A NEW APPROACH FOR ESTIMATING ESTABLISHMENT-BASED ORIGIN-DESTINATION TRIP MATRICES FOR URBAN COMMERCIAL VEHICLE MOVEMENTS

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ABSTRACT

The current knowledge on the relationship between urban commercial vehicle movement (UCVM) and the sustainability of transportation systems is very limited. Most of the existing efforts to study the UCVM process have relied on aggregate traffic count data. Such data are usually not sufficient to account for all types of the commercial vehicle movements happening in the city. In contrast, business-establishment based micro data on commercial vehicle movements are deemed more appropriate, albeit little has been done to date to collect and analyze such information. This is due to the high cost of gathering such micro observations especially in large metropolitan areas. In this paper, we propose and examine a robust method for generating establishment based origin-destination (OD) trip matrices that can be used to study UCVM in large urban regions. With an application to the Greater Toronto and Hamilton Area (GTHA), we adapt a microsimulation tour-based commercial vehicle movement model from Calgary, Alberta to estimate establishment-based tours using an exhaustive list of business establishments that was acquired from InfoCANADA. We report on the efforts undertaken to implement the Calgary model and estimate the OD matrices from the generated tours for the GTHA.

Introduction

Urban Commercial Vehicle Movement (UCVM) exerts substantial influence on traffic flow, road pavement damage and environmental emissions in urban areas. A proper assessment of these impacts requires detailed business establishment-based data on commercial movements, which are non-existent for the majority of cities. In Canada, only Calgary and Edmonton in Alberta and the Peel Region in Ontario have collected appropriate datasets for such analysis. However, the collection of such detailed data is time consuming and costly. Most of the existing efforts to model UCVM have depended on techniques known as Origin-Destination (OD) matrix expansion, where OD matrices are derived from traffic or cordon counts and zonal employment. However, OD expansion techniques have been criticized for being policy insensitive, as well as for failing to capture 'small' commercial vehicles, such as those used for services and deliveries.

To address these limitations, this study is focused on devising and applying a new technique for generating commercial vehicle OD matrices. The proposed approach differs in that the focus is at the micro-level on the business establishment as a shipper of goods and services. This focus is in contrast to the common approach that emphasizes zonal based employment. Through its refined nature, this proposed approach is hoped to provide better accuracy and therefore will have the potential to provide better policy handles.

The development of establishment-based origin destination commercial vehicle trip matrices will be used in a study to develop a strategy for Commercial Vehicle Movement in the GTHA. The latter is led by Metrolinx, the Transportation Authority in the Greater Toronto Area. The creation of the OD matrices will rely on devising methods to synthesize and estimate the commercial activities that individual establishments will engage in for shipping goods and services over space.

Background

The second half of the past century witnessed dramatic changes in the spatial structure of many cities around the globe. In Canada, as in many other developed countries, these changes were to a large extent the outcome of increasing automobile dependence along with the continuous investment in road infrastructure projects. The patterns of urban development, since the 1950s, have caused environmental problems that are believed to threaten the sustainability of the natural habitat. Such environmental concerns have put the future of urban development at the top of the political agenda in North America. Academics, practitioners and politicians are interested in developing a planning process that will provide a path to a sustainable city future.

As a result, the analysis of the urban transportation system has been at the heart of the planning process in cities. In doing so, emphasis was placed on passenger transportation in order to understand the intra-urban travel behaviour of households and their members. This is well reflected in the massive literature on the topic. Consequently, conventional four-stage urban transport modeling systems used by most metropolitan planning organizations (MPOs) as well as state-of-the-art integrated land use and transportation models are developed to simulate and predict passenger transportation (Hunt et al., 2005 for a detailed review of these models). By comparison, very little work has been done to address urban commercial vehicle movement (UCVM) in these models. One possible explanation for the lack of focus on UCVM is because passenger transportation is the major contributor of traffic (more than 85%) in an urban area.

