

**Using an Integrated Urban Model to Estimate the Contribution of
Commercial Vehicle Movement to Mobile Emissions in Urban Areas**

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Paper prepared for the National Urban Freight Conference
Long Beach, California, USA
February 1-3, 2006

December 2005

ABSTRACT

Metropolitan scale studies of transport-based air pollution have emphasized inputs from the passenger vehicle fleet, with minimal attention given to the role of urban goods movement. Furthermore, little is known about the spatial distribution of transport related emissions. This study uses an integrated urban land use and transport model (IMULATE) for Hamilton, Canada, to examine the contribution of trucking to the spatial distribution of mobile emissions in urban areas. Using tube data and intersection counts for commercial vehicles we produce an origin-by-destination matrix of commercial trips. The transportation module of IMULATE was adjusted to estimate the differential traffic volume, due to the presence of commercial trips, in all the links of the transport network. These estimates are then translated into emissions of carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (HC) and particulates. The results demonstrate the need to control for urban commercial vehicle movement when attempting to estimate mobile emissions in urban areas.

1. INTRODUCTION

Public perception concerning the impact of trucking on North American roadways typically focuses on the issues of road safety and congestion. Empirical data suggest that urban commercial vehicle movements (UCVM) account for roughly 6-18% of total urban travel (Cambridge Systematics, 2004; Hunt and Stefan, 2004; Stefan et al., 2005). Despite this relatively small contribution when compared with non-commercial travel, UCVM exerts substantial influence on traffic flow, road surface conditions, and environmental emissions (Hallmark and Isebrands, 2005; Kanaroglou et al., 2000; Stefan et al., 2005). 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 over the last decade.

With this in mind, this study uses an integrated urban land use and transport model (IMULATE), developed for the Census Metropolitan Area of Hamilton, Canada, to examine the contribution of UCVM to mobile emissions in urban areas. Pollutants most often associated with motor vehicles include Nitrogen Oxides (NO_x), Carbon Monoxide (CO), Hydrocarbons (HC) and particulate matter (PM). These pollutants have been linked, either in isolation or in combination, to negative ecosystem and human health effects. In addition, there is increasing interest in particulate matter (PM), associated usually with heavy-duty gasoline and diesel trucks. Research suggests that such matter can be detrimental to human health (Burnett et al, 1999).

Another objective of this paper is to review what is known about UCVM data availability and modeling. To this end, in the next section we review the relevant literature. We then describe the study area and the model we use for the analysis presented in this paper. This is followed by a detailed description of the methods used to evaluate the contribution of emissions from trucks during the morning peak period in the Hamilton Census Metropolitan Area (CMA). The results are discussed in the following section. We end the paper with concluding comments and a discussion of future research directions in estimating UCVM emissions in urban areas.

2. BACKGROUND

Despite increasing recognition of the impacts of UCVM on urban travel conditions, regular data collection and commercial vehicle modeling has not become a routine planning activity of US MPOs or similar organizations in Canada. This brief review examines UCVM survey design and data collection, key behavioural findings, and approaches to modeling UCVM flows in urban areas.

2.1 Survey Design and Data Collection

Several thorough reviews concerning data collection for commercial vehicle movements (UCVM) are available elsewhere (e.g., Cambridge Systematics, 2004; JFA, 1997; Jessup et al., 2004). These studies have looked at several issues, making recommendations for survey design, administration, and modeling. These efforts are not duplicated here, with focus given

instead to the synthesis of recommendations and conclusions from these reports. Generally speaking, there are four approaches to surveying freight/commercial movements, (1) telephone interview, (2) mailout-back, (3) roadside interview or highway intercept, and (4) mixed-methods combining aspects of the first three. Detail and quality concerning origin-destination flows, land use at stops, commodity type, weight, vehicle type/technology, stops and timing, and volume varies across survey methods (e.g., roadside interview, highway intercept, mail/fax) (Jessup et al., 2004). For example, the mail/fax questionnaire approach generally suffers from low response rates and very general spatial detail, while roadside interviews can achieve success in identifying inter- and intra-regional routing (Jessup et al., 2004; Kanaroglou and Taylor, 1999).

Two commonly raised issues are (1) multi-stakeholder participation to improve survey response, and (2) carefully matching survey methods to outcomes of interest (e.g., directed flows at the regional scale) (JFA, 1997; Jessup et al., 2004). In addition, researchers suggest that some thought should be given to the location of survey administration and the type of information that can be acquired at different locations in commercial vehicle networks (e.g., weigh-in-motions stations, toll plazas, ports, warehouses, establishment locations). Across review papers, concerns have been raised with respect to survey response rates, and limitations imposed on modeling by the type, quality, and availability of UCVM data. In addition, establishment surveys, targeting commercial activities by sector and vehicle type, have been identified as an approach to advancing the state of the art in UCVM modeling (Cambridge Systematics, 2004).

Some of the most innovative work on UCVM in North America is currently underway in Alberta, Canada (Hunt et al., 2004), Oregon State (Donnelly et al., 1999; ODoT, 2002), and California (e.g., Golob and Regan, 2003). Together, these initiatives have addressed several key points identified in the literature for advancing the state of the art. In particular, 24-hour establishment surveys carried out in Alberta address requirements for data on commercial movements by sector and vehicle type. Stefan et al. (2005) provide a summary of the Alberta activities that, when combined, shed light on commercial trucking within the Calgary-Edmonton Corridor, one of Canada's fastest growing urban regions. The work in Oregon has been conducted as part of the State DOT sponsored Transportation Land Use Model Integration Program (TLUMIP) (e.g., Donnelly et al., 1999; ODoT, 2002). Data collection related to trucking has been carried out in Oregon since the late 1990s. Examples include a commodity flow survey (1997), freight shipper and carrier survey, a truck intercept survey (1998), and a more recent initiative focused on truck generation and distribution (ODoT, 2002). Combined with earlier survey and empirical work conducted elsewhere in North America (e.g., Calgary – 1971; Hamilton – 1973; Province of Ontario – 1988; Berks County, PA – 1994, SCAG – 1988, 2003), considerable insight is emerging with respect to the behaviour of commercial vehicle fleets in urban areas.

2.2 Behavioural Findings

While similarities exist with respect to the behaviour of commercial vehicle fleets across urban areas, there is reason to believe that there are unique conditions that also give rise to distinct behaviours. The most basic evidence supporting this claim concerns the wide-range reported

for the percentage of urban travel comprised of commercial vehicles (6-18%). What this suggests, is that it may be difficult to generalize findings from one study to several areas, and that “local” data collection initiatives are required to support local planning of commercial movement strategies. With this in mind, it is useful to describe those general qualities that set UCVM apart from other activities carried out in urban areas. In doing so, the focus here will be given to travel and fleet characteristics, and spatiotemporal dimensions of UCVM.

Data on commercial vehicle miles traveled (CVMT) suggest that urban freight distribution, service vehicles (private and public), and rental cars make the greatest contribution to urban VMT next to auto-use for personal travel (Cambridge Systematics, 2004). Results for Calgary and Edmonton suggest that roughly 12% of weekday VMT is taken up by commercial vehicles, with at least 60% of stops being made by light-duty vehicles (e.g., cars, vans, pick-ups, SUVs) (Stefan et al., 2005). This finding is critical, pointing to requirements for UCVM models that recognize the contribution of light vehicles to commercial activities (Stefan et al., 2005). A different picture emerges for other facility types (e.g., highways). Data for Calgary suggest that more than 70% of the trucks traveling on the highway system are heavy trucks (e.g., semi-trailer) (City of Calgary, 2001).

With respect to the spatial qualities of UCVM, recent data for Calgary and Edmonton suggest that a relatively small proportion of UCVM involves through-traffic (external-external flows), with the majority of stops distributed throughout the city as opposed to having a CBD or regional focus (City of Calgary, 2001; Stefan et al., 2005). These data also point to orthogonal directional bias in the distribution of trucking volumes over space. For example, in Calgary, trucking is heavily concentrated in the north-end (the Edmonton side of the city), while the converse is true for Edmonton. Parameter estimates from a tour-based microsimulation of UCVM flows also point to directional trends in vehicular movement with differences in spatial behaviour reported across sectors (e.g., goods, service) (Hunt et al., 2003).

Looking into temporal characteristics, the literature is fairly consistent in reporting differential peaks in travel when comparing commercial with personal activities (Kanaroglou and Taylor, 1999; Stefan et al., 2005). Data for Calgary and Edmonton demonstrate a lag-effect with the peak in commercial travel following the a.m. peak for personal/work travel. In addition, daily peaks in personal travel occur over much shorter time periods than is the case for trucking, indicating a relatively sustained commercial vehicle flow throughout the core of the regular workday. Moreover, the late afternoon peak in personal travel is unmatched by a similar peak in commercial travel. Findings from other studies also indicate that temporal characteristics vary across the vehicle fleet and by route type (Kanaroglou and Taylor, 1999; Stefan et al., 2005). For example, heavy-duty trucks (such as semi-one or two trailers) are more likely to take their first trip before 6:00 a.m. when compared with light-duty trucks, and through traffic tends to occur outside the regular peak period associated with personal travel (Kanaroglou and Taylor, 1999; City of Calgary, 2001).

