PROVINCE OF ONTARIO'S COMMODITY FLOW AND LONG-DISTANCE TRUCK MODELS – A COMPREHENSIVE PICTURE OF FREIGHT MOVEMENT IN ONTARIO

Mausam Duggal, WSP | Parsons Brinckerhoff
Bryce Sharman, WSP | Parsons Brinckerhoff
Rick Donnelly, WSP | Parsons Brinckerhoff
Rob Tardif, Ministry of Transportation of Ontario
Shan Sureshan, Ministry of Transportation of Ontario
Sundar Damodaran, Ministry of Transportation of Ontario

Introduction

WSP | Parsons Brinckerhoff was hired by the Ministry of Transportation (MTO) to develop the *Transport and Regional Economic Simulator of Ontario* (TRESO), which is a passenger, freight and macroeconomic model covering the Province of Ontario with connections to the rest of the world. When complete, MTO staff will be able to use TRESO to evaluate a wide variety of policy, planning and investment scenarios that will affect major transportation corridors and systems across the entire province, as well as gateways to other North American locations. Commodity and freight modelling is a heavy emphasis within TRESO. Example scenarios of interest to MTO staff include the effects of: economic growth or decline, land-use changes (reflected by adding new firms within a region), changing use of E-commerce, changes to the rail and marine infrastructure and possible trade barriers on truck, rail and marine freight travel patterns.

This paper presents an overview of two TRESO components - the *commodity flow model* and the *long-distance truck* model. The paper describes their inputs, a brief and high-level description of their structure, and some preliminary model results.

Inputs

The key determinant defining the structure of a transportation forecasting model is data availability. The freight transportation data that are available for the two models can be split into demand, economic and supply categories.

Demand

- **2012 Commercial Vehicle Survey (CVS)**: A truck intercept survey organized by the MTO that reveals anonymized data showing the truck route, vehicle configuration and commodities carried.
- **Transport Canada Marine summary**: shows the annual tonnage of goods shipped between a handling port and an OD port, aggregated to SCTG2 commodity codes.
- **Transport Canada rail traffic summary**: shows the annual tonnage of commodities, aggregated by SCTG2 commodity codes, shipped between rail zones. There are 27 rail zones defined within Ontario, and the rest of North America is divided into a further 30 rail zones. The rail data also show tonnages of commodities that shipped using bulk, or intermodal transport.

Economic

- Economic growth forecasts are a critical component of TRESO, and are an exogenous input that were developed as part of the macroeconomic model. The macroeconomic model forecasts the GDP and socioeconomic growth in 39 industry categories for the following economic regions:
  - Within Ontario: Forecasts are produced for every Census Subdivision (CSD).
  - Canada/US: Forecasts are produced for every Canadian province and US state.
  - World: Forecasts are produced for selected countries that are large trading partners of Canada (or are expected to be in future years).
- Detailed-level Statistics Canada Input-Output data – otherwise known as Make and Use tables – were used to describe the commodity generation and usage by different industries.

Supply Data

Using existing network data sources, a North America wide multimodal network was developed with progressively greater detail in Ontario and the Census Metropolitan Areas of the Province. A traffic zone system that uses a combination of various census and international geographies was generated using automated procedures to aid spatial allocation within the models. Finally, a synthetic firm dataset for all of Ontario was created that includes the number of employees in the firm and its industry.

Table 1 shows the use of the above datasets across the two models.

Table 1. Datasets used by the models.

Data Type	Commodity Flow Model	Long Distance Truck Model
Demand	X	
Economic • GDP and socioeconomic forecasts • Make and Use tables	 X X	 X
Supply		X

Commodity flow model

Predicting economic growth and the resulting change in commodity flows is a crucial component of forecasting long-distance truck travel. Within TRESO, this role is performed by the *commodity flow model,* which maps levels of macroeconomic activity to flows by commodity and mode between points outside of and within Ontario. These flows are then mapped to shipments and resulting vehicle flows in the long-distance truck model, the *urban truck tour* model and the *drayage portion* of the rail and marine commodity flows. The urban truck tour is not part of this paper and will be presented separately.

Figure 1 provides a high-level overview of the commodity flow model structure. The primary inputs to this model are the Transport Canada marine and rail summary data, and the MTO CVS surveys. These datasets are processed to convert them to a spatial resolution suitable for further processing. As one example, the truck data aggregated to commodity flows between CSDs (also including external zones) from individual point locations because this is the resolution of the macro-economic model within Ontario.