Although recent empirical evidence suggests that UCVM is responsible for as low as 12% of total urban travel (Stefan et al., 2005b), it exerts substantial influence on traffic flow, road surface conditions and environmental emissions (Kanaroglou & Buliung, 2008). In a dynamic economy that is becoming service oriented and also due to firm suburbanization, commercial movement by light vehicles is likely to be on the rise. Coupled with contradicting evidence on the level of traffic that UCVM contributing, it is essential

not to dismiss commercial vehicle movement when analyzing the urban transportation system.

Recognition of the contribution of UCVM to local and regional economies, the impact of UCVM in cities, and the unique set of conditions and behaviours that facilitate and characterize UCVM have lead to increased research activity in the past few years. However, most of the current efforts to address the issue are based on conventional methods that do not rely on proper data to fully scrutinize the impact of UCVM on the urban transportation system. Conventional methods focus on estimating flows between origins and destinations based on aggregate data that are collected from intersection truck counts. Here, OD matrix expansion methods and four-stage models are involved (Freidrich et al., 2003). However, conventional methods suffer from several problems including the lack of policy response, the exclusion of half of commercial movements that are made with light commercial vehicles and the neglect of service trips (Stefan et al., 2005a). Other less commonly used methods employ the spatially disaggregate input-output approach to represent the commodity flows in the economy as done in the MEPLAN and PECAS integrated urban models (Hunt et al. 2005). However, the latter approach simplifies important elements of UCVM such as trip chaining and load hauling (Stefan et al., 2005a). More elaborate methods also focus on supply chain modeling where suppliers, warehouses and consumers of products are explicitly modeled in supply chains. However, this approach requires extensive data that are normally unavailable and difficult to obtain.

More recently, the agent-based microsimulation approach has become the state-of-the-art in household travel behaviour modeling. Within this approach, the total process of urban development is broken down into subprocesses and within these the micro agents (persons, households, firms, developers, etc.) and their decision behaviour is identified and analyzed. The microsimulation approach is believed to rectify many of the drawbacks in conventional land use and transportation planning models. Identified drawbacks in existing models include: (1) their aggregate nature; (2) their static nature and

lack of behavioral realism and (3) their weak response to long-term planning policies due to their inadequate policy sensitivity. Such drawbacks are believed to impede the performance of these models. Stefan et al. (2005a), Hunt and Stefan (2007) and Stefan et al. (2007) provide a pioneering effort by adopting the microsimulation approach to model UCVM in the City of Calgary in Alberta, Canada. However, it should be noted that their work is based on high quality data that were collected for the first time in Canada through extensive surveys (Hunt et al., 2006). Other notable efforts for UCVM data collection and analysis in Canada are those in the Greater Toronto Area (GTA) (Roorda et al., 2006).

The work on UCVM in Alberta provides considerable insight with respect to the behavior of the commercial vehicle fleet in the Calgary and Edmonton metropolitan areas (Stefan et al., 2005b; Hunt and Stefan 2007). The analysis of their data suggests that in both cities, UCVM accounts for about 12% of the total vehicle kilometers traveled (VKT). The data also indicate that light vehicles including small four-tire vehicles such as cars, vans, pick-ups and SUVs contribute more than 60% of commercial movements in both cities. Furthermore, more than 33% of stops by such vehicles are to deliver services. These findings underscore the serious limitation in relying on conventional methods to address UCVM. Stefan et al. (2005b) note that studies considering just transportation handling operations where good deliveries are the main focus in a city might be missing as much as 75% of UCVM. The general pattern of results from Calgary and Edmonton suggests a fair degree of similarities in the nature of UCVM on a typical weekday.

From a planning perspective, it is important to realize the existing difference between urban passenger transportation and UCVM. The latter is very different from the former in its travel pattern, fleet characteristics and spatio-temporal dimensions. It remains that UCVM is a major contributor to degrading urban air quality as suggested by Kanaroglou and Buliung (2008), and therefore should be considered as a major component of any transportation modeling system.