2.3 Modeling Approaches and Issues

At the core of UCVM analysis are essentially two modeling problems. The first involves the conceptualization and estimation of UCVM as flows between origins and destinations or, as has been done in recent studies, as tours beginning and ending at a commercial establishment (e.g., Hunt and Stefan, 2003; Hunt et al., 2003; Hunt and Stefan, 2005) (Figure 2.1). The second challenge involves the assignment of flows, modeled as trips or tours, to urban road networks. Procedures for modeling UCVM as origin/destination flows have been around for some time and include, matrix expansion methods, four-stage models and related approaches (e.g., Quick Response Freight Manual (QRFM) – Cambridge Systematics et al., 1996; Freidrich et al., 2003), spatially disaggregate input-output analysis, supply chain models (e.g., Boerkamps et al., 2000), and more recently, stochastic and behavioural microsimulation (e.g., Hunt, 2001; Hunt and Stefan, 2003; Hunt et al., 2003; Hunt and Stefan, 2005; OdoT, 2002). Detailed review of these various approaches can be found elsewhere (Cambridge Systematics, 2004; JFA, 1997; Stefan and Hunt, 2004).

When looking at the conceptualization of UCVM flows, the state-of-practice has typically involved a trip-based approach, with commercial movements modeled as trips between origin zones (O_i) and destination zones (D_j) (Figure 2.1). The more recent tour-based approach treats commercial travel as a tour beginning and ending at an establishment E , from sector i , located at zone k . Tour attributes include vehicle type (e.g., light, medium, heavy-duty) and tour type (e.g., goods, services, other). Tours are assembled as a series of stops S , classified by stop purpose, p . A tour will eventually terminate at the establishment of origin (Hunt and Stefan, 2003). In other words, stop purpose includes returning to the establishment of origin.

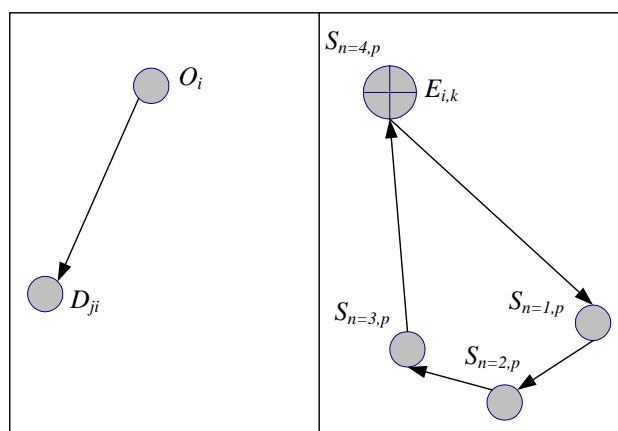


Figure 2.1: Conceptual models of urban commercial vehicle movements (UCVM)

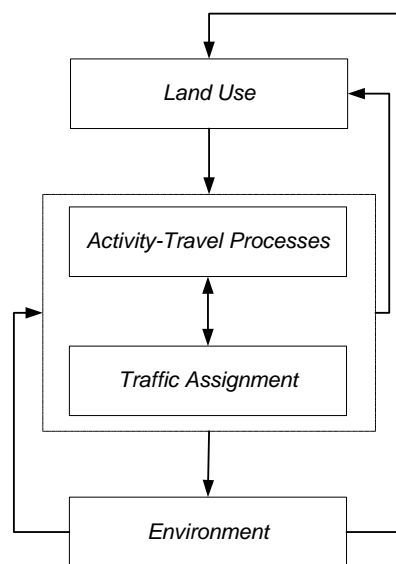
With respect to network assignment, several challenges arise when attempting to allocate UCVM flows to urban road networks. These relate to both intrinsic behavioural differences across passenger vehicle, public (buses), and commercial movements, and to the set of macro-level conditions that act to constrain UCVM. Because commercial and non-commercial vehicle activities essentially compete for the same network resources throughout the day, it is desirable to simultaneously account for these activities in network assignment procedures (e.g., Friedrich

et al., 2003). With respect to macro-level conditions, municipal bylaws place restrictions on the use of certain vehicle types on specific roadway facilities, and time-of-day restrictions are also enforced, regulating pickup/delivery activities (Kanaroglou et al., 2000; Stefan and Hunt, 2004). As noted by Stefan and Hunt (2004) UCVM network assignment procedures require a mechanism to control for such restrictions.

Generally speaking, behavioural realism and policy sensitivity increase as one moves from matrix expansion methods that typically oversimplify fleet characteristics and behaviours, to state of the art microsimulation (Figure 2.1). As has been noted in the literature, this augmented behavioural content requires extensive data collection, and a heavy computational cost can be associated with modeling the commercial tours of a population of vehicles (Hunt et al., 2003). While considerable advances are clearly being made with respect to internalizing the behaviour of commercial activities within transport planning tools, there has been little work carried out to interface UCVM models with procedures for estimating mobile emissions.

2.4 Urban Models and Mobile Source Emissions Modeling

Considerable research into the joint and separate modeling of urban land use and transportation systems has been carried out since the early 1990s, with many examples being traced back to earlier efforts (Buliung et al., 2005; Southworth, 1995). In particular, work on the development of integrated urban models (IUMs) intensified during the 1990s within a supportive legislative framework in the US (e.g., CAAA-1990; ISTEA-1991; TEA-21-1998), with significant modeling activity emerging from the Travel Model Improvement Program (TMIP). In general, the IUM framework internalizes linkages and feedback between urban transport and land use systems to support investigation of urban policy scenarios and the forecasting of future urban conditions (Figure 2.2). In some instances, the framework has been extended to include environmental modeling and feedback mechanisms (Strauch et al., 2003; Wegener, 2005).



Source: Adapted from Strauch et al. (2003)

Figure 2.2: Integrated Urban Modeling Framework with Environmental Feedback

Early on, recognition was given to the deficiencies of traditional approaches to travel forecasting for the modeling of mobile emissions (Stopher, 1993). Criticism focused on the spatiotemporal scale required to model mobile emissions and dispersion. Later, the "ideal" integrated urban model specification came to include estimation of atmospheric emissions generated by both private and commercial mobile sources (Miller et al., 1998; Miller et al., 2004; Southworth, 1995). The remainder of this section looks into the IUM and activity-travel modeling literature, summarizing progress that has been made with respect to endogenizing mobile emissions processes (Table 2.1). While the discussion emphasizes model systems and frameworks where details are available concerning environmental modeling, other initiatives have been included that have yet to be extended with emission modeling capabilities. Examples in this latter group include, ILUTE (Salvini and Miller, 2003), TASHA (Miller and Roorda, 2003), TLUMIP (Donnelly et al., 1999), and models that comprise the *Amadeus* framework (Timmermans et al., 2002; Veldhuisen and Timmermans, 2000).

SPARTACUS. The System for Planning and Research in Towns and Cities for Urban Sustainability (SPARTACUS) is a European initiative linking Echenique's MEPLAN land use and transportation model with modules for estimating indicators of environmental sustainability (CEC, 1998). It appears to be the most comprehensive operational example of a system with capabilities for land use, transport, and environmental (LTE) modeling. The SPARTACUS project has evolved within the 5th Framework of the EC into the Planning and Research of Policies for Land Use and Transport for Increasing Urban Sustainability (PROPOLIS) program (Lautso et al., 2004). PROPOLIS is basically a consortium that applies existing land use and transport models to evaluate urban policy effects in European cities and urban regions (e.g., MEPLAN: Bilbao, Helsinki, Naples, Vicenza; TRANUS: Brussels, Inverness; IRPUD: Dortmund).

SPARTACUS includes a module for disaggregating environmental and social indicators to a high-resolution raster (100x100m), the MEPLUS database and presentation module, and a decision support tool, USE-IT. This last module provides capabilities for evaluating the social, environmental, and/or economic effects of various policies. The system can be used to model the emission process from source to exposure. Modeling of mobile emissions is carried out by matching traffic conditions within each cell of a study area raster to functions that associate vehicle speeds and types with emission rates for PM, NO_x, and CO. Cell-based emissions results can be input to a Gaussian dispersion model to predict emission concentrations over space. The emission models linked to the system can process data for vehicle types beyond those available in the current transport models (Lautso et al., 2004). It is unclear from the literature if SPARTACUS can be used to isolate the contribution of different vehicle types to mobile emissions at either aggregate or disaggregate levels of analysis.

