The relative contribution of trucks to mobile source emissions in Hamilton*

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Executive Summary

While passenger car mobility and related tail-pipe emissions within urban areas have received considerable attention, very little is known about the contribution of commercial vehicles to mobile source emissions. More specifically, it is desirable to investigate not only the total volume of emissions, but also emissions by link in the transportation network. In this paper a methodology is discussed that enables the estimation of commercial truck emissions of nitrogen oxides (NO_x), non-methane hydrocarbons (NMHC) or simply hydrocarbons (HC), carbon monoxide (CO), and particulate matter (PM) at the aggregate and link levels. This methodology has been applied to the Census Metropolitan Area (CMA) of Hamilton, Ontario, Canada.

A truck origin-destination (O-D) matrix was supplied by the City of Hamilton. The concept of Passenger Car Equivalence (PCE) was used to transform this matrix into a passenger car O-D matrix. The integrated land-use and transport model IMULATE has been modified to incorporate the transformed commercial vehicle matrix, along with the matrix of passenger cars.

The relative contribution of trucks to mobile source emissions during the morning peak period can be shown at the link level, or aggregated to the regional level **(Table 1.0)**. A PCE value of zero implies the total absence of trucks in the network. Reported emission values in this case are attributed to passenger cars alone. PCE values greater than zero indicate the number of vehicles displaced in traffic flow by the presence of a single truck. Reported emissions under such conditions are affected by the presence of trucks.

Table 1.0: Aggregate emissions and trips made for varying PCE values

	HC		CO		NO_x		PM		Trips	
PCE	**kg**	**%**	**kg**	**%**	**kg**	**%**	**kg**	**%**	**trips**	**%**
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

kg - kilograms
% - percent increase over the 'cars only' scenario

Particulates behave differently than other emissions with respect to average link speed. HC and CO increase non-linearly with decreasing average speeds. PM is not as effected by average speed so much as it is by the number of trips taken. The contribution of trucks to urban mobile source PM emissions cannot be ignored as trucks emit 30 to 100 times more than catalyst-equipped passenger cars [13].

The results suggest that the estimation procedure is effective. The contribution of trucks to mobile emissions of HC, CO, NOx, and PM has been addressed at the aggregate and link levels. Emission estimates demonstrate sensitivity to the presence of trucks as modeled in this study. The presence of trucks is shown to increase the aggregate level of all pollutants and affect changes in link-based estimates.

While the results are encouraging it has been recognized that the potential of this procedure for generating accurate estimates is limited by the resolution of the observed truck data. It is also recognized that gas PM is emitted at such low rates that it is difficult to measure accurately. Another limitation of the present study 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, but warrants future consideration. Also, the reported results refer only to the morning peak period. The contribution of truck emissions during the rest of a typical day is expected to be significant since most freight trips avoid the morning peak period.

1. Introduction

Considerable discussion over the last two years within the Hamilton-Wentworth Air Quality Improvement Committee led to the conclusion that little is known about truck mobility in Hamilton-Wentworth. In January 1999, a memorandum of understanding was signed between McMaster University and the Regional Municipality of Hamilton-Wentworth for a study that would examine daily traffic volumes and the contribution of trucks to daily emissions from mobile sources in the Census Metropolitan Area (CMA) of Hamilton.

In many urban areas, including Hamilton-Wentworth, motor vehicles are the largest source of nitrogen oxides (NO_x), carbon monoxide (CO), and non-methane hydrocarbon (NMHC) emissions. NMHC are often referred to simply as hydrocarbons (HC). NO_x and HC are of concern because of their role in the formation of ground-level ozone.

In addition to HC, CO and NO_x, there is increasing interest in particulate matter (known as PM or particulates). It is important, when studying PM emissions from mobile sources, to include trucks. Trucks emit 30 to 100 times more PM than passenger vehicles. In this study, of particular concern is PM_{10} (defined as being 10 microns or less) due to its association with cardio-respiratory hospitalisations [11]. In this study, a procedure for estimating aggregate and link levels of CO, HC, NO_x and PM_{10} has been applied to the Hamilton CMA.

In Canada, the Environmental Protection Agency (EPA) emission model MOBILE 5A was adapted to Canadian standards (MOBILE 5C) and is used to support air quality planning and emission inventory development. Considerable effort has been made in developing an understanding of passenger vehicle mobility and related emissions within the Hamilton CMA ([2], [6], and [8]), using an integrated land-use and transportation models and MOBILE 5C. This study expands on the scope of previous efforts by capturing the relative contribution of trucks to the volume of traffic flow and mobile emissions.

This report is the third in a series of three. The objective is to report on findings from this study.

More specifically, this report intends to:

- Outline the approach taken and the data available
- Report findings for stated emissions

The remainder of the report is organised into three sections. The first two correspond to the topics above in the same order that they are referenced. The third and final section discusses the conclusions and considers adaptations that could potentially improve the accuracy of the results.

2. Methodology and Data

2.1 Methodological Framework

The method used in this study can be divided into four phases **(Figure 1)**. In the first phase trucking data was acquired from the City of Hamilton in the form of an origin-destination matrix. Each cell of this matrix records the number of commercial vehicles traveling between two zones located within the City of Hamilton. This matrix is discussed in detail in section **2.2**. In phase two, the concept of passenger car equivalency was studied and a methodology for its application to this study was developed. The PCE concept is discussed in section **2.3**. The third phase involved the transformation of the trucking data into a set of passenger car equivalent matrices. In phase four an integrated land-use and transport model, IMULATE, was modified to accommodate transformed truck trip matrices. It was during this phase that estimates of HC, CO, and NO_x emissions were derived. IMULATE is discussed further in section **2.4**. In section **2.5** a separate procedure for estimating PM emissions is discussed.