Study area and data

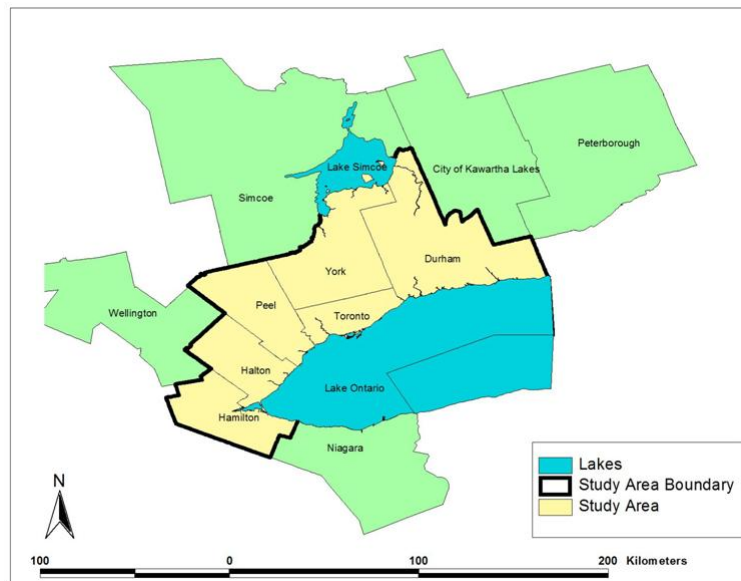This study is focused on the Greater Toronto and Hamilton Area, as shown in Figure 1.

Figure 1: Study Area

Since the collection of detailed business-establishment data requires immense resources for a vastly large economy like the Greater Toronto and Hamilton Area, this study is proposing an alternative approach that does not require the collection of such data, yet will be based on business establishments as the unit of analysis. The creation of the OD matrices will rely on devising methods to synthesize or/and estimate the commercial activities that individual establishments will engage in for shipping goods and services over space. The synthesis and estimation will be achieved by integrating three major sources of information:

1. A complete list of business establishment in the GTHA that will be acquired from InfoCanada

2. A micro sample of surveyed establishments with commercial vehicle movement activities. This micro-data pertains to surveyed establishments in the Peel Region in 2006-2007.
3. Model parameters from an agent-based microsimulation Urban Commercial Vehicle Movement model developed for Calgary, Canada (Hunt and Stefan 2007).

Other sources of information to be used will include GIS coverage of the traffic analysis zone boundaries and the transportation network in the GTHA. In addition, we will include any insight we can from other metropolitan areas where such estimates have been made – in particular Calgary. Finally, Statistics Canada data on interregional commodity flows and on employment patterns, and data from MTO's commercial vehicle survey, will be used in this modeling exercise.

Approximately 180,000 records pertaining to all economically active business establishments in the study area are acquired from InfoCanada. Each record included information on the name of the firm, its address, the number of employees it has, the sales volume it generates and the type of industry it is actively involved in based on the 6-digit Standard Industrial Classification (SIC) codes. The data also includes information which describes the nature of the business operation. The InfoCanada data were geocoded to the road network to establish a geographic location for each establishment on the map. The geocoding was performed based on the physical address of each establishment. A precision of over 93% match between the establishment addresses and the road network was achieved. Figure 2 provides the breakdown of the total number of business by municipality.

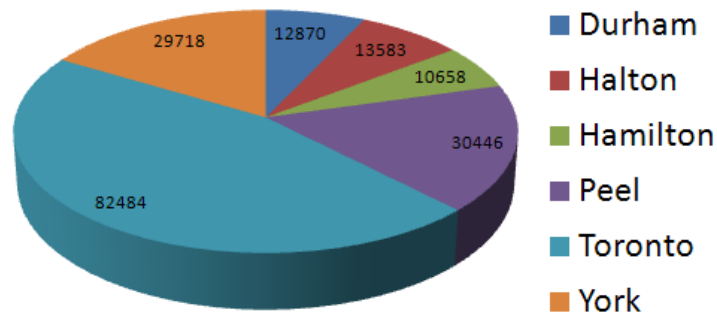## Number of Establishments in GTHA

Figure 2: Distribution of business establishments in the study area

The Peel region data were also analyzed. A total of 597establishments were surveyed. Each establishment included the following information:

- x-y coordinates
- number of employees
- number of employees by type (including number of truck drivers)
- industry classification (16 categories)
- square footage of firm location
- number and type of vehicles which arrived/departed on survey day
- number and type of vehicles owned
- yearly value of goods received/ shipped
- yearly number of shipments
- yearly value of shipments by broad geography (Peel, GTHA, ON, USA, etc.)
- frequency of shipments by mode

The analysis of the Peel data indicates that 346 firms provide example of outbound shipments which add up to 2217 shipments in total. On

the other hand, the data also indicates that 309 firms provides example of inbound shipments which add up to 986 shipments in total. Each shipment includes the following attributes:

- description of service / commodity
- value/ weight of commodity
- destination location
- mode of transport

Furthermore, 80 of the 597 establishments have detailed tour data associated with them. These tours are performed by 93 drives and collectively include 751 stops resulting in an average of 8 stops per tour.

Methods of Analysis

The proposed method to estimate UCVM origin-destination matrices will rely on the modeling framework developed for the City of Calgary (Hunt and Stefan 2007). Using the InfoCanada business establishment data as a baseline population, we will implement and utilize the Calgary microsimulation model to estimate commercial activities per business establishment in the Greater Toronto and Hamilton Area. Validations can then be performed using the available information from the Peel UCVM survey among other statistics. The Calgary UCVM model handles three types of commercial movements: tour-based movements (70%), fleet-allocator movements (24%) and external-internal movements (6%). Tour-based movements constitute the majority of UCVM in Calgary. Therefore, it is imperative that these types of movements be modeled when estimating the OD matrices. Figure 3 presents the modeling framework devised by Hunt and Stefan (2007) to model tours. The model starts by estimating the total number of generated tours per employee per day. This is then fed into a tour type and vehicle type model which determines the type of the tour (goods, service or other) and the type of vehicle that will be
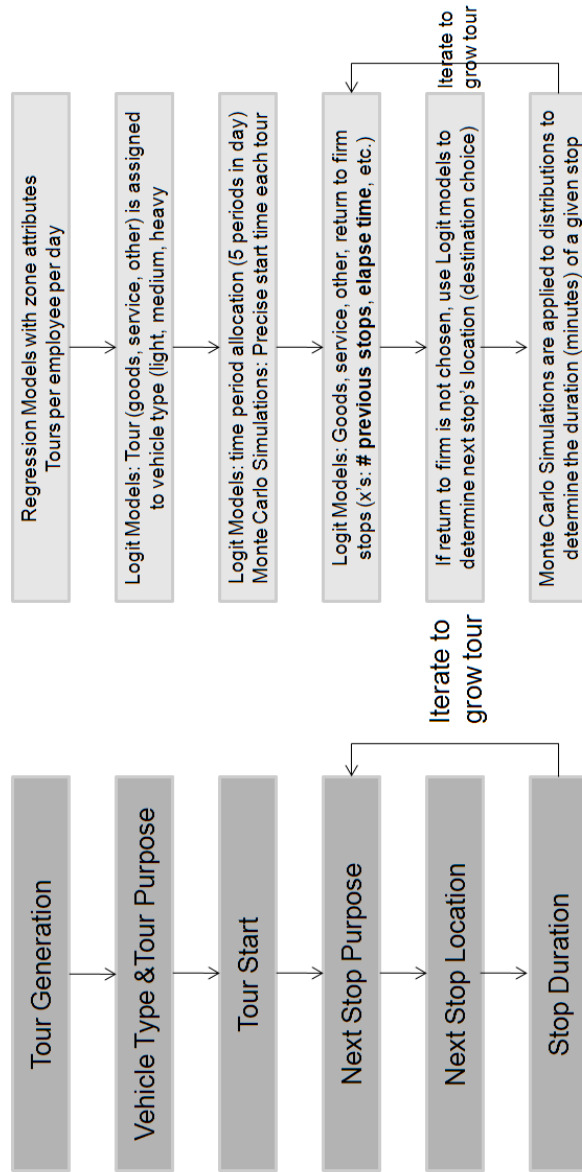
Figure 3: Tour-based microsimulation framework (*Source: Hunt and Stefan 2007*)

Tour Generation — Regression Models with zone attributes / Tours per employee per day