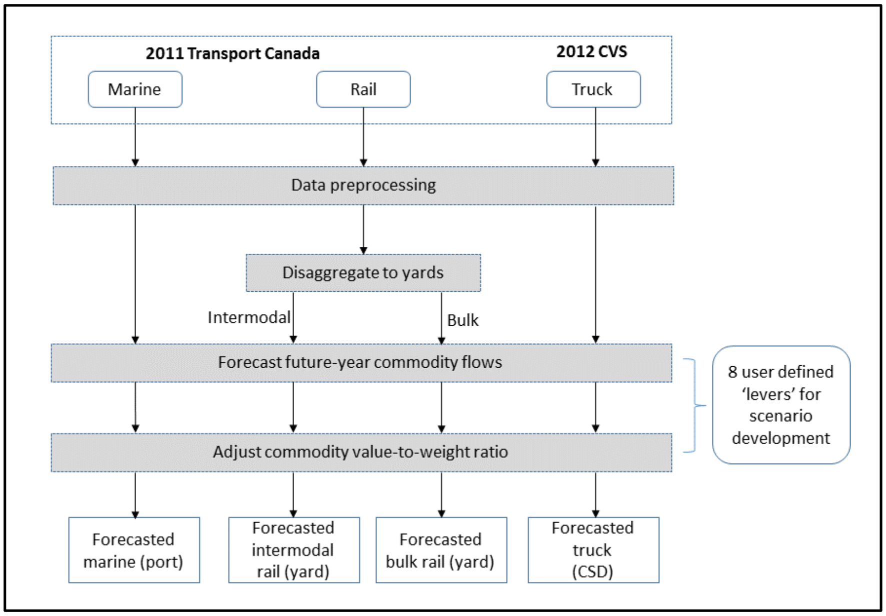


Figure 1: Commodity flow model flow chart

While the marine data was provided between ports and the CVS data provided origins destinations to precise locations, the rail data was only provided by Transport Canada between rail zones. Thus the rail data was first disaggregated down to rail yards, or actual rail loading and unloading facilities. Using a variety of different sources, 80 rail yards were identified in Ontario. Included in this process was the ability to distinguish rail yards as handling containerized commodities (intermodal) and handling bulk commodities. Using this processed information, commodities that were often shipped using intermodal transport or using bulk transport will be shipped to appropriate yards.

After the above processing, the future year commodity flows are forecasted by growing the truck, rail and marine base year flows, respectively, based on the economic growth forecasts from the macro-economic model. The commodities carried by truck are forecast differently than those carried by rail or marine, as the exact origins and destinations (CSDs) are known for trucks. For the other modes, however, the only origins and destinations that are known are where the commodities entered and exited the rail or marine systems. The final locations are unknown.

As a first step, the growth in each commodity produced and consumed within a region is calculated based on the economic (GDP) projections of that region, by industry with the help of the Statistics Canada Make and Use input-output tables. The *Make Table* shows the productions of commodities, by industry. Likewise, the *Use Table* shows the uses of commodities, again by industry. Using these tables, the growth by industry can be related to the growth in commodity using the following formulas:

$$CG_{p,k} = \frac{\left(GDP_i \cdot M_{i,k}\right)_f}{\left(GDP_i \cdot M_{i,k}\right)_b} \tag{1}$$

$$CG_{c,k} = \frac{\left(U_{i,k} \cdot GDP_i^T\right)_f}{\left(U_{i,k} \cdot GDP_i^T\right)_b} \tag{2}$$

where *CG* is ratio of commodity produced or consumed between the base and the forecast years, *M* is the make table, *U* is the use table. The subscripts in these equations are: *p*: produced, *c*: consumed, *b*: base year, *f*: future year, *o*: Ontario, *t*: CAD province or US state, *k*: commodity, *i*: industry.

It must be remembered that rail and marine flows were only observed while they remained in that system, hence the final origins and destinations were not known. For these modes, future year commodity growths within Ontario are forecast by multiplying the base-year flow by the ratio $avg(CG_{po},\ CG_{co})$; the average of the growth rates of commodity k produced within Ontario and consumed within Ontario. For imports and exports to and from Ontario, a similar equation is used where the base year flows are grown by the minimum value of the growth ratio of the producing province or state and the consuming province or state. The minimum value was used as the trading data for the other province or state are unobserved, hence there is no information about how any imbalances between the forecasts for the different regions could be addressed.