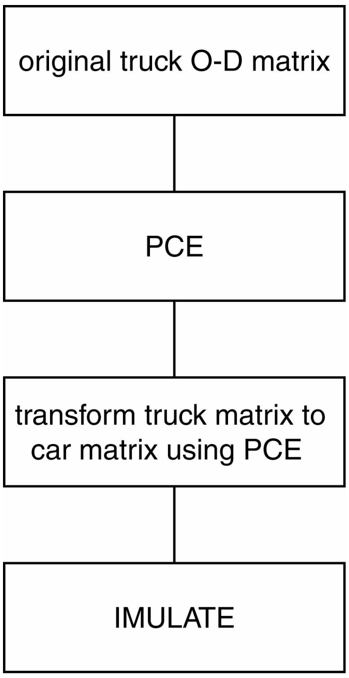

Figure 1: General Method Structure

2.2 Data Collection and Flow Matrix Determination

IMULATE's transportation model has been adjusted to include an origin-destination matrix of morning peak hour (7:00-8:00a.m.) commercial vehicle flows within the

Hamilton CMA. Bi-proportional updating was used to transform tube data and intersection counts into this matrix. Commercial vehicles 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.

Trip-ends within certain CMA municipalities (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 (i.e. combustion process, vehicle type etc.). 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 [5].

2.3 A Passenger Car Equivalency (PCE) Approach

Passenger Car Equivalencies (PCEs) have been used in the past to assess the effects of heavy-duty vehicles such as buses, recreational vehicles (RVs) and trucks on traffic conditions [3]. PCE values measure the number of base vehicles (usually passenger cars) displaced from traffic flow due to the presence of heavy-duty vehicles [3]. PCE estimation techniques are reviewed in detail in Elefteriadou et al. [3].

The literature suggests that PCE values vary by truck type, grade, road type, volume and vehicle mix [3]. In this study, a representative PCE value has been derived that controls for road type and access to specific truck routes. Vehicle type and grade are not considered. The aggregate nature of the truck trip matrix does not allow for the estimation of different PCE values for various vehicles types. The grade of the road is ignored as the entire transport network in the study area is characterized by links of moderate to low slope.

2.3.1 Truck Type

Addressing the contribution of trucks to mobile source emissions requires consideration of the type of truck(s) being modeled. Another data source was needed to address truck type due to the lack of detailed information in O-D matrix. At the time of the traffic counts (used to generate the truck O-D matrix), some vehicle classification was done at certain intersections, using a 14-class scheme. To describe the truck fleet, 28 of these intersections were selected at random and class counts for the morning peak hours were calculated **(Table 2.0)**.

Table 2.0: Vehicle classes used in Hamilton-Wentworth

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

'% of peak flow' refers to the percent of the total vehicle flow at the peak hour that class comprises.
'rank' is the order the classes rank in terms of percent of peak flow

Counts were summed for each class over these morning peak hours for each intersection. These sums were divided by the total sum for all vehicle classes at each intersection. The vehicle classes were then ranked based on percentage. The highest ranked class, strictly limited to trucks, was Vehicle Class 3 (2-axle light truck), comprising roughly 10.7% of the total vehicle flow over sampled intersections. Vehicle Class 3 was deemed the 'average truck' in 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. [3]. In turn, the EPA defines this SUT as a light duty diesel truck (LDDT) [13]. It is this truck class that is used to model the presence of trucks in this study. The rationale for not addressing other classes of trucks is that the sparse nature of the O-D matrix would negate the effect of emissions generated by other truck types. The sum of all truck vehicle classes is 14.24% of all vehicles. This is consistent with the percent of trucks in traffic flow found in Elefteriadou et al. [3].

2.3.2 Road Type and Number of Lanes

Trucks within the Hamilton CMA are restricted, by law, to a subset of links of the entire road network. This truck road network is shown in **Figure 2.** Road type and the number of lanes were controlled for by identifying which links on the truck road network were "freeways", "arterials", and "two-lane highways with low flows".