Table 2.1: Mobile Emissions Modeling in State-of-the-Art Urban Models

Model	Behaviour	State ^a	Mobile-E ^b	Modes ^c	Time ^d	Scale ^e	Application ^f
IMULATE	Trips-Aggregate	✓	✓	A,T, CV(PCE)	a.m. peak	L,R	Hamilton, Canada
ILUTE TASHA	Activity-Micro	✗ ✓	✓	A,T,NM, CV	24hr	L,R	Toronto, Canada
SPARTACUS PROPOLIS MEPLAN TRANUS IRPUD	Trips-Aggregate Disaggregate impact analysis	✓ ✓ ✓ ✓ ✓	✓	A,T,R, NM,CV	a.m. peak 24hr	L,R	Helsinki, Naples, Bilbao, Sao Paulo, Caracas....
ILUMASS IRPUD...	Activity-micro Disaggregate impact analysis	✗ ✓ ✓	✓	A,T,R, NM,CV	a.m. peak 24hr	L,R	Dortmund, Germany
TRANUS TRANUS- BURDEN7F- CUFM	Trips-Aggregate	✓	✓, ✗	A,T,NM, CV	a.m. peak 24hr	L,R,N	Mexico City, Sacramento, Baltimore, Oregon, Caracas, Panama City, Swindon, Barcelona.... Oregon, US
TLUMIP TRANUS- URBANSIM PECAS PCATS DEBNetS SAMS AMOS PORTLAND	Hybrid: Tours- Aggregate & Micro-Markets Activity-Micro Activity-Micro Activity-Micro Trip-Emissions	✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓ ✓	✓, ✗ ✓, ✗	A,T,CV A,T,NM A,O A,T,NM	24hr 24hr 24hr a.m. peak	State L,R L,R L	Kyoto, Japan AMOS: Washington, DC Portland, OR
AMADEUS MASTIC ALBATROSS RAMBLASS ABSOLUTE	Activity-Micro	✗ ✓ ✓ ✓ ✗		A,T	24hr	L,R R,N N L	Eindhoven, Utrecht, Amsterdam, Delft, Israel

^a ✓: Fully operational model, ✗: not yet fully operational, but specified at the conceptual level.

^b ✓: At least mobile auto-emissions, ✗: no commercial vehicle emissions.

^c A: auto, T: transit (may include rail, metro, streetcar, bus, etc.); NM: non-motorised; CV: commercial vehicles; R: rail; O: other. Listed modes included in model structure, mobile emissions not necessarily available for all modes.

^d Temporal resolution of behavioural and emissions modeling, not forecast regime.

^e Geographical coverage of simulation area, results can be extracted for sub-areas, and simulations can be carried out by adjusting characteristics of sub-regions. L: local, R: regional, N: national, State: Statewide, US.

^f Sample locations where modeling has been carried out. Locations in **bold** include emissions modeling.

ILUMASS. The Integrated Land-Use Modeling and Transportation System Simulation (ILUMASS) project has emerged in response to increasing environmental pressures related to the growth of European cities and the choices of individuals and households within urban transport and land use markets (Strauch et al., 2003). ILUMASS is both a modeling framework and a research consortium. The framework incorporates activity-based microsimulation and feedback between land use, transport, and environmental processes. Development will leverage past experience with the land use/transport microsimulation (e.g., Wegener and Spiekermann, 1996; Wegener and Fürst, 1999). Environmental modeling objectives are ambitious, similar to SPARTACUS, and include traffic noise propagation, and air pollution modeling (emission, dispersion and exposure). An interesting aspect of ILUMASS involves recognition of environmental feedbacks into the location decisions of households and firms (Strauch et al., 2003). As Wegener (2005) suggests, a feedback mechanism of this sort is relatively unique within IUMs.

TRANUS. The TRANUS (de la Barra, 1989) integrated land use and transport modeling system has been in development since 1982, and is one of the most widely applied integrated models today (Table 2.1). While TRANUS does not directly include a mobile emissions procedure, modeling of this sort has been achieved by linking TRANUS with external procedures for translating vehicular activities into emission estimates. This approach has been used to look at GHG emissions and other emissions from transport for Mexico City (www.modelistica.com), and in Sacramento, California (Johnston and de la Barra, 2000). In the Sacramento application, TRANUS outputs were processed by the California emissions model BURDEN7F, producing estimates of total organic gases (TOG), CO, PM, and NO_x for various transport planning scenarios.

SAMS, AMOS, and PCATS. The Activity-Mobility Simulator (AMOS) and the Prism-Constrained Activity-Travel Simulator (PCATS) are two examples of activity-based microsimulation models, capable of simulating individual level behaviours during a single day of the week (Kitamura, 1997; RDC, 1995). Both models have strong theoretical ties to Hägerstrand's Time Geography, particularly with respect to the role of constraints on behaviour (Hägerstrand, 1970). PCATS simulates activity engagement and travel, while AMOS predicts individual response to TDM strategies. PCATS has been coupled with a dynamic network simulator (DEBNetS) and used to forecast CO₂ emissions in Kyoto, Japan (Kitamura et al., 1998). AMOS has been embedded within the Sequenced Activity Mobility Simulator (SAMS) conceptual framework. SAMS includes a module for generating air quality emissions (Kitamura et al., 1996). The SAMS framework has not been extended to include environmental impacts resulting from UCVM.

PORTLAND. Shiftan and Suhrbier (2002) have used activity-based models developed for Portland (see MBRC and Bowman, 1998) to investigate the impacts of four TDM policies on mobile emissions, tours, trips, and VMT. Tested policies included pricing strategies (e.g., SOV tolls), telecommuting incentives, transit improvement, and a combination of proposed measures. Their approach involves the decomposition of tours into trips, followed by assignment of composite trip tables (including external truck trips) to a regional network. Assignment procedure results include estimates of VMT and average link speeds under the

various policy scenarios. Adjusting for “cold/hot” start operating conditions, emissions were estimated at the link level using the US EPA’s MOBILE model. Emission reductions were reported to be marginal (~3%) under the various scenarios. This finding appears to complement research suggesting that net environmental benefits from TDM will be offset by latent demand for activities and travel (e.g., Nagurney, 2000; Noland and Quddus, 2006; Stathopoulos and Noland, 2003). Although truck trips appear to have been included in the comprehensive trip matrix, it is unclear if these “trucks” are associated with personal or commercial applications. In addition, no attempt was made to adjust for the disproportionate impact of trucking on facility operating conditions.

Despite progress in advancing behavioural modeling objectives, state of the art research reveals that little effort has been extended to modeling emissions from mobile sources (Table 2.1). In fact, of the models considered here, only five cases could be identified where applied research has been carried out (IMULATE, SPARTACUS, TRANUS, PCATS, PORTLAND). In addition, operational modeling of mobile source emissions within IUMs has emphasized personal travel, with few examples endogenizing UCVM emissions. Of the five identified models, only IMULATE emerges as a clear example where an attempt has been made to isolate the contribution of trucking to mobile emissions. Most examples rely on external models (e.g., MOBILE, BURDEN7F) to generate link or system-wide estimates of mobile emissions by processing vehicle activity data output from the transport modules of IUMs. This appears to be a reasonable approach, leveraging the expertise of external organizations and researchers, and the considerable expense involved in generating emission profiles for domestic vehicle fleets.

Recent evidence suggests that trucking activities have a disproportionate impact on facility operating conditions (Al-Kaisy et al., 2002; Al-Kaisy et al., 2005; Webster and Elefteriadou, 1999), and that discrepancies exist between the emission signatures of passenger cars and trucks under various operating conditions (Hallmark et al., 2004; Hallmark and Isebrands, 2005). Given this evidence, it is surprising to discover that little attention has been given to evaluating the contribution of trucking to environmental emissions in urban areas. In general, progress in this area has likely been hampered by the lack of UCVM data.

3. IMULATE – GENERAL STRUCTURE

The Census Metropolitan Area (CMA) of Hamilton is located on the west shore of Lake Ontario approximately 75km southwest from the city of Toronto (Figure 3.1). The CMA is divided into eight municipalities, as shown in the map. In 2005, the estimated population of the CMA was about 600,000, mainly concentrated in the City of Hamilton, and the municipalities of Dundas, Burlington, and Stoney Creek. The traditional economic base of the city has been the heavy steel industry, located by the harbour in the City of Hamilton. In recent years, the service sector is successfully competing with, and has surpassed, the manufacturing sector in terms of employment. The presence of heavy industry partially explains the relatively poor air quality of Hamilton within the Canadian context (Hamilton Air Quality Initiative, 1997). The Niagara escarpment separates the city into the lower and the upper part (known also as the

mountain). Both the lower and upper city is relatively flat, with access from one to the other provided by five major transport links.

