODUCTION

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INTRODUCTION

This paper provides an analysis of how freight transportation production is measured, some key limitations of the traditional approaches and potential innovative solutions to address the main concerns. Measuring production appropriately is a key task when productivity is assessed or when comparisons of mode performance are conducted either from a financial perspective or from a social one. Traditional measures such as tonne-kilometres introduce a bias in the comparability of freight production especially across different modes. Innovative measures could address some of the main concerns raised by these limitations. The paper explores the potential benefits of using innovative methods to measure freight production.

TRADITIONAL FREIGHT PRODUCTION MEASUREMENTS

A popular traditional measurement of freight production takes two major factors of transportation into account: the mass of the shipment displaced (for example measured in tonnes) and the distance of the movement (for example measured in kilometres). The product of the two factors gives the level of "production" for a given shipment (in this instance, it is measured in tonne-kilometres). The sum of these products obtained for each shipment could give the entire production (or output) of the relevant aggregate of the transportation industry. For example, the sum of all shipments expressed in tonne-kilometres and moved by rail in a given year represents the annual production of

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the rail mode in Canada. Table 1 provides estimates of tonne-kilometres produced in 2000 and 2006 for the five freight modes.

Table 1 Freight Production in Canada 2000, 2006
(Billion of tonne-kilometres)

Sector	2000	2006	Change	AAGR
Trucking	244.99	292.19	+47.20	3.0%
Rail	322.44	352.47	+30.03	1.5%
Marine[2]	998.60	1155.03	+156.42	2.5%
Air[2]	2.38	2.23	-0.14	-1.1%
Pipelines	309.47	333.21	+23.74	1.2%
Total	1877.88	2135.13	+257.25	2.2%

Data Source: Transport Canada

The freight production level could then be compared to the quantity of inputs (capital, labour, energy) used to produce this output yielding a measure of the performance or productivity of a mode or the sector as a whole.

Given the presence of a variety of modes in the freight transportation sector, taking into account factors such as speed and reliability, could be important in analysing production.

Another popular measure of "production" is the computation of gross revenues of freight carriers. In this case, the value of production is assumed equal to the carriers' monetary receipts or shippers' outlay of funds for the services provided by the carriers. Obviously, this measure can only cover production of for-hire carriers and thus excludes significant parts of the Canadian transportation system[3]. Because of this partial coverage, revenues as a measure of production will not be included in the present discussion.

[2] Only half of international shipping is accounted for in this table because the other half is assumed to belong to our trading partners.
[3] Private trucking is believed to account for approximately 40% of the trucking activity in Canada. Moreover, the importance of private shipping activities is unknown and data on for-hire international shipping revenues are difficult to obtain.

A NUMBER OF LIMITATIONS

The traditional measure of freight transportation production (the tonne-kilometre) is the product of two important elements of a shipment: its mass and the distance of the movement. The relative importance of each of the two factors disappears once the product "mass by distance" is computed. Thus, a shipment weighing one kg that is displaced at a distance of 1000 km would represent a production of one tonne-kilometre (t-km). A shipment weighing one tonne transported on a distance of one kilometre would also amount to a production of one t-km. However, for a carrier, the two shipments would necessitate a completely different set of equipment and processes to complete the delivery. Hence, it appears appropriate to keep the information on shipment weight (tonnage) and the number of shipments as well as the tonne-kilometres to conduct production analyses.

Another limitation of the tonne-kilometre is due to the variety of "mass layers". The weight of a shipment usually includes the weight of packaging, but generally excludes the weight of the vehicle. Including the weight of the packaging overestimates somewhat the level of production since only the unpacked good has a value for the shipper. This is particularly true for containerized traffic if the weight of the container itself is included in the revenue-t-km computation. Not including the weight of the vehicles tends to underestimate the physical level of effort to move freight, but not the production itself. One would note that since the ratios of net freight weight over vehicle gross weight vary significantly depending on the density[4] of the good moved, this would generate a variance of performance regarding for instance, the quantity of energy needed to move a type of freight compared to another one over the same distance.

The distance of the shipment is measured as the distance travelled, not the great circle distance between the origin and the destination. Hence, indirect routing appears to produce more than the actual level of production, which should be measured as the net movement between the origin and the destination. This limitation may be

[4] The density of a shipment is measured by the ratio of its mass over its volume.

particularly important when productions of different modes are compared because the modal networks (roads, railways, ports, airports, pipelines) are different and allow only limited routing. For instance, depending on the vehicle, the traveled distances between Toronto and Vancouver change:

- By plane: 3,400 km
- By truck: 4,400 km (on Canadian roads)
- By train: 4,800 km
- By ship: 13,300 km (via the Panama Canal).