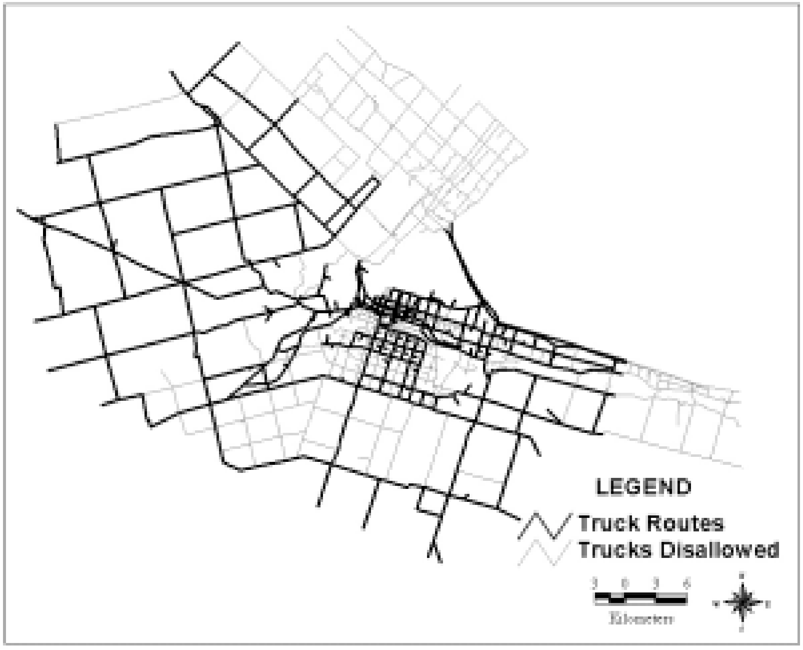

Figure 2: Hamilton-Wentworth Trucking Routes

These are the three road types that influence the assignment of PCE values [3]. Tables in Elefteriadou et al. were used as a guide in determining PCE values. 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. Arterials do not provide an opportunity for passing, and therefore the impact of heavy vehicles is more pronounced. The mean PCE was found to be 2.48 over 805 truck route links. A PCE of 2.48 implies that roughly two and half passenger cars are displaced from the traffic flow for every individual truck. The upper and lower bounds of a 90% confidence interval were 2.544 and 2.416 respectively. In the interest of sensitivity analysis it was decided that PCE values other than the mean, the lower and upper bounds of the confidence interval were needed. PCE values of 0, 1, 2, 2.42, 2.48, 2.54, 3, 4 and 5 were chosen for the purpose of conducting simulations. The truck O-D matrix was multiplied by each of these scalars, creating six separate PCE matrices. Simulations were run, and emissions recorded for each PCE step and compared. A PCE value of zero, or the 'cars only' scenario, implies the total absence of trucks in the network. Cars are denoted by the EPA, and in this study, as light duty gas vehicles (LDGV). LDGVs in the Hamilton CMA are assumed to be using unleaded fuel and to be catalyst equipped.

2.4 Integrated Land-Use and Transport Models

Integrated land-use and transport models address the relationship between urban land-use and transportation systems. Embedded within the formal structure of these models is the recognition that land-use influences the properties of transport infrastructure and travel behaviour which recursively affect spatial patterns of urban land-use [7]. These models can be used to simulate the affect of transport and land-use policies on the characteristics of transportation systems and patterns of urban land-use over time. Detailed reviews of existing operational models and applications can be found in Southworth [9] and Miller et al. [7].

IMULATE, the model used in this study, is an extension of existing operational models. A detailed description of the model is found in Anderson et al. [1]. The general structure of IMULATE consists of four sub-models, and is illustrated in **Figure 3**.

The first of these, POPMOB, handles intraurban migration and place of work assignment of the resident workforce within a system of 151 census zones. The second sub-model, TRANDEM, handles trip generation, distribution and mode split. TRANDEM estimates the number of work, school and discretionary (i.e. shopping, recreational) trips by mode. The TRAFFIC ASSIGNMENT sub-model uses a stochastic user equilibrium algorithm to assign interzonal automobile trips (from TRANDEM) to a model of the Hamilton CMA's road network. The road network model consists of over 1100 nodes and 1500 links. The feedback between the transportation model and POPMOB is consistent with other operational models of this kind [9].

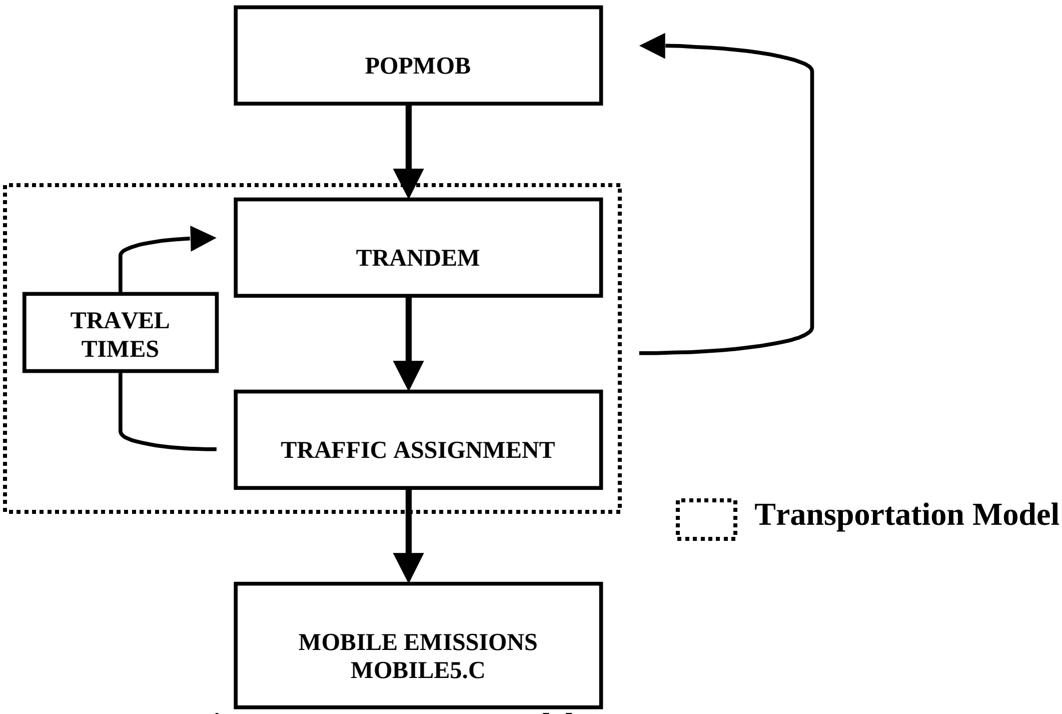

Figure 3: IMULATE Model Structure

The MOBILE EMISSIONS extension uses link flows and average speeds from the TRAFFIC ASSIGNMENT sub-model to estimate 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 stop-and-go conditions, commonly associated with congested roadways. Under these conditions tail-pipe emission levels of HC and CO will be higher than under driving cycles associated with higher average speeds.