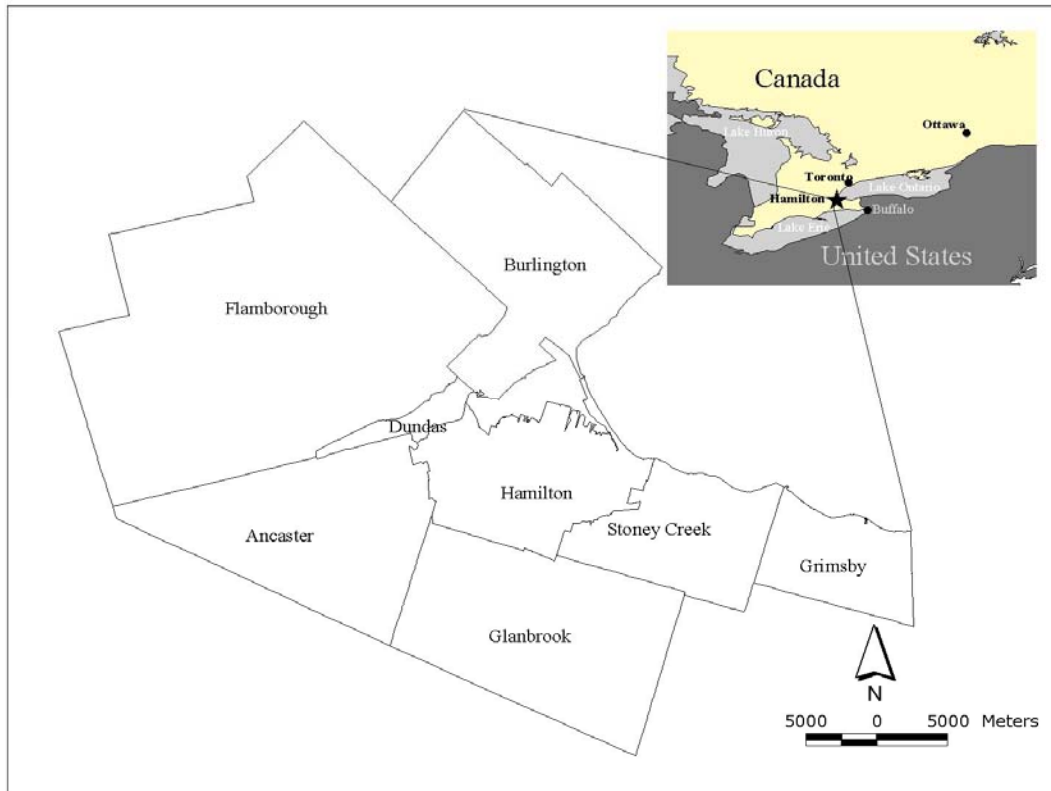


Figure 3.1: The Hamilton Census Metropolitan Area

IMULATE is an integrated transport and land use model designed to predict traffic loads on links of the transport network for the morning peak period (7:00 to 8:00am) in the Hamilton CMA. The initial conception and operationalization of the model are described in detail in Anderson et al (1994). The general structure of IMULATE is illustrated in Figure 3.2. It consists of three main modules. The first is the land-use module, made up of two sub-modules; POPMOB that handles intraurban population mobility, affected by a host of urban characteristics, including the availability and price of housing, and; EMPLOC that determines the location of firms in the urban area as places of employment. POPMOB and EMPLOC work in tandem to produce a place of residence to place of work matrix within a system of 151 zones (census tracts). Second is the transport module, which operates on the output of the land-use module. It consists of two sub-modules; TRANDEM that uses discrete choice models to estimate the number of work, school and discretionary (i.e., shopping, recreational) trips by mode, and; TRAFFIC ASSIGNMENT that uses a stochastic user equilibrium algorithm to assign interzonal automobile trips (from TRANDEM) to the CMA's road network. The latter consists of about 1100 nodes and 1500 links. The feedback between the transport and land use modules ensures that land use changes are reflected in the estimated traffic volumes.

The third module of IMULATE uses link flows and average link speeds produced by the transport module and estimates emissions of CO, HC and NO_x for each link. For this purpose, a formal link has been developed with MOBILE5.C, the Canadian version of the U.S. Environmental Protection Agency's (EPA) mobile source emissions model. Average link speeds are used as indicators of roadway congestion. Link speeds lower than those under free flow are considered representative of the driving cycle that automobiles face in congested roadways. MOBILE5.C allows creation of a functional relationship between average link speeds and emissions of CO, HC and NO_x.

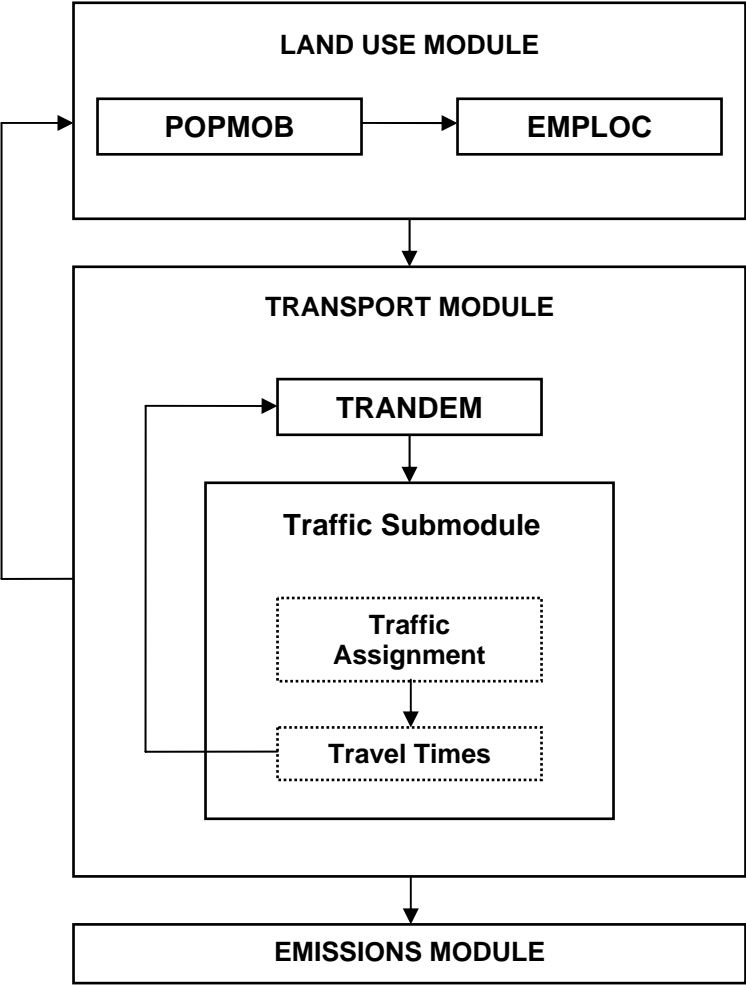


Figure 3.2: The Integrated Model for Urban Land use Transport and Environment

4. METHODOLOGY AND DATA

This study proceeds in four steps. First, an origin-by-destination matrix of commercial vehicle trips, C, at the census tract level was acquired from the City of Hamilton. Second, the concept of passenger car equivalency (PCE - number of passenger cars that correspond to a typical

truck) is discussed and a method is developed for the determination of representative mean value for it, E , in the study area. In the third step, we combine the origin-by-destination matrix of commercial vehicle trips C with the estimated E value to produce an origin-by-destination matrix of passenger cars that is equivalent to the commercial vehicle matrix. Since E is a scalar, the matrix sought is the product EC . In step four the derived matrix is added to the passenger cars origin-by-destination matrix P , estimated within the TRADEM module of IMULATE to produce $T = P+EC$, which is used as input to a stochastic user equilibrium routine that determines the traffic flow on the network. After equilibrium is achieved the estimated traffic flows are passed to the emissions sub-module of IMULATE to produce estimates of HC, CO, and NO_x emissions by link, and for the study area as a whole. Since emission factors for the determination of PM emissions are not included in IMULATE, a separate procedure has been developed and is discussed later in this section. One can examine several scenarios by varying the passenger car equivalency scalar value of E . In particular, we are interested in examining the sensitivity of the results to the value of E . A time step, or the simulation period for IMULATE is five years. The simulation period for this study is 1996 to 2001.

4.1 The Commercial Vehicle Trips Matrix

IMULATE's transportation model has been adjusted to include an origin-destination matrix of morning peak hour (7:00-8:00am) urban commercial vehicle flows within the Hamilton CMA. This matrix was generated from data collected during the 1998 Hamilton Commercial Vehicle Survey. The collected data included tube data and intersection counts. Bi-proportional updating was used to transform the count data into the matrix C . Commercial vehicles in this context include anything identified by an observer as being a vehicle used for commercial purposes. As a result, heavy and light-duty gas and diesel-powered vehicles ranging from pick-up trucks to trucks with six or more axles are included in the matrix. It is also important to note that trip-ends within the municipalities of Burlington and Grimsby have not been included due to incomplete enumeration. The aggregate nature of the commercial vehicle matrix imposes a limitation on this study in that specific vehicle types cannot be extracted.

