COMMODITY-BASED GOODS MOVEMENT MODEL FOR THE ONTARIO AUTO INDUSTRY

Wen Xie and Matthew J. Roorda

Introduction

In Ontario, the understanding of truck movement has not kept pace with the increase of trucking activity. The truck industry in Canada has grown dramatically over the last decade from an annual revenue of $16 billion in 1997 to $32 billion in 2006 (Transport Canada, 2007). Despite more recent economic downturns, trucking is the mode of freight transport that continues to experience the greatest rates of growth relative to other modes. Truck transport provides the level of service demanded by the current just-in-time inventory systems, synchronous manufacturing processes and express retail delivery, which contributes to the growth of trucking activity. Truck transport is a prominent mode for intra-provincial good movement with 80% of commodity weights moved by truck (Transport Canada, 2007). The truck mode also plays an important role in Canada-US trade. Approximately 80% of the value of Ontario's trade with the United States moves by truck (Ontario Trucking Association, 2007). Given the importance of freight transportation to regional economics as well as the direct impact of truck volume on road congestion, it is necessary to develop a better picture of regional commodity flow by truck to support policy and infrastructure decision-making in Ontario.

One reason for the underdevelopment of truck demand models in Canada is the widely recognized deficiency in goods movement data. Obtaining information on trucking activity depends on the cooperation of private companies. However, private firms sometimes hesitate to provide information that is related to their business strategies, resulting in lower response rates than passenger travel surveys. Freight surveys also suffer due to the fact that no one person, or even one company, is necessarily knowledgeable about all of the salient information about shipments, their value, their mode of transport, the origin, destination and purpose of delivery. Finally, goods movements vary much more, day to day, than do passenger movements since companies typically ship and receive deliveries less often, less regularly, and to/from a greater variety of local, national and international locations, than do people whose main activity destinations are work or school and a limited number of shopping, social and recreation locations.

Roadside interviews are the current practice for collecting data about intercity truck movements in Ontario (MTO, 2001). However, the roadside interview program in Ontario misses significant flows of goods that never pass a survey station. It also makes no formal economic linkage to the businesses that generate demand for freight movement. There seems to be some opportunity, given knowledge gathered from other sources, to enhance the quality of the origin destination information available from the roadside interview stations.

Increasing attention is being given to commodity-based models, which are designed to capture the fundamental economic mechanisms driving freight movements. Commodity-based models use econometric data such as input–output (I-O) [1] data to generate commodity productions and attractions, and to determine the flows of commodities, which ultimately leads to truck trips and travel by other modes of transport. Commodity-based modelling approaches are usually considered to be more suitable for regional modelling (i.e. the flow of goods truck flows between counties or municipalities) than for urban modelling.

Gravity Model Approach with Gradient-based Updating

[1] I-O tables record the intermediate goods and services that are exchanged among industries and the desposition of finished goods and services to consumers, government, and foreign buyers.

This study uses a gravity model to estimate a preliminary O-D matrix, which is adjusted with commodity link flow information using an OD matrix updating technique. The impedance function is calibrated based on observed mean travel time, and is applied to the gravity model to distribute zonal commodity totals to origin and destination pairs. The matrix adjustment is performed in the EMME2 transportation planning software using an available macro based on gradient approach (Spiess, 1990). The final solutions are compared to the observed/partial O-D matrix using goodness-of-fit criteria.

Data used in the model estimation and validation include roadside interview data from 2001 Ontario Ministry of Transportation's Commercial Vehicle Survey (CVS) (MTO, 2001), Canadian Input Output tables (Statistics Canada, 2007a,b), Statistics Canada population and employment information (Statistics Canada, 2007c,d), truck shares from Transport Canada's annual report (Transport Canada, 2001). Total commodity production and attraction for Ontario are calculated from Input-output tables based on the System of National Accounts of Canada. Total commodity production and attraction by geographic zone are estimated by applying the distribution of population and employment by industry to the Ontario commodity production and attraction totals. Commodity link flows are assembled from CVS. Truck mode shares are introduced to the input data to convert the commodity values transported by all modes to commodity transported by trucks.

A commodity flow table is developed for the commodity group "motor vehicles and other transport equipment and parts" in this study. Ontario has been North America's second largest motor vehicle assembler. Auto manufacturing is one of the key manufacturing industries in Ontario. Automobile and transport equipment has also been the top commodity transported by truck for international trade. In recent years, however, Ontario's auto manufacturing industry has been hammered by high gas prices, a weakening global economy, fluctuations in the value of the Canadian dollar, and a shift in consumer tastes away from trucks and SUVs. Truck plant closures and job cutting are sweeping the manufacturing heartland. The down turn of auto manufacturing industry has a significant impact on Ontario's economics and employment. The study of commodity-based truck traffic for "motor vehicles and other transport equipment and parts" becomes more interesting and meaningful under these circumstances.