2.5 PM Estimation

The MOBILE5C emissions model does not estimate particulates. As a result, a separate methodology for the estimation of link and aggregate levels of PM has been developed. In this section, the methodology will be explained and results will be presented. 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 used in conjunction with EPA PM emission factors for combustion exhaust, tire wear, and brake wear to generate PM estimates. Due to data limitation, other particulate emissions factors such as idle emissions and fugitive dust are not included.

Literature from the EPA suggests that the total exhaust particulate emission factor for light-duty gasoline vehicles (LDGV) is calculated from the sum of lead, direct sulfate, and a carbon emission factor which includes soluble organics and other remaining carbon [12]. 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.

2.5.1 Selecting PM Emission Factors

For these reasons, in this study, the carbon emission factor is used to calculate PM exhaust emissions. Model year and the technology type of trucks and cars affect the carbon emission factor ([12], [13]). Average age of the Hamilton CMA vehicle fleet (model year) was approximated from U.S. data, collected by Polk [14]. The average model year for both the car and truck fleet was found to be 1990. The simulation that estimated PM ran from 1996 to 2001. The midpoint of this estimation would be half way through 1998. In 1996, the average age of cars was 8.3 years [14]. Subtracting the average age (roughly eight and a half years) from the year of estimation left a model year of 1990.

The nearest EPA age category for cars (LDGVs) was 1981 and newer. The PM exhaust emission factor for this category is 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 [12]. The PSC is defined to be the maximum aerodynamic diameter (between 1.0 and 10.0um) of the particles in the emission factors [12]. In this study a PSC of PM_{10} is modeled. The fraction of particles less than or equal to the PSC is determined from fractions in EPA 1985a. For catalyst equipped LDGVs, 1981 and newer, using unleaded fuel the fraction of particles less than or equal to PM_{10} is 0.98 [12]. The flow on each link was multiplied by the length (in miles) of that link in the 'cars only' scenario to get total number of car miles traveled (CMT). CMT was then multiplied by the carbon emission factor for light duty, unleaded gasoline vehicles 1981 and newer. The total amount of particulate matter emitted from combustion exhaust for LDGVs on a typical day from 1996-2001 was 8 kilograms.

For the purposes of this study, it is assumed that the Hamilton truck fleet, and the average truck used to represent the fleet as a whole, is a light duty diesel truck (LDDT). This was necessary to describe the Hamilton CMA truck fleet and attach PM emission factors. In 1996, the average age of trucks was 8.6 years [14]. 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 (LDDT, 1990) is 0.291 gram/mile. Again, to determine the amount of PM_{10} a PSC is applied. For all model years of all diesel vehicles, including 1990 LDDT, the fraction of particles less than or equal to PM_{10} is 1.00 [12].

For the purpose of estimating PM, the road network in this study is broken into links that are truck routes and links that are non-truck routes. Intersection counts reveal that trucks account for approximately 15% of the volume on truck route links.

2.5.2 PM Estimation Methodology

The PM exhaust (***PME***) estimates for truck route links, *i*, are calculated by:

$$\boldsymbol{PME_i} = (0.15\, \boldsymbol{f}_i\, \boldsymbol{l}_i\, \boldsymbol{EE}_{LDDT}\, \boldsymbol{PSC}_{LDDT}) + (0.85\, \boldsymbol{f}_i\, \boldsymbol{l}_i\, \boldsymbol{EE}_{LDGV}\, \boldsymbol{PSC}_{LDGV})$$

where $\boldsymbol{f}_i$ is the total traffic volume on truck route link *i*, $\boldsymbol{l}_i$ is the length of truck route link *i* in miles, $\boldsymbol{EE}_{LDDT}$ is the light duty diesel truck PM exhaust emission factor (0.291 g/mile), $\boldsymbol{PSC}_{LDDT}$ is the fraction of particles less than or equal to PM_{10} for light duty diesel trucks (1.00), $\boldsymbol{EE}_{LDGV}$ is the light duty gas vehicle PM emission factor (0.0043 g/mile), and $\boldsymbol{PSC}_{LDGV}$ is the fraction of particles less than or equal to PM_{10} for light duty gasoline vehicles (0.98).

The PM exhaust estimates for non-truck route links, *j*, are calculated by:

$$\boldsymbol{PME_j} = (\boldsymbol{f}_j\, \boldsymbol{l}_j\, \boldsymbol{EE}_{LDGV}\, \boldsymbol{PSC}_{LDGV})$$

where $\boldsymbol{f}_j$ is the total traffic volume on non-truck route link *j*, $\boldsymbol{l}_j$ is the length of non-truck route link *i* in miles, $\boldsymbol{EE}_{LDGV}$ is the light duty gas vehicle PM emission factor (0.0043 g/mile), and $\boldsymbol{PSC}_{LDGV}$ is the fraction of particles less than or equal to PM_{10} for light duty gasoline vehicles (0.98).

PM from combustion exhaust for the entire system is given by:

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

The PM tire wear and brake wear emission factors for all vehicle categories and model years are 0.002 gram/mile/tire, and 0.0128 gram/mile respectively [12]. A PSC for PM_{10} is applied to these emission factors as well.