Vehicle Type & Tour Purpose — Logit Models: Tour (goods, service, other) is assigned to vehicle type (light, medium, heavy)

Tour Start — Logit Models: time period allocation (5 periods in day) / Monte Carlo Simulations: Precise start time each tour

Next Stop Purpose — Logit Models: Goods, service, other, return to firm stops (x's: **# previous stops, elapse time, etc.**)

Next Stop Location — If return to firm is not chosen, use Logit models to determine next stop's location (destination choice)

Stop Duration — Monte Carlo Simulations are applied to distributions to determine the duration (minutes) of a given stop

Iterate to grow tour

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used to perform the tour (light, medium or heavy commercial vehicle). Figure 4 provides an example of a tour that starts and ends at the business establishment. Upon determining the type of the tour and the vehicle used to deliver the tour, the start time of the tour is determined by running a multinomial logit model which determined the period of the day when the tour will happen. This is then scaled down to the precise start time of the tour via Monte Carlo Simulations. As shown in Figure 4, a tour might consist of several stops, although many tours are two-leg tours. To account for the stops, a next stop purpose model is utilized. This is a multinomial logit model that determines whether the next stop will be to deliver a service, goods, perform other duties such as going to lunch or return to the establishment. The next stop purpose model is sensitive to a number of variables including the number of previous stops and the elapse time, both of which are acting as a disutility for a next stop to take place. That is, the higher the number of previous stops and the larger the elapse time between stops, the less likely that a next stop will occur and the vehicle is more likely to return to the establishment, other things being equal. If a return to establishment is not chosen, then a next stop destination choice model is used to determine the next stop location. The duration of the stop is determined through Monte-Carlo simulations. Notice that in order to establish a profile for the tour activities, the tours are being grown through an iterative process, as shown in Figure 3.
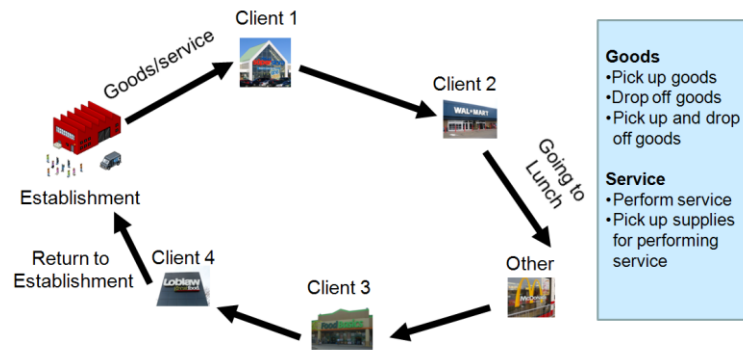

Figure 4: Example of a Tour-activity

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As for the fleet allocator movements, these are treated with separate models. According to Stefan et al. (2007), these movements are generated by a coordinated fleet with few specific generators such as mail and courier, garbage and recycling trucks, city parts and road maintenance and newspaper and flyer deliveries. In a way, these movements are not easy to survey, however, they are less demand sensitive and have more predictable patterns compared to tour-based activities. As such, they can be modeled via conventional gravity models. Stefan et al. (2007) present a fleet allocator model for Calgary, which is based on components from the tour-based model presented in Hunt and Stefan (2007). Finally, external-internal commercial movements can be handled via conventional gravity models.