For trucks, within-Ontario commodity flows are forecast using a different procedure. Future year productions and consumptions of each commodity are forecast by CSD using equations 1 and 2. A Furness (matrix balancing) approach is then used to calculate the matrix flows between CSDs. Truck-carried imports and exports to Ontario, and through trips, are calculated using the same method as used for the rail and marine flows.

The commodity flow model was built to give the MTO a flexible tool for scenario analysis. Thus, a set of eight 'levers' or degrees of freedom were designed to allow for varying forecasts and in some cases for calibration. A list of the levers is noted below:

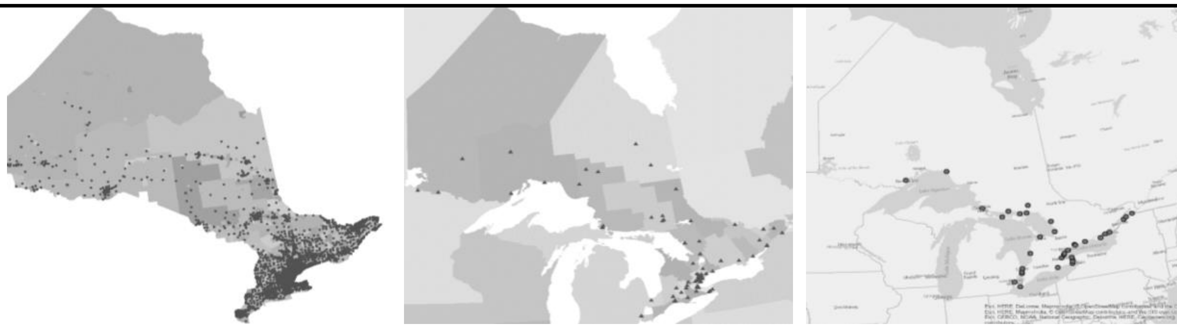
Lever (1-4)	**Lever (5-8)**
GDP by industry	Rail\Marine drayage flag (0/1)
Make and use tables	Rail yard proportion of commodities within rail zone
Rail containerization flag (0/1)	Commodity containerization ratio (by SCTG2)
Rail bulk flag (0/1)	Commodity value-to-weight ratio

For brevity, lever 8 and its applicability is noted below. Recognizing that technological changes have caused a drop in commodity weight while value has steadily risen e.g. television sets, the *Commodity value-to-weight ratio lever* allows the analyst to use it in scenario analyses to reflect the change of the value (in real $) of a kilogram of a commodity. This value is important as economic forecasts – such as the Gross Domestic Product (GDP) – are given in dollars. It has been found in trucking surveys in the United States that while the value of goods shipped has risen over time, the weight of these commodities has dropped due to changing technology.

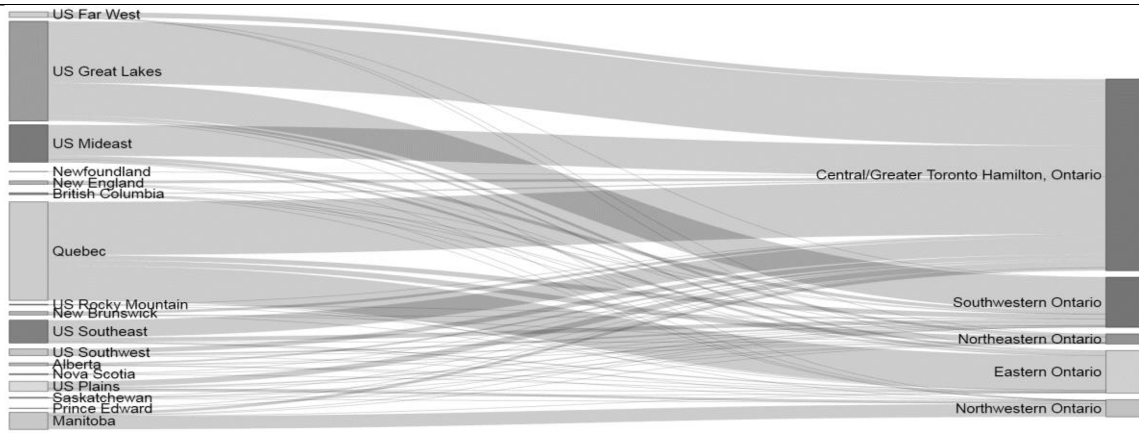
The output of the commodity flow model is as follows:

- Rail: Commodity tonnages between rail yards (and external zones) by SCTG2 commodity. Separate outputs are produced for intermodal and bulk flows.
- Marine: Commodity tonnages between rail yards (and external zones) by SCTG2 commodity.
- Truck: Commodity tonnages between CSDs (and external zones) by SCTG2 commodity.