The tire wear emission factor for all vehicle categories and model years ($\boldsymbol{TWEF_{av}}$) in grams/mile is calculated as:

$$\boldsymbol{TWEF_{av} = (0.002\ PSCtire_{av}\ ANOT_v)}$$

where $\boldsymbol{PSCtire_{av}}$ is the tire particle size cutoff for PM_{10} for all vehicles (1.00), $\boldsymbol{ANOT_v}$ is the average number of tires per vehicle. For both LDDT and LDGV, $\boldsymbol{ANOT_v}$ is 4 [12].

The PM tire wear (***PMTW***) estimates for truck route links, *i*, are calculated by:

$$\boldsymbol{PMTW_i} = (\boldsymbol{f}_i\ \boldsymbol{l}_i\ \boldsymbol{TWEF}_{av})$$

where $\boldsymbol{f}_i$ is the total traffic volume on truck route link *i*, $\boldsymbol{l}_i$ is the length of a link in miles, $\boldsymbol{TWEF}_{av}$ is the PM tire wear emission factor for all vehicles (0.008 g/mile). Similarly, the PM tire wear (***PMTW***) estimates for non truck route links, *j*, are calculated by:

$$\boldsymbol{PMTW_j} = (\boldsymbol{f}_j\ \boldsymbol{l}_j\ \boldsymbol{TWEF}_{av})$$

PM from tire wear for the entire system is given by:

$$PMTW_{TOTAL} = \sum_{i=1}^{n} PMTW_i + \sum_{j=1}^{m} PMTW_j$$

The brake wear emission factor for all vehicle categories and model years ($\boldsymbol{BWEF_{av}}$) in grams/mile is calculated as:

$$\boldsymbol{BWEF_{av} = (0.0128\ PSCbrake_{av})}$$

where $\boldsymbol{PSCbrake_{av}}$ is the brake particle size cutoff for PM_{10} for all vehicles categories and model years (0.98).

The PM brake ware (***PMBW***) estimates for truck route links, *i*, are calculated by:

$$\boldsymbol{PMBW_i} = (\boldsymbol{f}_i\ \boldsymbol{l}_i\ \boldsymbol{BWEF}_{av})$$

where $\boldsymbol{f}_i$ is the total volume on truck route link *i*, $\boldsymbol{l}_i$ is the length of a link in miles, and $\boldsymbol{BWEF}_{av}$ is the PM brake wear emission factor for all vehicles (0.0125 g/mile).

Similarly, the PM brake ware (***PMTW***) estimates for non truck route links, *j*, are calculated by:

$$\boldsymbol{PMBW_j} = (\boldsymbol{f}_j\ \boldsymbol{l}_j\ \boldsymbol{BWEF}_{av})$$

PM from brake wear for the entire system is given by:

$$PMBW_{TOTAL} = \sum_{i=1}^{n} PMBW_i + \sum_{j=1}^{m} PMBW_j$$

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

$$\boldsymbol{PM_{total} = PME_{total} + PMTW_{total} + PMBW_{total}}$$

The total amount of particulate matter emitted by cars and trucks at PCE 1.00 during the morning peak hour (7:00am-8:00am) of a typical day between 1996-2001 was 99 kilograms. **Table 2.1** shows the contribution of brake wear, tire wear, and exhaust emission to the total of PM emissions for cars and trucks at PCE 0.00 and PCE 1.00.

Table 2.1: Aggregate PM emissions from brake wear, tire wear, and exhaust for PCE 0.00 and PCE 1.00

	PCE 0.00			PCE 1.00			Percent increase in totals
	Car	Truck	Total	Car	Truck	Total	from PCE 0.00 to PCE 1.00
miles traveled	1900288.38	0.00	1900288.38	1807957.06	175349.81	1983306.86	4.4
brake wear PM (kg)	23.84	0.00	23.84	22.68	2.20	24.88	4.4
tire wear PM (kg)	15.20	0.00	15.20	14.46	1.40	15.87	4.4
exhaust PM (kg)	8.01	0.00	8.01	7.62	51.03	58.65	632.4
total PM (kg)	47.05	0.00	47.05	44.76	54.63	99.39	111.3

3. Results and Discussion

IMULATE was run for passenger cars, starting at base year 1986 and running to 2006 at five-year intervals. The road network was updated at each five-year period as required (i.e. the Lincoln Alexander Expressway was added in 1996). A PCE value of zero, or the ‘cars only’ scenario, implies the total absence of trucks in the network. Reported emission values in this case are attributed to passenger cars alone. This is the base scenario against which all subsequent scenarios involving trucks with PCE values are compared. The relative contribution of trucks can be shown at the link level, or aggregated to the regional level **(Table 3.0)**. Results of the aggregate level will be discussed first, followed by a discussion of link level findings.

Table 3.0: Aggregate emissions and trips made for varying PCE values

	HC		CO		NO_x		PM		Trips	
PCE	**kg**	**%**	**Kg**	**%**	**kg**	**%**	**kg**	**%**	**trips**	**%**
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

kg - kilograms
% - percent increase over the 'cars only' scenario

Increasing the PCE value is equivalent to increasing the volume of vehicle traffic that will be loaded onto the network. This serves as a proxy for the presence of truck traffic. The procedure of loading additional base vehicles onto the network leads to increased load on network links. In certain cases (e.g. truck routes) increased link congestion and lower average link speeds result. The relationship between certain mobile source emissions (HC, NO_x, and CO) and average link speed is known to be non-linear [2]. That relationship is reproduced here as well **(Figure 4)**.