Commodity-based Truck Traffic Model for Ontario

Zone System

Traffic analysis zones in the province of Ontario are defined based on the consideration that the model is estimated from a limited number of roadside interview stations and aggregate employment information. This study follows the approach of Al-Battaineh and Kaysi (2005) who suggest that employment and population be used to distribute provincial production and consumption totals. The zone system is intended to be consistent in detail with the number and location of observed roadside counting stations. For this reason, in areas that have sparse coverage in the MTO CVS, the study zones are defined as Census Divisions (CD). In the Greater Golden Horseshoe (GGH) area, which has a higher concentration of employment and better coverage of CVS stations, Census Subdivisions (CSD) are adopted as the zones in the Regions of Durham, York, Peel, Halton, Niagara, Waterloo, and Simcoe and the Cities of Toronto and Hamilton. There are 103 internal zones in total.

The selection of representation for external stations is based on the border crossings between Ontario and the US and the highway crossings between Ontario and Quebec and Manitoba. There are 16 border crossings recorded in CVS 2001, through which the truck drivers make their trips. These 16 border crossing are considered as external stations in the model.

The goods movement network for truck transport is represented by provincial highways. To allow commodity flows to be assigned to the network, it is necessary to code zone centroids at freight generating points at realistic locations. It is unrealistic to code the centroid at the geometric center of a zone if a large area around the centroid is only farmland. For the purpose of this study, the freight generating points are assigned to places where the automotive manufacturers or employment concentrate.

There are at least three limitations in the simplified network coding practice. First, trucks can use links that are not part of the provincial highway network. However, most inter-regional flow of provincial significance does use the provincial highway network. Second, assumptions are made in the coding of centroid connectors about the distribution of zonal production or attraction to each highway access point, which may lead to local area inaccuracies in the commodity assignment to the highway network. Third, the centroids are coded for the purpose of modelling the transportation equipment commodity category transported on the highway. More general freight activities centers should be coded as centroids if different commodity categories are considered in the commodity-based truck demand model.

Commodity Generation

The commodity production and attraction for each internal zone are estimated by assuming Ontario total input and output by industry is distributed in proportion to relevant categories of employment and population.

The yearly zonal commodity production and attraction are calculated using equation 1 and 2, respectively:

$$O^{z'} = \sum_{i \in I} \left[\left(\frac{E_i^{z'}}{\sum_{z \in Z} E_i^{z}} \right) \times M_i \right]_i \qquad \text{(Equation 1)}$$

$$D^{z'} = \sum_{i \in I} \left[\left(\frac{E_i^{z'}}{\sum_{z \in Z} E_i^{z}} \right) \times U_i \right]_i + \left(\frac{P^{z'}}{\sum_{z \in Z} P^{z}} \right) \times F \qquad \text{(Equation 2)}$$

Where

$O^{z'}$ is the production of the commodity in zone z'.

$D^{z'}$ is the attraction of the commodity in zone z'.

$E_{i'}^{z'}$ is the employment in zone z' for industry i

$P^{z'}$ is the population in zone z'

$M_{i'}$ is the Ontario total output of the commodity from industry i

$U_{i'}$ is the Ontario total input of the commodity to industry i

F is Ontario final demand of the commodity

Z is all internal zones

I is all industries defined in two-digit NAICS

The Canadian Input-output Tables provide total 2001 Ontario input, output and final demand of commodity group "motor vehicle, transport equipment and parts", which is referred as "commodity m".

The generation and attraction of commodity m in each zone largely depend on the magnitude of the manufacturing industry, and particularly those manufacturers that produce and/or consume commodity m. The production and attraction of commodity m by each internal zone are calculated using Equations 1 and 2 and employment from Census of Canada and the Canadian Business Patterns. The resulting values are annual totals and represent commodity flow by all transportation modes.

The study includes external stations which accommodate commodity flows with one or both ends outside Ontario. The Commercial Vehicle Survey (CVS) records the commodity value in trucks that pass each border crossing station and is used to calculate external (trans-border) commodity flow.