Using the travelled distance could therefore be a questionable measure of production from a shipper perspective, but it is a good measure to record the level of effort needed from a carrier. Shipment statistics that would record the direct actual distance of each shipment between its origin and its destination would certainly be a valuable and innovative improvement to monitor and report the actual production of the transportation system that records only an estimated travelled distance.

Great Circle Distance

This is a demonstration on how direct distance (great circle) can be calculated if the exact points of origin and destination are recorded by their respective latitude and longitude.

Knowing that each degree is divided into 60 minutes and each minute into 60 seconds, conversion in degrees of a longitude or a latitude would be equal to: degrees + (1/60) Minutes + (1/3600) Seconds.

For instance, the Canadian Parliament in Ottawa is located at:
δ = 45º, 25’, 15” North means δ = 45.424852459973366 degrees of latitude
λ = 75º, 41’, 24” West means λ = -75.69966852664947 degrees of longitude

The coordinates have to be expressed in radians. Knowing that each degree = (π / 180º) radians, we have for Parliament:
δ = 0.792813238 radian of latitude

λ = -1.321208458 radian of longitude

Similarly, for British Columbia's Parliament in Victoria we have:
δ' = 0.845082298 radian of latitude
λ' = -2.153216555 radians of longitude

Then, the distance is computed using a haversine formula:

$$gc(\delta, \lambda, \delta', \lambda') = 2R \arcsin \sqrt[2]{\sin^2\left(\frac{\delta' - \delta}{2}\right) + \cos\ \delta\ \times\ \cos\ \delta' \times \sin^2\left(\frac{\lambda' - \lambda}{2}\right)}$$

Where:

R is the radius of Earth ≈ 6367 kilometres
δ is the latitude (in radians).
λ is the longitude (in radians).

In our example, the direct (great circle) distance between the two parliament buildings is thus: 3574.5 km

(source of haversine formula: Wikipedia)

A challenge linked to measuring production by measuring the direct distance between the shipment's origin and destination is due to the potential use of more than one mode to deliver the transportation service. The freight transportation system usually involves more than one mode to complete a shipment from origin to the destination. For those multimodal shipments, an allocation process would have to be implemented in order to allocate the total production (from the true origin to the final destination) among all modes that contributed to delivering the shipment. A simple allocation formula could take the respective distance traveled of each involved mode as a weight factor to distribute the actual production of a shipment to each mode (as measured by the actual distance between the origin and the destination of the shipment).

Missing Factors

Elements of shipments other than weight shipment and distance traveled that are not taken into account in the measurements of freight production by the tonne-kilometre include but are not limited to:

- volume of the shipment
- speed
- reliability of the service
- predictability of time for pick-up and delivery
- flexibility
- value of moved goods
- rate of in transit loss and damage
- rate of empty returns[5]
- externalities (e.g., air pollution, greenhouse gas emissions, human impact of accidents), and
- transaction costs.

Volume versus Weight

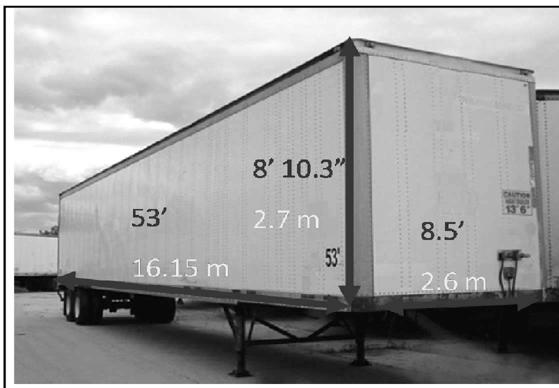
Freight transportation vehicles (e.g., trucks & trailers, railcars, vessels, cargo airplane) have limits on the volume of the cargo they can carry as well as on the cargo weight. Hence, depending on the density of the cargo, one of the limits could be reached before the other. Shipments that reach the weight limit first can be considered as "dense". Shipments that reach the volume limit first could be labelled as "light". For each vehicle type, it is possible to compute a density threshold that corresponds to a theoretical shipment that would occupy the entire volume available on the vehicle and yet not go over the vehicle weight limit.