Empirical evidence suggests that the accuracy of mobile source emission estimates may be affected by the ability to control for road conditions and certain properties of the vehicle fleet (for example, combustion process and vehicle type). Ideally, a suitable classification scheme of trucks should be established before the assignment of emission factors. A universally acceptable truck classification scheme does not exist. For example, the U.S. EPA classifies trucks by weight, while the Ontario Ministry of Transportation (MTO) and the Regional Municipality of Hamilton-Wentworth classify trucks by axle (Kanaroglou and Taylor, 1999).

4.2 Passenger Car Equivalency (PCE)

Passenger car equivalencies were introduced to the literature in the *Highway Capacity Manual* (HCM) of 1965, and defined as: "The number of passenger cars displaced in the traffic flow by a truck or a bus, under the prevailing roadway and traffic conditions". In other words, PCEs measure the number of base vehicles (usually passenger cars) removed from traffic due to the presence of heavy vehicles (Al-Kaisy et al., 2005; Elefteriadou et al., 1997; Sumner et al., 1984). There has been little change to the PCE definition since the 1960s (see TRB, 2000), and

PCE values are still used to evaluate the impact of heavy vehicles on traffic operations under free-flow conditions (Al-Kaisy et al., 2005; Elefteriadou et al., 1997).

PCE estimation procedures can be distinguished by the travel characteristic used to define an equivalency criterion. Past research has used vehicle headway, delay, platoon formation, speed, vehicle hours, travel-time, density, and queue discharge flow (QDF) (see Al-Kaisy et al., 2005; Elefteriadou et al., 1997). While the HCM publishes PCE measures for various facility-types (e.g., 2-lane and multilane highways and freeways), classified by grade and heavy vehicle type (Truck, RV), it assumes free-flow operating conditions¹. Traffic simulation studies provide some contrast to the HCM approach, indicating variation in PCEs by heavy vehicle type, road grade and facility type, volume, vehicle mix, and traffic conditions (Al-Kaisy et al., 2002; Al-Kaisy et al., 2005; Elefteriadou et al., 1997; TRB, 2000). For example, Webster and Elefteriadou (1999) found increases in PCE values with traffic flow, free-flow speed, and segment length/grade, and decreasing PCEs with number of lanes and truck percentage.

More recently, understanding of the impact of heavy vehicles on traffic flow, under variable conditions - i.e., operating within the congested or uncongested regime has become more sophisticated (e.g., Al-Kaisy et al., 2005; Webster and Elefteriadou, 1999). The latest evidence suggests that the effect of heavy vehicles during congested conditions is much greater than under free-flow conditions (Al-Kaisy et al., 2002). Using a mixture of field observation, empirical evidence, and traffic micro-simulation, Al-Kaisy et al. (2005) reported across the board increases in freeway PCEs over those published in the HCM. This raises obvious concerns with respect to the application of free-flow PCEs to the evaluation of traffic operations under congested travel conditions (Al-Kaisy et al., 2005). The current emphasis of research on freeway operating conditions, suggests an opportunity exists to revisit the PCE concept as it applies to heavy vehicle operation, under the congested regime, along lower capacity facilities such as urban arterials and two-lane highways.

Within our framework, since we use an integrated model and congestion is estimated by link, it is conceivable to take account of congestion in determining the PCE values by link, provided one accepts a functional relationship between the two. In the absence of such a relationship, we assume that PCE values are invariant to congestion, implying a potential underestimation of emissions. Using the speed-flow PCEs estimated by Elefteriadou et al. (1997), we assign representative PCEs to network segments according to link type. Commercial vehicles within the Hamilton CMA are restricted, by law, to a subset of links in the road network, as shown in Figure 4.1. This subset consists of 805 links.

Values are assigned to links by type according to the following scheme: Freeways, two-lane highways, and arterials with four lanes are given a PCE value of 2, while arterials with two lanes are given a PCE value of 5. The latter type of arterials does not provide an opportunity for passing, and therefore the impact of heavy vehicles is more pronounced. The mean PCE value over the 805 truck route links was found to be 2.48. This value implies that, on average, two and half passenger cars are displaced from the traffic flow for every individual commercial

¹ Buses are treated the same as trucks under the assumption that they have a similar impact on the traffic stream.

vehicle. The upper and lower bounds of a 90% confidence interval were 2.54 and 2.42, respectively. Since our estimate of PCE is rather crude, we decided to perform some sensitivity analysis by allowing PCE to attain the values 0, 1, 2, 2.42, 2.48, 2.54, 3, 4 and 5. The value of 0 implies the total absence of commercial vehicles in the network, corresponding to the “passenger cars only” scenario.

The aggregate design of our study does not allow taking account of the commercial vehicle type in the determination of PCE values. Furthermore, we ignore the grade of the links. As discussed earlier the upper and lower parts of the Hamilton CMA are relatively flat, justifying the assumption of ignoring the grade for links that are in each one of them. There are five links, however, that connect the lower with the upper part, for which the grade is substantially different than zero. Trucks are allowed to use three of those links. Given, however, that those links are arterials with four to six lanes and that they constitute a small proportion of the total number of links, we felt that ignoring the link grade is justified. Our framework, however, is capable of handling different link grades.

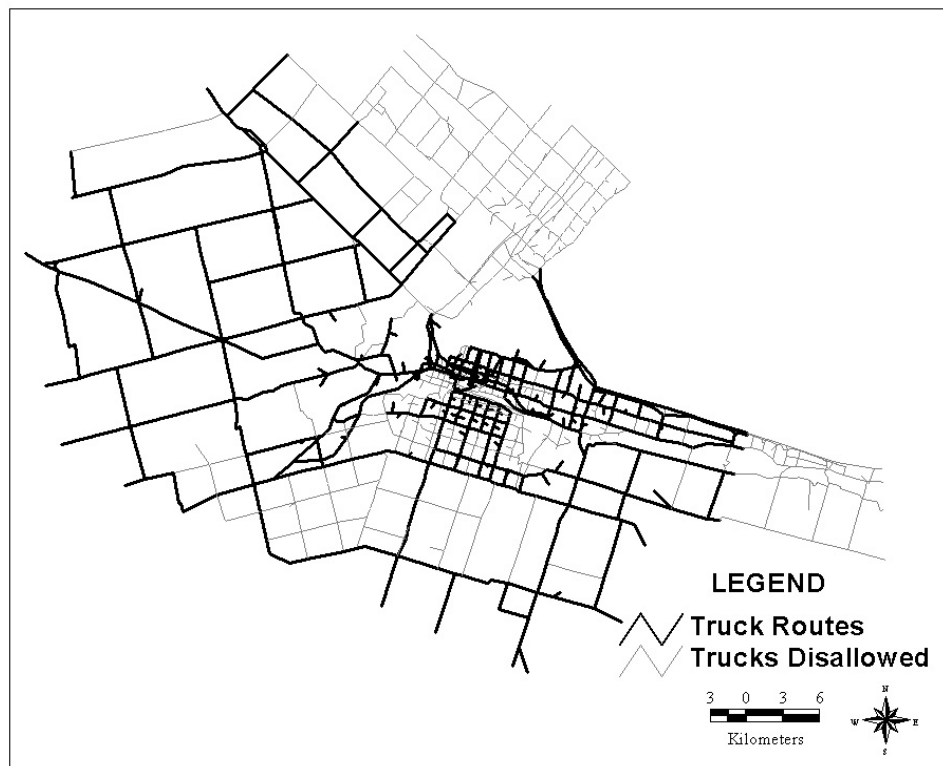


Figure 4.1: The Hamilton CMA Trucking Routes

4.3 PM Estimation

The MOBILE5.C emissions model does not estimate particulates. In this sub-section, we present a methodology for the estimation of PM at the link and aggregate levels. Particulate emissions come from a variety of sources including combustion exhaust, tire wear, brake wear, idle emissions, and fugitive dust. In this study, IMULATE is combined with EPA PM emission

factors to generate PM estimates from combustion exhaust, tire wear, and brake wear. Data limitations for this study do not allow PM estimation from idling and fugitive dust.

The total exhaust particulate emission factor is calculated from the sum of lead, direct sulfate, and a carbon emission factor which includes soluble organics and other remaining carbon (USEPA, 1985a). Carbon is the primary element of diesel and gas powered mobile source combustion. Lack of detailed information on the Hamilton CMA vehicle fleet prohibits the use of lead and direct sulfate emission factors.

To address the contribution of urban commercial vehicles to PM emissions we require information on the type of vehicles and emissions from those vehicles. Since these data are not available, we resort to evaluating the average type of urban commercial vehicle and the frequency of its appearance in links within the Hamilton network during the morning peak period. At the time of collection of the traffic counts that were used to generate the origin-by-destination matrix of commercial vehicle trips, a vehicle classification was done at 28 randomly selected intersections of the network. The classification scheme employed is shown in Table 4.1, along with the percentage frequency of appearance of the different vehicle types. Interestingly, these data substantiate results reported for other cities (e.g., Calgary, Edmonton), with light vehicles taking up the largest percentage of observed commercial vehicle types during the peak period (e.g., Stefan et al., 2005).