Freight Mode Choice

Rail and truck modes (and to a lesser extent marine and air modes in the Toronto Area) compete to move manufactured products. The mode choice decision involves many factors, including distance, time, cost, reliability, damage or theft potential, and frequency of service. Little data are available to assess mode choice. Therefore, simple truck share factors are assumed to represent the commodity flows that are transported by truck. Clearly, a single truck share factor is insufficient to represent the truck-haul commodity flow between zones for a regional model. Urban or short-haul trips are captive to the truck mode, while long-haul trips may involve intermodal rail. The "Transportation in Canada Annual Report" (Transport Canada, 2001) is used as the best available source of information to approximate truck share factors for 2001.

Truck shares are approximated for the study area depending on the relative locations of the origin and destination zones, as follows:

- Commodity flow within the Greater Golden Horseshoe – 100%;
- Commodity flows between zones in the rest of Ontario – 90%;
- Commodity flows between Ontario and external zones (except from US to Ontario) - 60%;
- Commodity flow from US to Ontario – 80%.

Traffic Assignment

The O-D matrix estimation method aims to minimize the deviation between estimated link flow and observed link flow, as well as the deviation between other observed and estimated values. To provide estimates of the link flow, the estimated O-D matrix must be assigned to the transportation network, ideally accounting for delays associated with congestion. Accounting for congestion poses several complications to the procedure, as follows:

- To determine congestion delay, it is necessary to have information about the flow of passenger cars as well as truck volumes. Modelling of passenger travel at the provincial level is beyond the scope of this research.
- Congestion delay varies by time of day. Modelling of the time of day is beyond the scope of this research.
- With congestion, the route assigned for each trip may change, depending on the O-D matrix. This means that a separate traffic assignment would be required for each candidate OD-matrix, a computationally intensive proposition. While it is possible to use

parallel distributed computing to achieve this, it would require multiple licenses of a transportation planning software such as EMME/2 or TransCAD.

For these reasons, an "all or nothing" traffic assignment is used to assign the shortest travel time route for each Origin-Destination pair, assuming free-flow traffic conditions.

Construction of an Observed OD matrix for Model Validation

The Commercial Vehicle Survey (CVS) is the only data source available to derive an observed commodity O-D matrix for validation purposes. The observed O-D matrix from the CVS is used to validate the performance of the gravity model method using formal goodness-of-fit statistics. However, this validation should only be considered a partial indicator of success, because the Ontario CVS OD commodity flow matrix is a partial estimate of the commodity flows (since roadside counting stations cannot fully capture all truck flows). For each survey record, the CVS database contains information about the commodity value, the commodity origin and destination, trip origin and destination, and the provincial/international border crossing if the trip enters/leaves Ontario.

Expansion factors are applied to each of the records, such that the total commodity value estimated for each data collection site (DCS) incorporates both the value carried by trucks surveyed at the DCS and an estimate of the values carried by trucks passing by the DCS (using traffic counts and information from other DCSs). The observed commodity O-D matrix is constructed by summing the expanded trip records associated with each O-D pair.

Gravity Model Approach with Gradient-based Updating

A preliminary O-D matrix for the "motor vehicles and other transport equipment and parts" commodity is first estimated based on a production-constrained gravity model, as shown in Equation 3. The required inputs for the model include production and attraction at each zone and an impedance function. The production and attraction are obtained from Ontario input/output table, as described previously. A negative exponential impedance function $f(t_{ij}) = e^{-c(t_{ij})}$ is used for this gravity model[2]. The parameter c in the impedance function represents the sensitivity to travel time. This parameter is calibrated such that the estimated mean travel time matches the observed mean travel time from the Commercial Vehicle Survey, assuming a free flow travel time between zones. The resulting parameter estimate is 0.0038, which indicates that the distribution of commodities in the "motor vehicle, other transportation equipment and parts" commodity type is relatively insensitive to travel time.

$x_{ij} = O_i D_j f(t_{ij}) / \Sigma_{j'} D_{j'} f(t_{ij})$ (Equation 3)

Where:
x_{ij} = Commodity flow from origin zone i to destination zone j
O_i = Production of commodity at zone i
D_j = Attraction of commodity at zone j
$f(t_{ij})$ = Impedence function
t_{ij} = travel time from zone i to j

The second step of the matrix estimation is to update the preliminary matrix using a gradient method in which observed commodity link flow information is taken into account. The truck share factor is applied to the preliminary matrix to obtain the commodity flow matrix by truck mode. The gradient-based approach was proposed by Spiess (Spiess, 1990), who uses a steepest descent method for the solution of a bi-level structured problem. This gradient approach is implemented in EMME/2 transportation planning software with a macro called DEMADJ. Spiess developed this algorithm based on two principles:

1. Minimization of the difference between observed and estimated link volumes.
2. Travel patterns in seed matrix not changing more than necessary.

---

[2] The exponential impedance function based on travel time is recommended in Quick Response Freight Manual (1996).