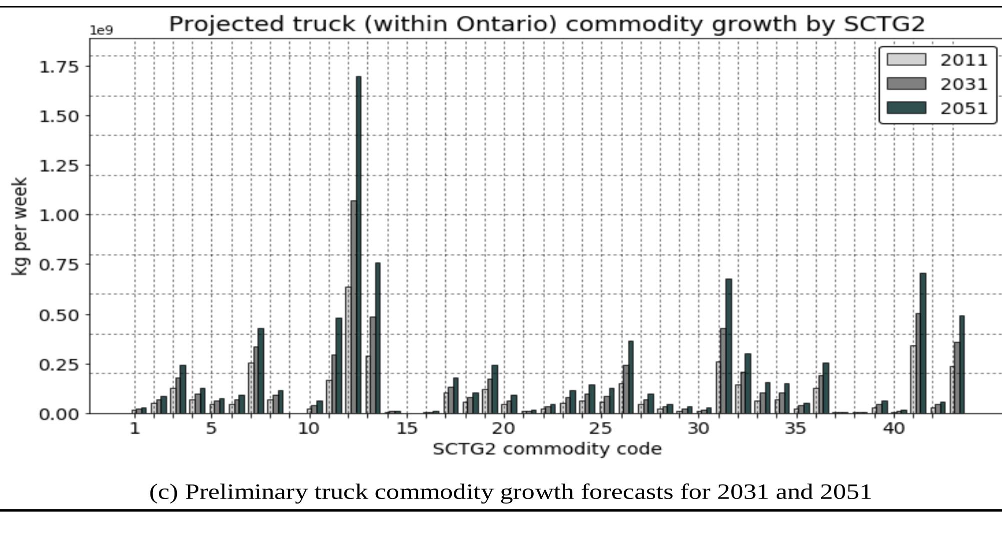
Figure 2 shows example outputs from the commodity flow model. Figure 2 a) shows example truck origins and destinations, and the railyards and marine ports within Ontario. Figure 2 b) shows the origins and destinations (by region) of imports to Ontario that were shipped by truck. Finally, Figure 2 c) shows an example scenario of the projected growth of commodities carried by truck within Ontario. While Figures 2 b) and 2 c) show results for the truck mode, these results can also be compiled for rail and marine modes, and also for selected regions of interest.



(a) Example truck points, rail yards and marine ports



(b) Sankey diagram showing base year trading patterns of imports by truck into Ontario



(c) Preliminary truck commodity growth forecasts for 2031 and 2051

Figure 2: Example commodity flow model results

Long–distance truck model

The *long-distance truck* model takes the commodity flows produced by the *commodity flow model*, and then assigns truck trips to represent the trucks that deliver these commodities. To aid in the conversion of commodity flows to trucks, observed shipping characteristics were mined from the CVS, as is described in this section.

Figure 3 shows the overall structure of the long-distance truck model. As is seen in this diagram, there are three primary types of truck trips that are forecast. From right-to-left in the diagram, these are:

1. Drayage trips to drop off and pick up commodities that were sent and received by rail and marine modes. Air transportation is not considered here as no data were available for this mode.
2. Trips to deliver truck-carried commodities forecast by the *commodity flow model*
3. *Other* truck trips, which are defined later.

The number of *drayage trips* to an intermodal facility (rail yard or marine port) are calculated based on the commodity tonnage originating from and destined to each facility. These are converted into the number of trucks by dividing the tonnage by the average truck weights for drayage trips, by each SCTG2 commodity code, observed from the CVS. As the commodity flow outputs tonnes per year, this division produces the truck equivalents per year. A scaling factor between the number days in a year is accepted as an input into the model for both rail and marine, and hence the analyst can input the length of the shipping season, by mode. The other end of a drayage trip is selected by sampling a firm from the synthetic population of firms – an input to TRESO – within the maximum drayage distance defined for the intermodal facility. During the sampling, firms are weighted by the number of employees and also by the make table coefficient (for origins) or the use table coefficient (for destination) of the commodity. After a firm is sampled, two trips are created, a first trip from the firm to the intermodal facility, and a second trip in the reverse direction. All drayage trips are assumed to be empty in one direction.