Table 4.1: Vehicle classes used in the CMA of Hamilton

Vehicle Class	Vehicle Type	# of axles	% of peak flow[*]	Rank^{**}
2	Car, pick-up, van	2	65.63	1
1	Subcompact	2	18.50	2
3	2-axle light truck	2	10.70	3
6	3-axle single unit truck	3	1.39	4
4	Bus	2	1.16	5
12	3S2 tractor trailer	5	0.84	6
14	6 or more axles	6	0.48	7
11	2S2 tractor trailer	4	0.33	8
5	Car with 1-axle trailer	3	0.30	9
9	4-axle single unit truck	4	0.20	10
13	Other 5 axle	5	0.17	11
8	Car with 2-axle trailer	4	0.14	12
7	2S1 tractor trailer	3	0.11	13
10	3S1 tractor trailer	4	0.02	14

^{*} refers to the percent of the total vehicle flow at the peak hour that class comprises.

^{**} denotes the order the classes rank in terms of percent of peak flow

The highest ranked class, strictly limited to trucks, was Vehicle Class 3 (2-axle light truck), comprising 10.7 percent of the total vehicle flow over the sampled intersections. On this basis, we considered for our purposes Vehicle Class 3 the average or representative type of commercial vehicle for the Hamilton fleet. This can be compared with a 'Single Unit Truck (SUT), with a length of 12.2m and a weight-to-horse power ratio of 300' defined in Elefteriadou et al. (1997). Also, the EPA defines this SUT as a light duty diesel truck (LDDT) (USEPA, 1993a). The sum of all truck vehicle classes is 14.24 percent of all vehicles. This is consistent with the percent of trucks in traffic flow reported in Elefteriadou et al. (1997). For our purposes, in what follows, we consider a rough estimate of 15 percent of commercial vehicles, including buses.

4.3.1 Selecting PM Emission Factors

As discussed earlier, this study is limited to estimating PM exhaust emissions through the carbon emission factor. Model year and the technology type of trucks and cars affect the carbon emission factor (USEPA, 1985a; USEPA, 1993a). Average age of the Hamilton CMA vehicle fleet (model year) was approximated from U.S. data, collected by the Polk Data Company (1998).

The average model year for both the car and truck fleet was estimated to be 1990 as follows. As mentioned earlier, the simulation period for this study was 1996 to 2001. The midpoint of this period would be half way through 1998. In 1996, the average age of cars was 8.3 years (The Polk Data Company, 1998). Subtracting the average age (roughly eight and a half years) from the midpoint of the year 1998 gives us a model year of 1990.

The nearest EPA age category for passenger cars (LDGVs) was 1981 and newer. The PM exhaust emission factor for this category is $EE_{LDGV} = 0.0043$ gram/mile. To determine the amount of PM of certain particle sizes, a Particle Size Cutoff (PSC) is applied to this emission factor (USEPA, 1985a). The PSC is defined as the maximum aerodynamic diameter of the particles in the emission factors (USEPA, 1985a). PM_{10} , includes particles of 10 micrometers or less in aerodynamic diameter, and is of particular concern due to its association with cardio-respiratory hospitalisations (Burnett et. al., 1999) and other health effects (HAQI, 1997). In this study a PSC for PM_{10} is determined from tables provided by the USEPA (USEPA, 1985a). For catalyst equipped LDGVs, 1981 and newer, using unleaded fuel the fraction of particles less than or equal to 10 micrometers in diameter, $PSC_{LDGV} = 0.98$.

To determine the exhaust emissions factor and the PSC for light duty diesel trucks (LDDT), we follow the same procedure as for the passenger cars. In 1996, the average age of trucks was 8.6 years (The Polk Data Company, 1998). Subtracting the average age (roughly eight and a half years) from the year of estimation left a model year of 1990. The PM exhaust emission factor for this category is $EE_{LDDT} = 0.291$ gram/mile. To determine the PSC for particles less than 10 micrometers in diameter we note that for all model years of all diesel vehicles, including 1990 LDDT, the value is $PSC_{LDDT} = 1.00$ (USEPA, 1985a).

4.3.2 The Calculation of PM Emissions

For the purpose of estimating PM, the road network in this study is broken into links that are part of truck routes and links that are not part of truck routes. The PM exhaust (PME) estimate for a truck route link i is calculated as:

$$PME_i = 0.15 f_i l_i EE_{LDDT} PSC_{LDDT} + 0.85 f_i l_i EE_{LDGV} PSC_{LDGV}$$

Where, f_i is the total traffic volume on link i , and l_i is the length of link i . The factors .15 and .85 reflect our estimate that 15 percent of the flow on a truck route link i is from trucks and the remainder 85 percent from passenger vehicles.

The PM exhaust estimate for non-truck route link j is calculated as:

$$PME_j = f_j l_j EE_{LDGV} PSC_{LDGV}$$

Where, f_j is the total traffic volume on link j , and l_j is the length of link j .

Assuming that we have n truck route links and m non-truck route links, PM from combustion exhaust for the entire system is given by:

$$PME_{TOTAL} = \sum_{i=1}^n PME_i + \sum_{j=1}^m PME_j$$

The PM tire wear emission factor for all vehicle categories and model years is $E_{tire} = 0.002$ gram/mile/tire, while the particle size cut-off for all vehicles is $PSC_{tire} = 1.00$ (USEPA, 1985a). Since the emission factor is per tire, one needs the average number of tires per vehicle, which is $ANOT_v = 4$ (USEPA, 1985a). Obviously, the tire wear emission factor does not vary by the type of link. So the tire-wear emission $PMTW_k$ for any link k is given by:

$$PMTW_k = f_k l_k E_{tire} PSC_{tire} ANOT_v,$$

and the PM tire wear emissions for the entire system are given by:

$$PMTW_{TOTAL} = \sum_{k=1}^{m+n} PMTW_k$$

The PM brake wear emission factor for all vehicle categories and model years is $E_{brake} = 0.0128$ gram/mile, while the average particle size cut-off over all vehicles and model years is $PSC_{brake} = 0.98$. Since there is no variation by link type, the PM brake wear emission $PMBW_k$ for any link k is given by:

$$PMBW_k = f_k l_k E_{brake} PSC_{brake},$$

and the PM break wear emissions for the entire system are given by:

$$PMBW_{TOTAL} = \sum_{k=1}^{m+n} PMBW_k$$

Total PM for the entire system, then, is the sum of PM emissions from combustion exhaust, brake wear, and tire wear.

$$PM_{TOTAL} = PME_{TOTAL} + PMTW_{TOTAL} + PMBW_{TOTAL}$$

5. RESULTS AND DISCUSSION

Establishing the contribution of commercial vehicles to mobile emissions requires an initial estimation of network flows from passenger vehicles only. As discussed earlier, this is achieved by letting $E = 0$, in which case $\mathbf{T} = \mathbf{P}$. That is, the matrix passed to the stochastic equilibrium routine of TRANDEM is equivalent to the matrix of passenger cars only. This is followed by a series of estimations, where $\mathbf{T} = \mathbf{P} + \mathbf{E}\mathbf{C}$ and E attains positive values other than 0, as discussed in the methodology section of this paper. The results of each of these estimations are compared to the results of the passenger vehicles only scenario, allowing the assessment of changes in link and total emissions for the study area. The rationale for the selection of values for E is discussed in detail in the methodology section. The procedure allows assessing the sensitivity of emission estimates to subtle variations in equivalency values.

5.1 Aggregate Level Results

The results for the whole of the study area are summarized in Table 5.1. The first column displays the passenger car equivalency values used in the simulations. In the discussion that follows, estimates of emissions for $E = 0$ are used as a base case for comparison. Aggregate emissions are simply summations of emission estimates across all links in the road network. The last column in the table reflects the percent increase in passenger vehicle trips beyond the base case.

Increasing the PCE value is equivalent to increasing the volume of vehicle traffic loaded onto the network. The additional traffic serves as a proxy for the presence of commercial vehicles in the network. Loading additional base vehicles onto the network leads to increased traffic on network links. For certain links, especially those on truck routes, the result is increased congestion and lower average speeds. When interpreting the emissions results, it is important to remember that within this study HC, NO_x , and CO emissions are functionally linked to the average speed (or driving cycle) in each one of the links. As the PCE value increases from 0 to 2.48 (the estimated average), the number of trips increases by 11.9 percent, while HC and CO emissions increase by 23.4 and 24.1, respectively. So, the behavior of those two pollutants is very similar. On the other hand, NO_x behaves differently. The same increase in PCE and number of trips results in a 10.9 percent increase in NO_x emissions. The difference is in the

functional relationship of emissions factors to link speed (Anderson et. al., 1996). While for HC and CO the emission factors drop rapidly as average link speed increases, NO_x emission factors tend to initially marginally decrease with speed, but then remain stable until about 30 miles/hour, increasing with speed from then on.