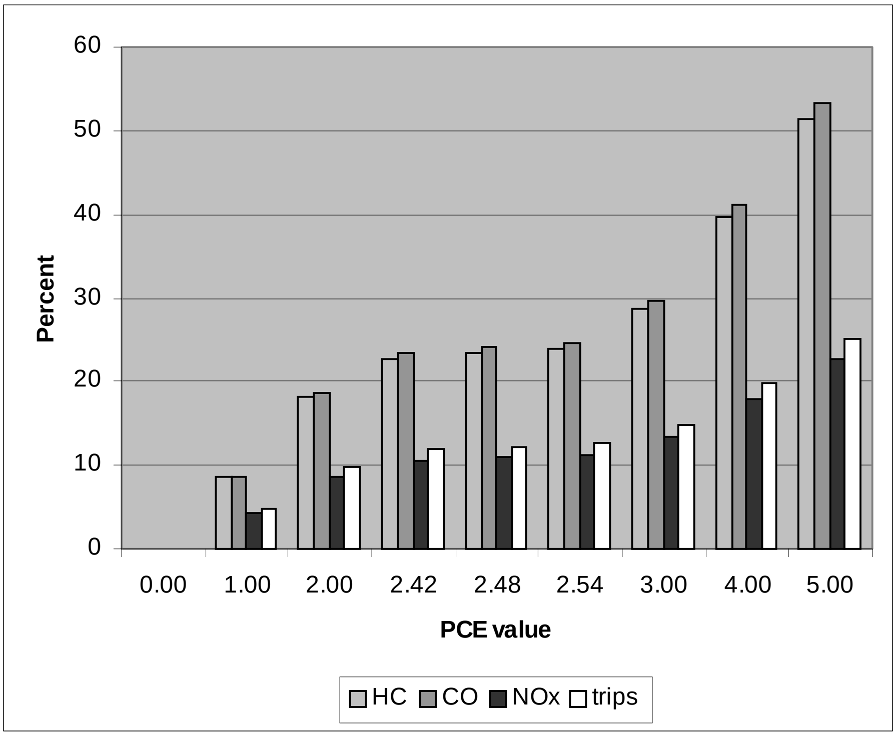

Figure 4: Percent increase in HC, CO, NOx, and trips with varying PCE

Particulates behave differently than the other emissions with respect to average link speed. HC and CO in **Figure 4** increase non-linearly with decreasing average speeds. PM is not as effected by average speed so much as it is by the number of trips taken **(Figure 5)**.