Towards an Operational Model

The implementation of the Calgary model is carried out by developing a series of computer programs using the GAUSS programming language. The objective is to implement the modeling framework presented in Figure 3 using the model parameters reported in Hunt and Stefan (2007). As a first step, the InfoCanada business establishment data were analyzed to identify those establishments that are likely to engage in delivering services or goods within the study area. The type of the industry and the nature of the business were considered in the identification process. The Peel UCVM data were also utilized to observe the establishments that engage in commercial vehicle movement activities. Next, population synthesis techniques were employed to generate some of the establishment's attributes that will be required by the tour-based models and which were not on the InfoCanada records. The synthesis procedure can be characterized by the diagram in Figure 5.
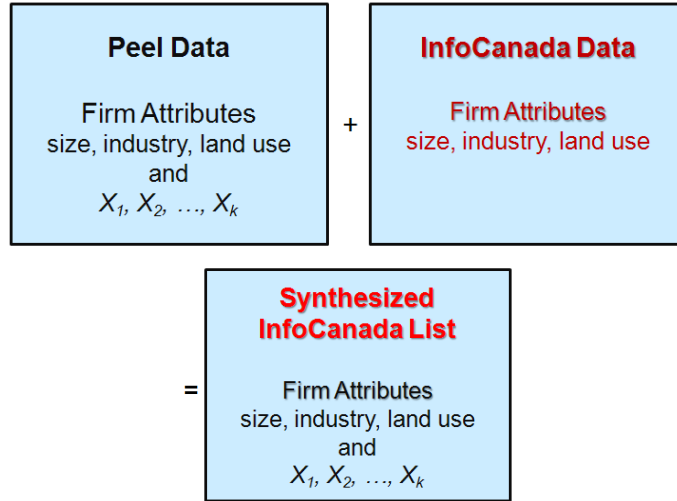
Figure 5: Synthesis Procedure

While work is underway to implement the tour-based model and estimate the establishment-based origin-destination, a plan is devised to validate and assess the quality of the output results. It is hoped that the devised model will produce aggregate results that match general known statistics that are reported in the literature. For instance, when considering the generated trips from the estimated tours by vehicle type and trip purpose, we will examine to see if our figures follow the patterns reported for Calgary (see Figure 6).
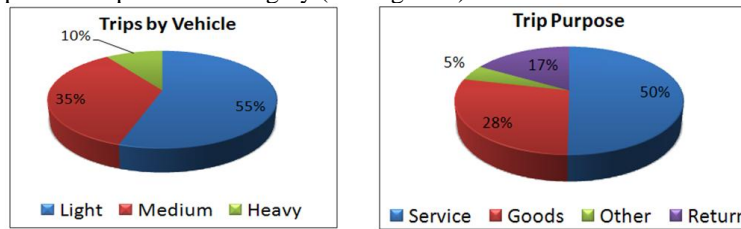

Figure 6: Calgary's UCVM trips breakdown by vehicle and trip purpose

Other tests will include assigning the generated OD matrices to the road network to determine the traffic flows due to commercial

movement in the study area. The estimated flows will be compared against traffic counts collected by the Ministry of Transportation of Ontario in 2006 and which were made available to us. Also, estimated tours and associated OD matrices for the Peel Region will be analyzed and compared to the Peel Region UCVM survey data. Other verifications will be based on crude aggregate estimates that were generated from aggregate OD estimation methods. Table 1 provides such estimates for the study area. Also, since we are using a microsimulation model, we will be able to estimate the exact time of commercial trip starts. Therefore, we will be checking the outcome results for a trend similar to Figure 7, which is reported in Calgary.

Table 1: Crude estimates of generated UCVM trips in the study area

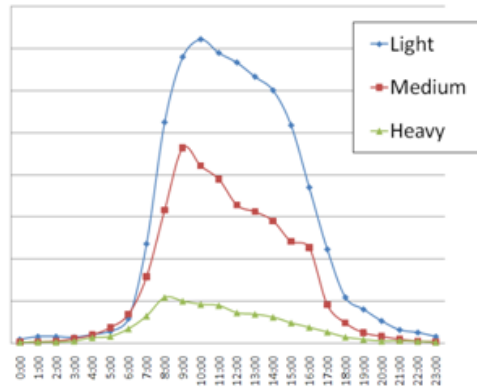| Vehicle	Period of day	Hamilton	Toronto	Total
Light	AM Peak	10,767	82,050	92,817
	PM Peak	9,229	70,323	79,552
	Off Peak	63,303	482,395	545,698
Medium	AM Peak	7,139	54,376	61,515
	PM Peak	4,819	36,723	41,542
	Off Peak	33,979	258,920	292,899
Heavy	AM Peak	2,746	20,849	23,595
	PM Peak	1,030	7,819	8,849
	Off Peak	7,928	60,187	68,115

Figure 7:

Hourly pattern of commercial vehicle trips in Calgary

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