Table 5.1: Aggregate Emissions and Trips by PCE Value

PCE E	HC		CO		NO _x		PM		Trips	
	kg	%*	kg	%*	kg	%*	kg	%*	n	%*
0.00	12929	0.0	137556	0.0	9476	0.0	47	0.0	174996	0.0
1.00	14035	8.6	149563	8.7	9877	4.2	99	111.3	183452	4.8
2.00	15275	18.1	163174	18.6	10299	8.7	104	121.7	192297	9.9
2.42	15865	22.7	169707	23.4	10478	10.6	106	125.9	195851	11.9
2.48	15955	23.4	170700	24.1	10507	10.9	107	126.5	196396	12.2
2.54	16033	24.0	171560	24.7	10534	11.2	107	127.2	196960	12.6
3.00	16641	28.7	178250	29.6	10733	13.3	109	131.9	200940	14.8
4.00	18071	39.8	193956	41.0	11181	18.0	114	142.4	209798	19.9
5.00	19592	51.5	210879	53.3	11634	22.8	119	152.9	218686	25.0

* Denotes percent increase over the ‘passenger cars only’ scenario

Unlike the other pollutants, PM emissions are not affected by congestion and the average speed on a link, but by vehicle-miles traveled (strictly speaking this might not be true -congestion and stop and go will augment brake-use, and brake dust emissions). This is evident in the PM emission figures shown in Table 5.1. What is important in those figures is the increase in particulate matter emissions when commercial vehicles are introduced at all, that is when the PCE value changes from 0 to 1. For a 4.8 percent increase in the number of trips, PM emissions increase by 111.3 percent. To understand better this relationship, it is important to examine the source of emissions. Table 5.2 provides a breakdown of emissions by brake wear, tire wear, and exhaust for this particular case.

Table 5.2: Aggregate PM Emissions by Type for PCE Value

Source	PCE E=0.00			PCE E=1.00			Increase (%)
	Car	Truck	Total	Car	Truck	Total	
VMT	1900288	0.0	1900288	1807957	175350	1983307	4.4
Brake wear (kg)	23.8	0.0	23.8	22.7	2.2	24.9	4.6
Tire wear (kg)	15.2	0.0	15.2	14.5	1.4	15.9	4.6
Exhaust (kg)	8.0	0.0	8.0	7.6	51.0	58.6	632.5
Total (kg)	47.0	0.0	47.0	44.8	54.6	99.4	111.5

The first striking result in Table 5.2 is that the introduction of commercial vehicles causes the vehicle-miles traveled (VMT) by passenger cars to decrease from 1,900,288 to 1,807,957. This decrease is the response of passenger car drivers to the disutility of the extra congestion introduced with the commercial vehicles, which entails changing mode of travel or not taking

the trip at the morning peak period. Perhaps the most important result reported in Table 5.2 is that the exhaust system represents the primary source of PM emissions introduced by commercial vehicles. Out of the 54.6kg of particulate matter produced by commercial vehicles, 51kg originates at the tailpipe. These results indicate that to reduce particulate matter emissions in urban areas, one has to pay close attention to commercial vehicles in general and their exhaust systems in particular.

5.2 Results at the Link Level

In this sub-section we focus on the spatial concentration of congestion and emissions through a selected set of figures. Figure 5.1 depicts the ratio of flow to capacity when PCE is $E = 2.48$. Thicker link lines are associated with ratio values greater than 1, meaning that traffic flow exceeds capacity (volume to capacity ratio), rendering the link congested. A comparison with Figure 4.1 indicates that the congestion occurs primarily on truck routes.

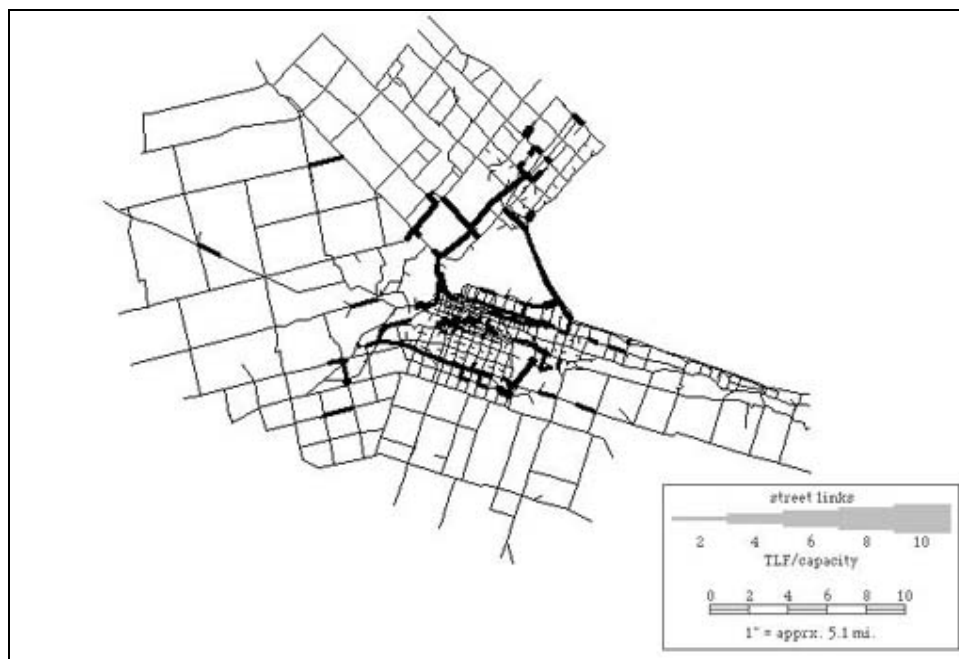


Figure 5.1: Ratio of link flows to link capacity, PCE value $E=2.48$

With respect to emissions, Figures 5.2 and 5.3 show spatial variation in link-based estimates of HC. The first of the figures is based on estimates from passenger cars alone, while the second includes commercial vehicles with PCE value $E = 2.48$. In these figures, a thicker link line is associated with a higher emission level for HC. The effect of the inclusion of commercial vehicles in the system is shown clearly. As expected, the effect appears to be stronger along the truck routes shown in Figure 4.1.

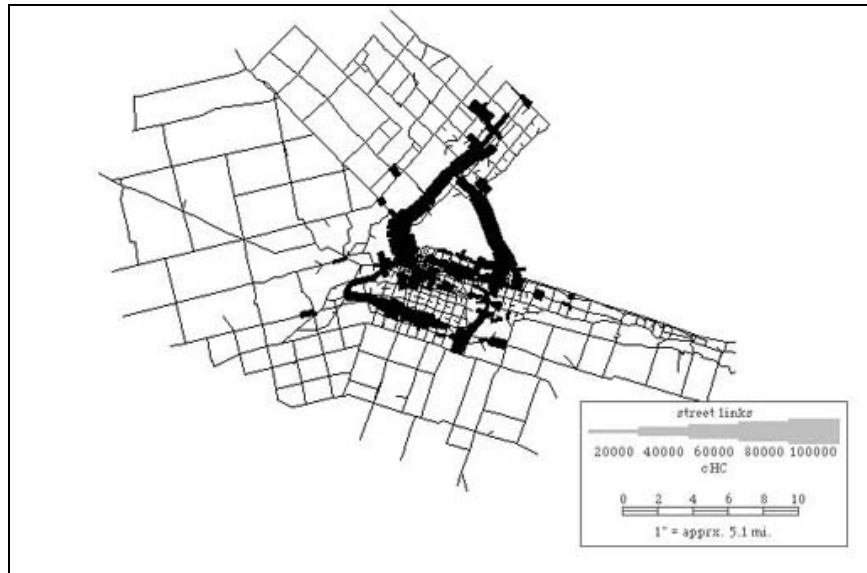


Figure 5.2: Emissions of HC for Passenger Cars, PCE Value E = 0

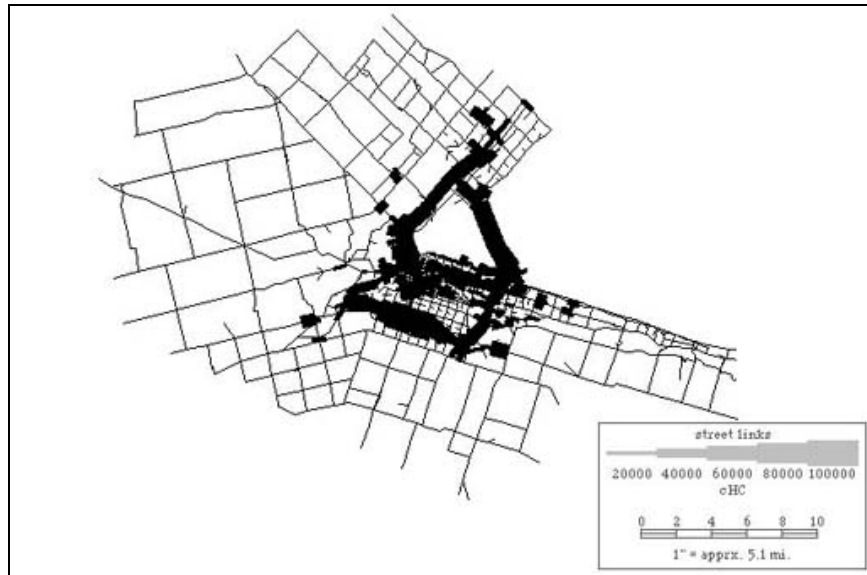


Figure 5.3: Emissions of HC with Commercial Vehicles, PCE Value E = 2.48

Similar figures for CO and NO_x show a pattern almost identical to that for HC, so they are not shown here. It is interesting, however, to examine the results for particulate matter, shown in Figures 5.4 and 5.5. Again, thicker link lines are associated with higher levels of emissions, given in grams/mile. From our earlier discussion on PM emission factors, we know that the number of trips on a link, rather than the level of congestion or the average link speed, affects the level of PM emissions. With the inclusion of commercial vehicles in the network, and the