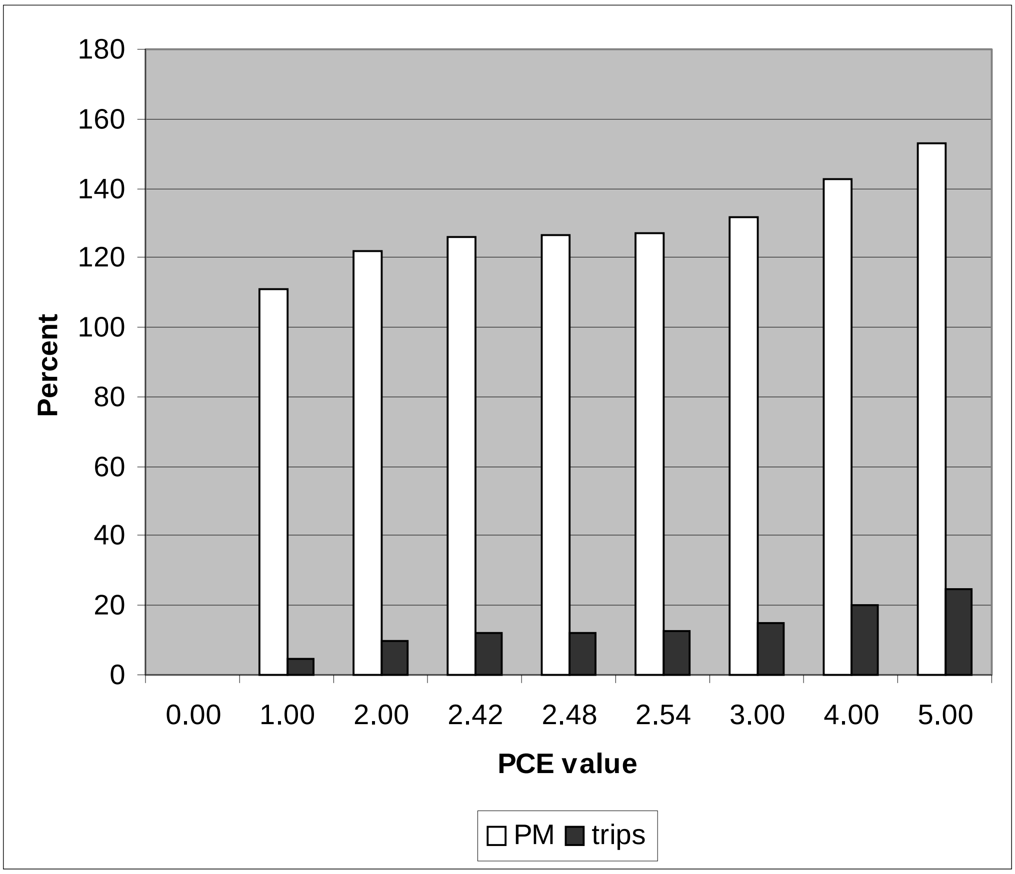

Figure 5: Percent increase in PM and trips for varying PCE

Increases in CO and HC for increasing PCE values suggest that emission estimates are sensitive to the presence of trucks and resulting roadway congestion **(Table 3.0)**. Because emissions of CO, HC, and NO_x are dictated by average speed, a meaningful analysis of the contribution of trucks to these emissions is in the comparison of PCE 0.00 and the average PCE value of 2.48. In this comparison, a 12% positive adjustment in base vehicles, to reflect the presence of trucks, yields a 24% increase in CO and a 23% increase in HC emissions. Similarly, accounting for trucks in this way has a positive effect on NO_x (11%) but the effect is not as pronounced. The most dramatic effect is seen in PM, with an 111% increase resulting from a 5% adjustment in base vehicles (PCE 0.00 to PCE 1.00). As PM emissions are not as affected by average speed as they are by vehicle distance traveled, the relative contribution of trucks to PM is found in the investigation of the PCE 1.00 scenario, where the truck O-D matrix is unadjusted. While further study of the results is warranted, these findings are valuable. HC and NO_x emissions are part of the chemical process that generates ground level ozone, while particulate matter has a proven association with respective increases in respiratory and cardiac hospital admissions [11]. The contribution of trucks to urban mobile source PM emissions cannot be ignored as trucks emit 30 to 100 times more than catalyst-equipped passenger cars [13].

Analyzing the results at the link level reveals the spatial concentration of emissions. The contribution of trucks to all emissions is visible along truck routes. **Figures 6** through **17** illustrate the spatial pattern of traffic flows, congestion, and emissions and allow for comparison between the cars only scenario and that with trucks at PCE 2.48. Selected figures are presented below, while others can be found in the attached **Appendix**.

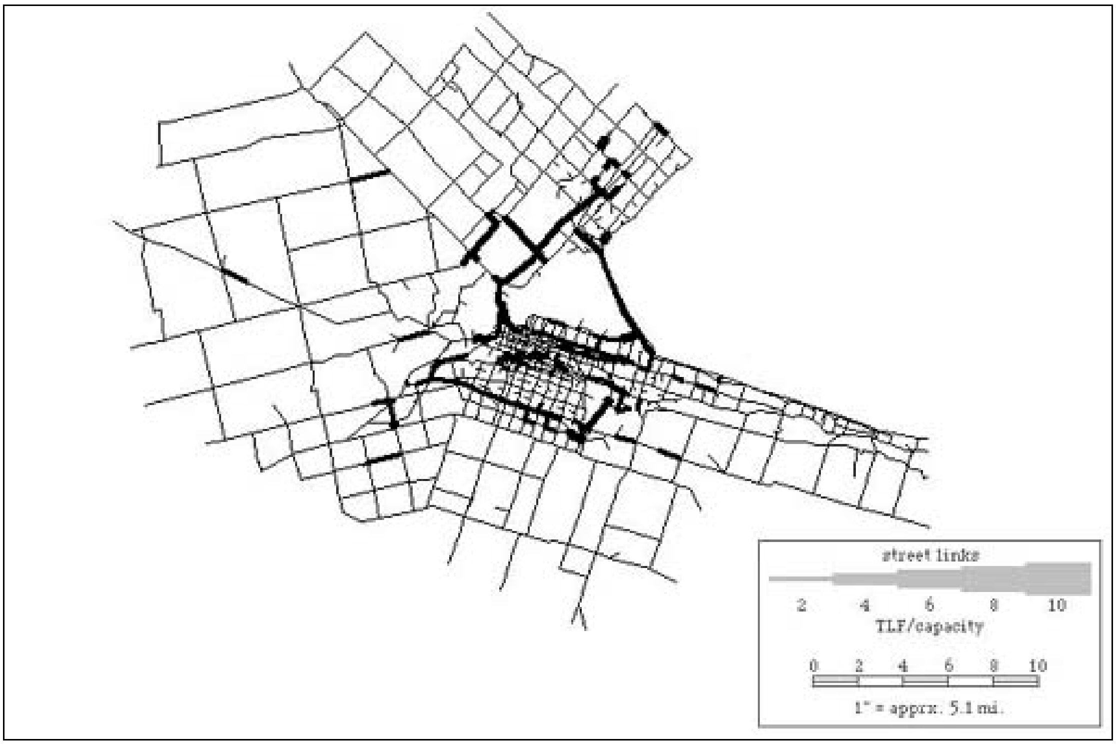

Figure 6: Total link flows divided by capacity with trucks at PCE value 2.48

Figure 6 is designed to show the spatial pattern of congestion. The total link flow on each link is divided by the capacity of that link. The thickness of the lines demonstrates areas where flow exceeds link capacity. **Figure 6** shows the impact on congestion for trucks at PCE 2.48.

Figures 11 and **12,** in the Appendix, show the spatial pattern of link flows without trucks and with trucks at PCE value 2.48 respectively. The pattern of flow is similar in both scenarios, but the thicker lines in **Figure 12** show the greater impact trucks have on flow. Comparing these figures with **Figure 10** through **17** shows the association of flow with increased emissions. The thick lines in these figures can be compared with the thick lines in **Figures 7** to **10** and **Figures 14** through **17.** The spatial pattern in these figures shows that congestion can be associated with increased emissions.