The truck forecasts from the commodity flow model are forecast using a similar procedure. First, however, the truck commodities are split between medium and heavy trucks. When data mining the CVS data, we found that the medium trucks are primarily used for shorter trips than heavy trucks, and also that the ratio between medium and heavy trucks varies by commodity. The ratio of medium to total trucks by SCTG2 were processed from the CVS data into text files, which are read by the long-distance truck models and act as one of the levers in the model for scenario evaluation and calibration. Firms within the origin and the destination CSDs are sampled using the procedure described above to produce exact origin and destination locations, which in this case are firms. Similar to the commodity flow model, the user has seven levers in the long distance model for scenario evaluation and calibration.

Levers (1-4)	**Levers (5-7)**
GDP ratios – other trucks	Synthetic firm generation
Proportion of medium trucks by SCTG2	Empty truck model decay parameters
Conversion factors – temporal analysis	Time of day profiles for medium and heavy trucks
Max. drayage distance to intermodal facilities	

The final type of input are *other* trucks. The CVS recorded a number of trucks that were either not carrying commodities but other items such as company tools. There were also cases where the driver reported being unaware of the commodity carried. Note that empty trucks are not included here as they are accounted for by a different sub-model within the long distance model. As the commodity of these trucks is not known, they are forecast simply by scaling the truck flows by the ratio of the GDP of Ontario in the forecast year to that of the base year.

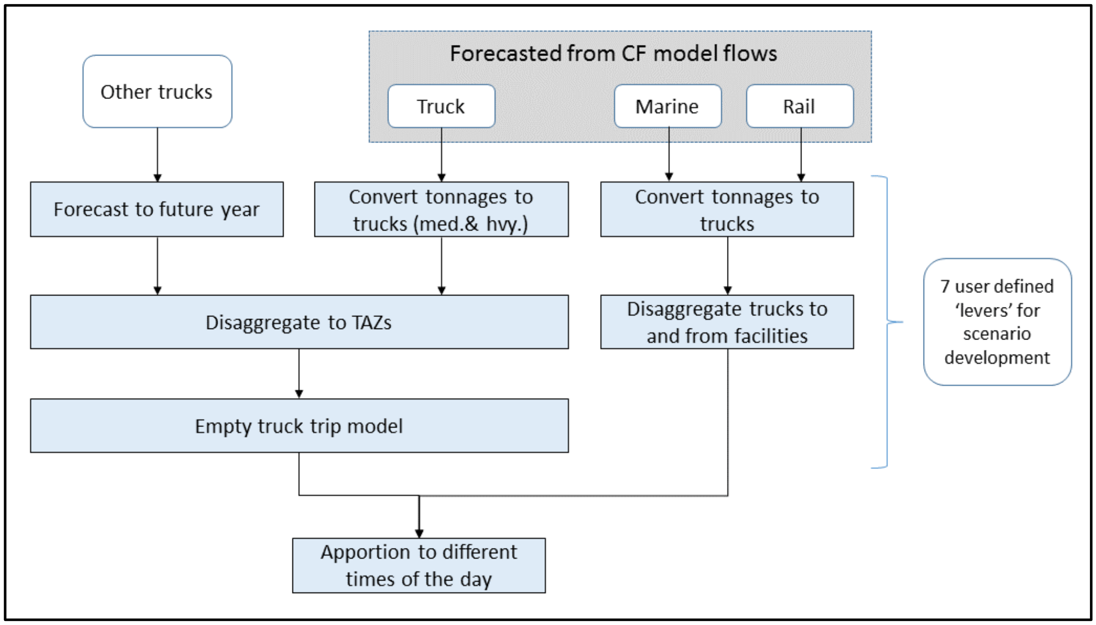


Figure 3: Long-distance truck model flow chart

It is well understood that empty trucks form a significant portion of truck volumes on roadways. These are accounted for using the empty truck model of Moeckel & Donnelly (2016). This model was chosen as it uses empty trucks to balance the number of trucks into and out of the traffic analysis zones (TAZs).

The *long-distance truck model* produces the following as results:

- A list of truck trips, segregated by commodity carrying trucks, other trucks and drayage trucks. This includes the following for every truck trip:
  - Origin: firm ID, industry code, and location (x and y, TAZ and CSD)
  - Destination: firm ID, industry code, and location (x and y, TAZ and CSD)
  - SCTG2 commodity code
- Empty truck trip matrices for medium and heavy trucks

The list of truck trips can either be used to assign trucks using an agent-based approach traffic assignment software, such as MatSIM. The long-distance model also rearranges the list of trips to produce origin destination matrices that can be assigned using aggregate trip assignment software, such as EMME.