10 iterations are allowed before the updating process stops. Two goodness-of-fit statistics are calculated to determine how well the modelled matrices match the observed OD flows. An improved fit is indicated by increasing R^2 and a decreasing RMSE (Root mean squared error).

The comparisons of estimated matrices and observed matrix are summarized in Table 1. All of the values in the table are measured in millions of dollars per week.

Table 1 Comparison of Observed O-D Matrix and Estimated O-D Matrices using Gravity Model Approach

Commodity flow ($million/week)	Estimated matrix			Observed matrix
	Step 1: Preliminary matrix from gravity model (all modes)	Step 2: Matrix after truck mode shares applied	Step 3: Matrix after gradient method adjustment	Ontario CVS
Internal to Internal	978	922	1295	1148
Internal to External	1120	672	868	856
External to Internal	611	468	565	696
External to External	478	362	302	139
Total	3187	2424	3030	2839
Intra-district flows	31	30	30	68
Maximum district-to-district flow	103	62	83	83
R^2	0.34	0.31	0.42	
RMSE	2.85	2.77	2.57	

The Spiess updating process clearly improves the fit of the modelled matrix to the observed CVS matrix. The final estimated matrix (after Step 3) has a total commodity value of 3.03 billion dollars per week, which is 7% higher than the observed matrix total. Commodity flows within Ontario (Internal to Internal) and through Ontario (External to External) are overestimated by approximately $150 million each, commodity imports are under-estimated by approximately $130 million, and commodity exports are modelled very closely.

Figure 1 shows the correlation between observed and estimated O-D matrix cell values. There is a lot of scatter in this plot, showing that the gravity model procedure only captures part of the variance in commodity flows in Ontario at the district to district level. Figure 2 and Figure 3 compare observed and estimated commodity generation. The correlation is better, because this is a more aggregate measure of matrix performance. Figure 4 compares the observed flow and estimated flow on all highway links. The convergence of points along the diagonal axis indicates that a very close correspondence has been achieved for flows at the link level.

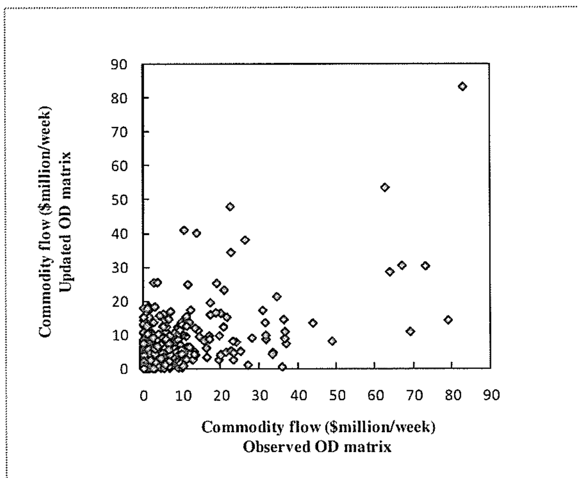

Figure 1 Comparison of observed and estimated OD matrix cell values (after OD updating using the gradient method)