[5] An empty return of a vehicle does not produce freight transportation but generates financial and social costs such as air pollution. Since some commodity movements generate more empty returns than others, and the proportion of backhauls (loaded returns) could also vary by region or by origin-destination pair, a fair measure of resources used (and costs) to generate production in one direction should take into account the rate of empty returns of vehicles. One would note that general cargo flows generate a lower proportion of empty returns than commodities that are moved by dedicated vehicles (e.g., tanker). One would also note that the issue of empty return is irrelevant for pipelines.

<u>Trucks and trailers</u>

To illustrate how a threshold could be computed, one could take the example of a typical road truck and trailer combination. Figure 1 shows a typical 53' road trailer that is common on Canadian roads. The available volume is approximately 113 cubic metres.

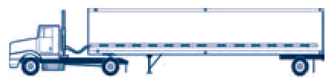
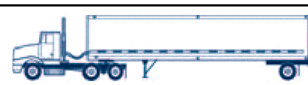
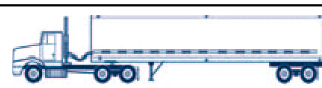
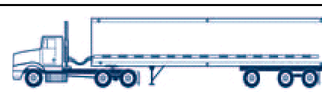
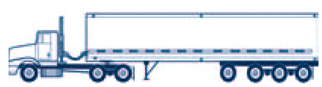
Figure 1 : Road Trailer Volume



$16.15\text{ m} \times 2.6\text{ m} \times 2.7\text{ m} = 113.4\text{ m}^3$

In Canada, provinces regulate weights and dimensions of road commercial vehicles including tractor and trailer combination. These regulations may impose more stringent weight limits during thaw periods. Moreover, the maximum total weight of the tractor and trailer combination could increase with the number of axles. For instance, the *Ministère des transports du Québec* (MTQ) published a guide with a series of potential combinations that clearly show that trend (summarized in Table 2).

Table 2: MTQ Maximum Total Weight by Configuration

Axles	Configuration	Maximum Weight (kg)
3		25500
4		35500
5		40500
		41500
6		40500
		49500
7		48500
		55500

Source: http://www.mtq.gouv.qc.ca

Table 3 below shows that the maximum total weight varies between 55.5 tonnes in Quebec, to up to 63.5 tonnes in Alberta and British Columbia. Knowing that an empty tractor and trailer weigh approximately 15 tonnes, one could compute that the maximum cargo weight would vary between 40.5 and 48.5 tonnes. Combining this range with the available volume of 113.4 m^3 for a 53' trailer, this means that the threshold that would distinguish a dense commodity from a light commodity lies between 357 and 427 kg per m^3 for trucks pulling a 53' trailer in Canada.

Table 3: Maximum Trucks Total and Cargo Weight by Jurisdiction

Jurisdiction	Maximum Weight (kg)	Cargo Weight (kg)	Density (kg/m3)
British Columbia	63500	48500	428
Alberta	63500	48500	428
Saskatchewan	62500	47500	419
Manitoba	62500	47500	419
Ontario	63500	48500	428
Quebec	55500	40500	357
New Brunswick	62500	47500	419
Prince Edward Island	62500	47500	419
Nova Scotia	58500	43500	384
Newfoundland	62500	47500	419
USA Interstate	36287	21287	188

Sources:
http://www.mto.gov.on.ca/english/trucks/irp/manual/appendix_a.shtml
http://www.mtq.gouv.qc.ca

Railcars

Railway companies operate a number of railcar types in Canada. A list of the most commonly used cars appears in Figure 2 and in Table 4 below. A difference between respectively the proportion of railcars movements and tonnage transported by car type indicate that cargo density varied by railcar type.

Figure 2: Railcars and Tonnage by Car Type, 2000-2009

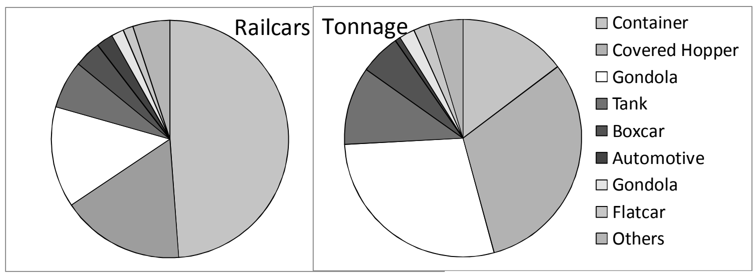


Table 4: Railcars and Tonnage by Car Type, 2000-2009

Description	Railcars Movements	Tonnage
Container	48.8%	14.7%
Covered Hopper	16.8%	31.0%
Gondola	13.8%	28.4%
Tank	6.6%	10.7%
Boxcar	3.6%	5.5%
Automotive	2.3%	0.8%
Gondola	1.7%	2.1%
Flatcar	1.4%	2.1%
Others	5.1%	4.7%