trips they contribute confined only to certain routes, the effect on PM is more pronounced particularly along trucking routes.

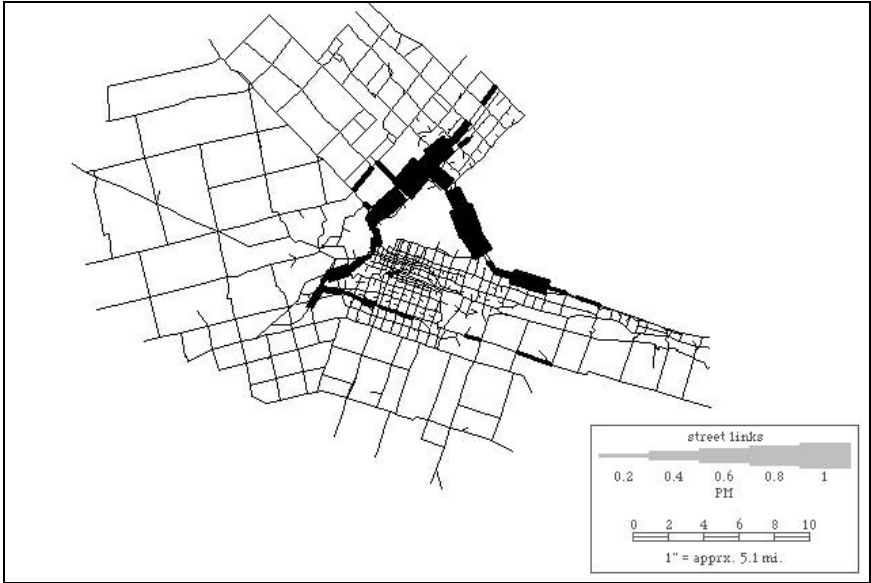


Figure 5.4: Emissions of PM for Passenger Cars, PCE Value E = 0

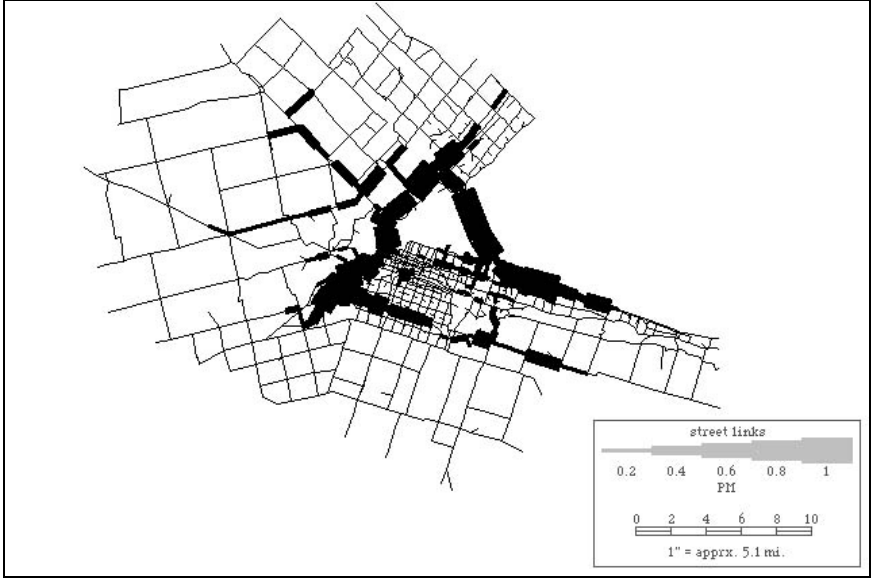


Figure 5.5: Emissions of PM with Commercial Vehicles, PCE Value E = 1.00

The results obtained suggest that not controlling for the presence of commercial vehicles results in low estimates of link emissions within certain parts of the Hamilton CMA. Exposure to mobile source pollutants or estimates of ground level ozone would potentially be understated under such conditions.

6. CONCLUSIONS

A procedure for evaluating the contribution of trucks to mobile source emissions within urban areas has been presented and applied to the Census Metropolitan Area of Hamilton, Canada. We demonstrate that the application produces plausible results. The contribution of urban commercial vehicle movements (UCVM) to emissions of HC, CO, NO_x and PM has been addressed at the aggregate and link levels. Emission estimates demonstrate sensitivity to passenger car equivalency (PCE) values. With respect to HC and CO, a percentage increase in number of trips due to the presence of trucks induces twice as high a percentage increase in emissions. The additional trips decrease average speed on the network causing a disproportional increase in emissions because of the non-linearity in the relationship between link speed and emissions. This is not the case, however, for NO_x emissions that tend to increase with the link speed.

The presence of trucks is shown to produce a dramatic increase in particulate matter emissions as well. The analysis indicates that this increase is mainly due to combustion exhaust emissions from trucks, as opposed to tire and break wear. Overall, a 4.4 percent increase in vehicle miles traveled because of the presence of trucks can produce a 111 percent increase in PM emissions. For all pollutants link level changes tend to be focussed along trucking routes.

While the results are encouraging, the potential of this procedure for generating accurate estimates is limited by the resolution of the observed trucking data. Another limitation is that only trips with origins and destinations within the Hamilton CMA are included. The contribution of trucks passing through the CMA is not dealt with. In the presence of current data on inter-city trucking, we anticipate that the contribution of external flows to emissions could be relatively small (e.g., City of Calgary, 2001). To be certain of this, data for the Hamilton CMA need to be collected. Furthermore, the current focus of the model is the morning peak period traffic volumes and related emissions, while the majority of truck trips in urban areas take place outside this period.

Having looked extensively into the literature, some further recommendations can be made with respect to future work. To overcome the present lack of understanding of the impacts of UCVM on urban emissions several things need to happen. Data describing heterogeneity in fleet characteristics and behaviours are required to move beyond emissions modeling using aggregate origin/destination UCVM matrices. In addition, availability of disaggregate data of this sort could be matched with current research into dynamic microscopic emissions modeling, e.g., CEMEM - Barth et al. (2000); VT-Micro – Rakha and Ahn (2004); Rakha et al. (2004), providing a micro-level emissions capability that could be plugged into state of the art microsimulation models of land use/transport and environment interactions (e.g., ILUMASS, ILUTE). With this in mind, it is apparent that more work needs to be carried out with respect to UCVM data collection. While data are available for some urban regions (e.g., Edmonton, Calgary, Oregon), planning organizations have not adopted regular freight data collection and updating as a routine planning activity. Surveys should target details concerning inter and intra-regional flows, by sector and vehicle type, and should be proposed within a multi-objective framework that will be of interest to a wide-range of private and public sector stakeholders.

Lastly, considerable research has been undertaken outside the IUM community to develop mobile models capable of producing inputs to pollutant dispersion models (e.g., Bachman, 1998; Bachman et al., 2000; Potoglou and Kanaroglou, 2005). Bachman et al. (2000) developed the Mobile Emission Assessment System for Urban and Regional Evaluation (MEASURE). It is a GIS-based regional mobile emissions model that can provide peak hour or daily emissions estimates by facility type, operating mode, and pollutant type (VOCs, NO_x and CO), for individual grid cells covering a study region. Other research has looked to develop coupled systems with capabilities for both emissions and dispersion modeling (e.g., Gualtieri and Tartaglia, 1998; Jensen et al., 2001; Kinnee et al., 2004; McHugh et al., 1997). More recently, researchers have looked into the emissions generated by the entire urban vehicle fleet (passenger cars, and trucks classified by type and/or technology) (e.g., Kinnee et al., 2004; Rakha et al., 2004). This work should be consulted to enhance the emissions modeling capabilities of integrated urban models.

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