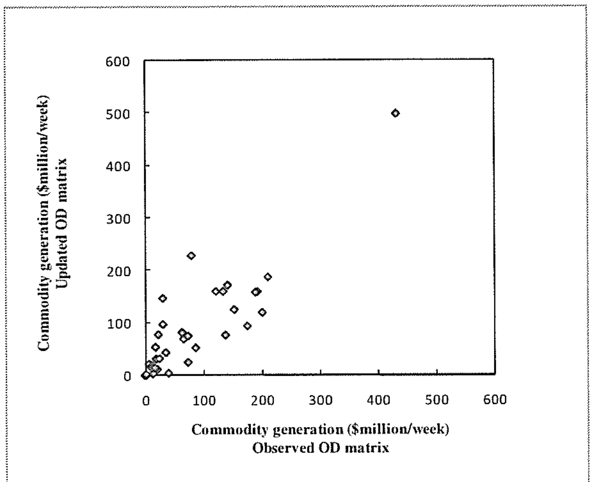

Figure 2 Comparison of observed and estimated commodity generations

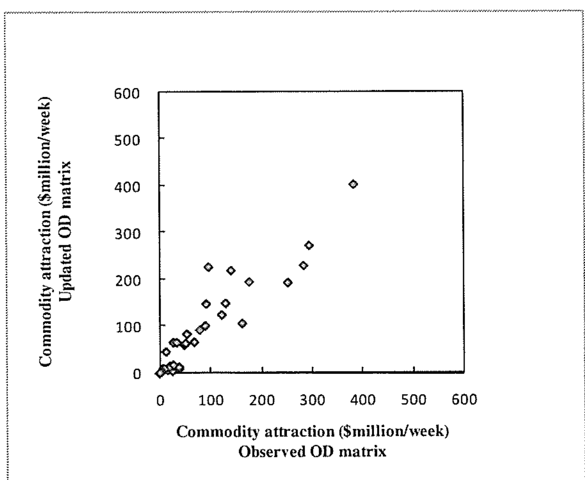

Figure 3 Comparison of observed and estimated commodity attractions

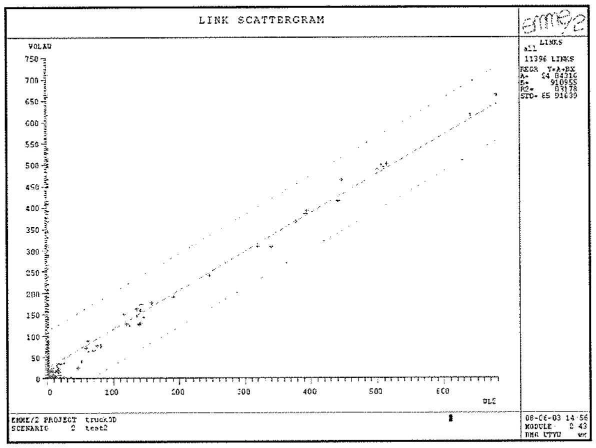

Figure 4 Comparison of observed and estimated link flows

Conclusion

This research develops and examines a commodity-based approach in estimating truck traffic using available data sources, with a focus on a case study for a single commodity group - "motor vehicles and other transport equipment and parts" in Ontario, Canada.

The study has established a step by step procedure for utilizing freight data from various sources to improve our estimates of OD commodity flows in Ontario. These data include roadside interviews from the MTO CVS, provincial input/output tables, population and employment, and truck shares. Estimates of freight transportation demand such as zonal commodity production/attraction, commodity link flow, average travel time and O-D demand estimates are constructed from these data sources. Although the study focuses on one commodity group "motor vehicles and other transport equipment and parts", a similar procedure can be adopted for other commodity groups.

The modelling approach has potential applications in the assessment of the changing economic fortunes of the auto industry in Ontario and changes in the distribution of auto manufacturers and suppliers throughout the province. Given the major restructuring that is currently taking place in the auto industry in Ontario, such tools are of key relevance for assessing the resulting impacts on existing highway infrastructure and future infrastructure needs.

Future research is recommended to focus on exploring truck O-D estimation techniques designed to expand the types of data used in model estimation to further improve our freight transport demand estimates. We also recommend test applications of the model for the analysis of future scenarios for investment in the auto sector.

References

Al-Battaineh, O., & Kaysi, I. A. (2005). Commodity-based truck origin-destination matrix estimation using input-output data and genetic algorithms. *Transportation Research Records: Journal of the Transportation Research Board,* (1923), 37-45.

MTO (2001). 2001 MTO Commercial Vehicle Survey. Transportation Planning Branch. Ministry of Transportation of Ontario.

Ontario Truck Association (2007). Industry Snapshot. Retrieved April 10, 2007 from http://www.ontruck.org/news/industry/

Spiess, H. (1990). A Gradient Approach for the O-D Matrix Adjustment Problem. EMME/2 Support Center, 1990.

Statistics Canada (2007a). Inputs and outputs, by industry and commodity, S-level aggregation and North American Industry Classification System (NAICS), annual (dollars), CANSIM. 1961 to 2002. Retrieved April 10, 2007 from http://cansim2.statcan.ca/

Statistics Canada (2007b). Final demand categories, by commodity, S-level aggregation, annual (dollars), CANSIM. 1961 to 2002. Retrieved April 10, 2007 from http://cansim2.statcan.ca/

Statistics Canada (2007c). Labour force survey estimates (LFS), employment by North American Industry Classification System (NAICS), seasonally adjusted and unadjusted, monthly (persons). CANSIM. Retrieved August 17,2008 from http://cansim2.statcan.ca/

Statistics Canada (2007d). Census of Canada, 2001: profile for Canada, provinces, territories, census divisions, census subdivisions (profile series: 97c0025). Ottawa, Ont.: Statistics Canada. Retrieved Feb 26, 2007 from

Transport Canada (2001). Transportation in Canada Annual Report 2001. , http://www.tc.gc.ca/pol/en/anre/menu.htm

Transport Canada (2007). Transportation in Canada Annual Report 2007. , http://www.tc.gc.ca/pol/en/anre/menu.htm