Source: Transport Canada

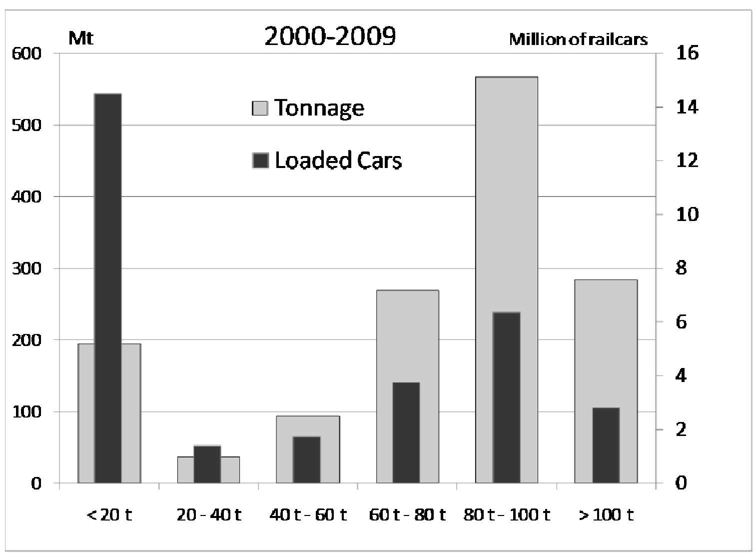
One would note that the important segment of containerized general cargo is essentially volume-constrained on rail as it is shown in Figure 2 and in Table 4.

Knowing that most of Class 1 rail networks impose a cargo weight limit of between 75 to 85 tonnes per railcars[6], it is possible to analyse what portion of railcar traffic moved “dense” commodity (i.e., are subject to a weight constraint) and what proportion moved “light” commodity (i.e., subject to a volume constraint).

[6] Most of the networks have upper limit of between 263 000 lbs and 289 000 lbs, i.e., 120 tonnes and 130 tonnes, but the car itself may weigh almost 30 t.

We performed a statistical analysis of railcar movements in Canada during the 2000 to 2009 period. As it is showed in Figure 3, close to 40% of loaded railcars had an average weight smaller than 20 t, way under the upper limit of between 75 t to 85 t. Moreover, 62% of railcar movements had an average weight of less than 70 t, which makes the transported commodity very likely volume constrained (light) rather than weight constrained (dense). However, these volume-constrained railcars carried only 29% of the rail tonnage during that decade. Hence, if we assume that the other railcar movements were rather weight constrained, this means that weight-constrained cars moved approximately 70% of the rail tonnage. As a result, about 70% of the rail tonnage was weight-constrained and more than 60% of the railcar movements were volume-constrained.

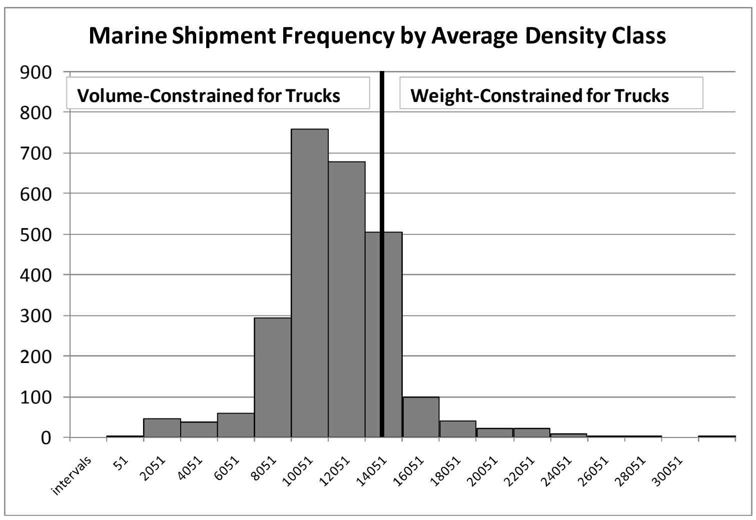
Figure 3: Railcars and Tonnage by Load per Car Class