Figure 4 shows preliminary and uncalibrated results showing heavy and medium truck volumes in Southern Ontario that were assigned using EMME on TRESO's network, which includes all of Ontario and extends to the rest of Canada and the continental United States. These results are promising as they show reasonable truck patterns of heavy and medium trucks, with the medium trucks primarily in urban areas and heavy trucks being the primary vehicles transportation goods over longer distances. Calibrations and refinements to the input parameters are expected during testing and calibration when more detailed comparisons will be made against the traffic counts.

References

Moeckel, M. & Donnelly, R. (2016) "A model for national freight flows, distribution centers, empty trucks and urban truck movements". *Transportation Planning and Technology*, 39(7).

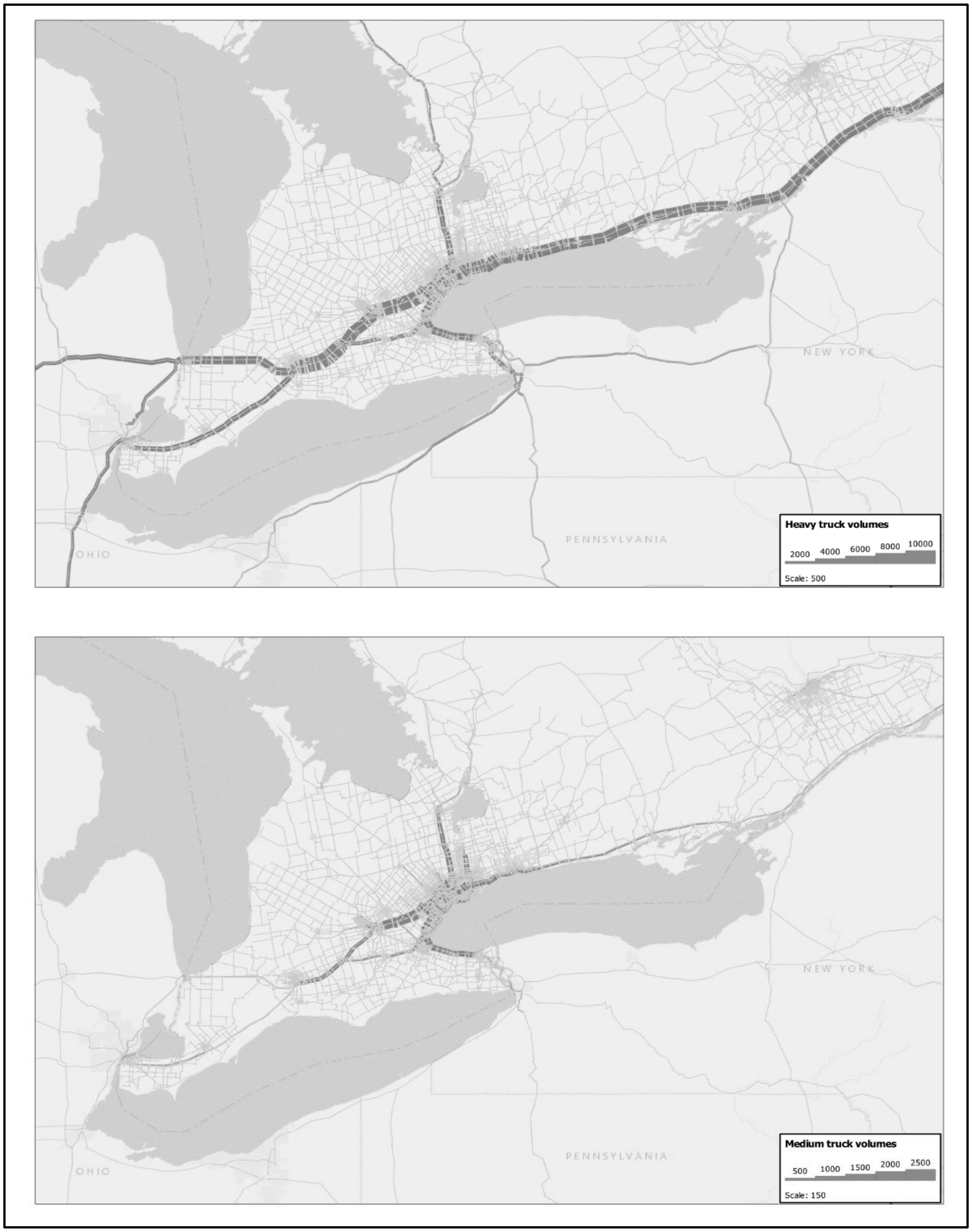


Figure 4: Preliminary base year heavy and medium truck volumes