MARINE CONTAINERIZED TRAFFIC

A statistical analysis of marine containerized traffic confirms that the intermodal freight movements are volume constrained (i.e., light) rather than weight constrained (i.e., dense). Marine statistics are reported by ship call: the weight and the number of all handled loaded containers along with a list of commodities (either loaded or unloaded) are recorded among other information on shipments. This allows computing the average weight per TEU (Twenty-foot unit equivalent: a volume unit that corresponds to 36.3 m^3) for each ship call[7].

Figure 4: Marine Containers Ship Calls, 2007



Source: Transport Canada computation of micro-data from Statistics Canada

In 2007, more than 2,575 port calls were recorded in Canada. We computed their average cargo weight in kilograms per TEU in order to perform a frequency analysis of the density classes. As shown in Figure 4, marine containerized traffic has very frequently, an average density of less than 15.5 tonnes per TEU, or less than 428 kg/ m^3.

[7] The port of Vancouver reports containerized traffic by month rather than by ship call and this traffic is not included in this computation.

This is close to the trucking threshold in most of the provinces and this means that most of containerized traffic is “light” even from a trucking point of view.

TWO MARKETS SEGMENTS

Given the importance of the volume of shipments that are light (volume constrained) for the surface modes (rail and trucking), measuring freight production only by using tonne-kilometre is not appropriate. It appears to be appropriate when distinguishing general cargo movements (light) from the other movements (dense) in the way freight production is measured.

Since the average unit value of general cargo (light) is generally greater than the average unit value of bulk commodities (coal, potash, grains, etc.) (dense), the time sensitivity of the movement of general cargo is potentially higher than dry or liquid bulk commodities. Because of their higher time sensitivity, general cargo is usually transported at faster speeds than bulk and dense cargo. This is an additional argument in favour of measuring general cargo production separately. Thus implementing a monitoring system based on “volume-great circle distance” for general cargo would be a major improvement to the current freight monitoring system.

While reporting on reliability could be difficult at an aggregate level, taking into account the velocity of shipments would be another potential improvement. For this, the time elapsed between the time of loading at the origin (T_o) and the time of unloading at destination (T_d) of each shipment would be the numerator (T_d - T_o) and the actual distance between the origin and the destination (D_{od}) would be the denominator for each shipment. Analysts could then either group shipments velocity by class or compute weighted average using TEU-kilometre as a weighting factor to assess the performance of each mode.

$$V = \frac{(T_d - T_o)}{D_{od}}$$

Where:
V: the velocity of a shipment (e.g., expressed in h/km)
T_d: time of unloading at destination

T_o: time of loading at origin
D_{od}: great circle distance

Innovation Required

The suggested improvements to reporting the production of freight movements at the modal or industry level would require some innovative solutions. Monitoring the multimodal shipments may represent special challenges such as how handling time between two modes would be accounted for and to what mode this time should be allocated to. Efforts should also be directed at reporting shipment' volumes in order for a volume-distance reporting system implementation. As it is the case when mass is measured, the volume of packaging may represent some challenges on how to process it in the measure of production.

Conclusions

The traditional way to measure and report freight production in tonne-kilometre appears to be a poor measure of freight production for general cargo. In effect, general cargo is light and shipments of such are usually volume constrained rather than weight constrained. Therefore, a measure of volume-distance would be more appropriate for this important segment of the freight transportation industry.

Since general cargo represents more than half of surface shipments in Canada, the introduction of a measure of volume-distance at least for that market segment appears desirable.

The traveled distance of a shipment reflects more the effort of the carriers than their actual production from the shippers point of view. The actual distance between the origin and the destination of the shipment would be a more appropriate measure of production. This is especially true if one were to compare different modes that use different networks with different degrees of flexibility (i.e., more or less indirect routing). It would be innovative to add the great circle distance of each shipment in transportation statistics. This innovation could be implemented if latitudes and longitudes of both the origin and destination were recorded.

Another improvement to measure freight production pertains to velocity. To compute the latter, the freight monitoring system would have to record for each shipment (or for a representative sample) the time of loading and unloading. Data on timings should be available for each segment of the whole shipment to clearly identify each mode performance as well as time elapsing between two modes at the intermodal nodes.

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