Figure 7 and **8** show spatial variation in link-based estimates of HC. The thicker links in **Figure 8** are road sections that exhibit large levels of HC as a result of the inclusion of trucks. As expected, the effect appears to be stronger along the truck routes shown in **Figure 2**.

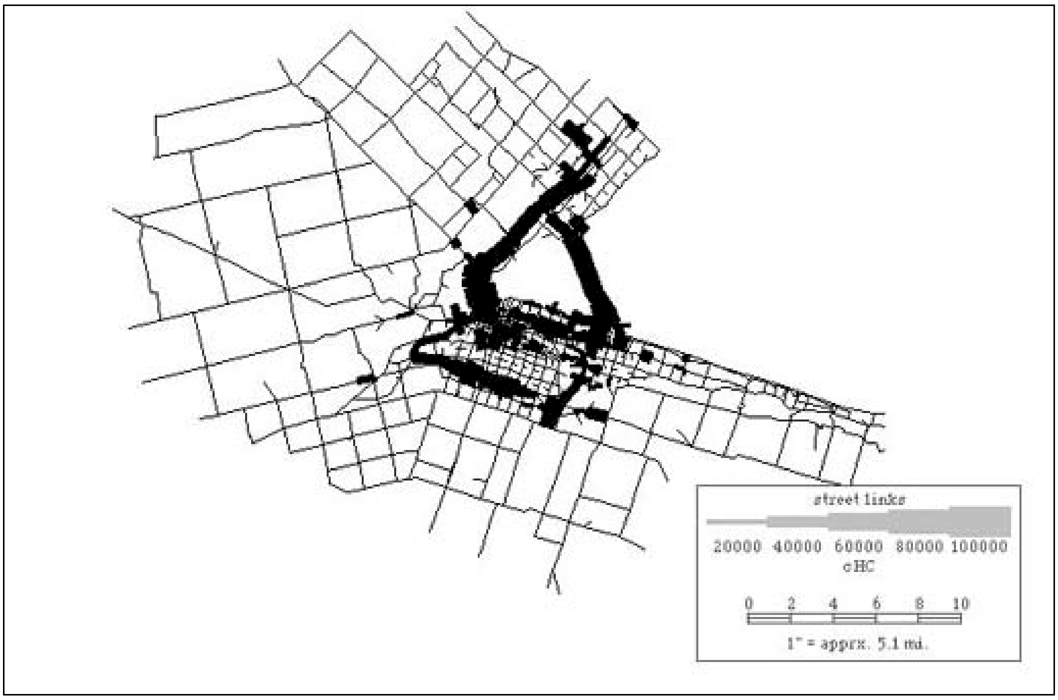

Figure 7: Emissions of HC for cars only (PCE 0.00)

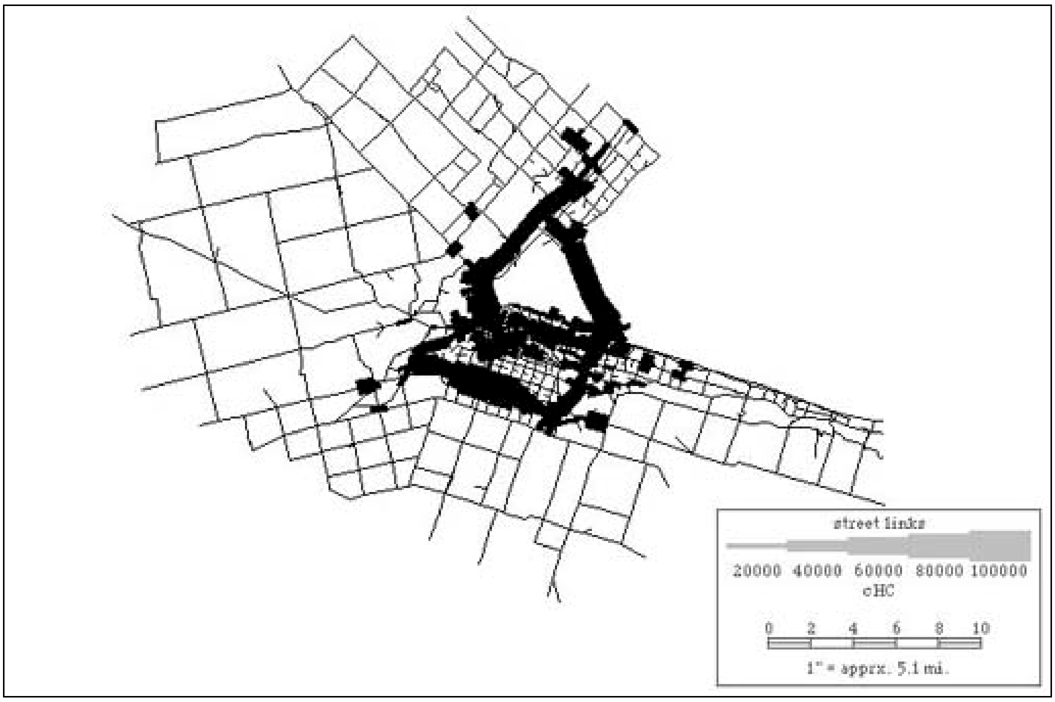

Figure 8: Emissions of HC with trucks at PCE value 2.48

Shown in **Figures 12**, **13** and **14**, **15** (appendix) are similar spatial patterns for the residuals of CO and NO_x. This suggests that not controlling for the presence of trucks 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.

Figure 9 and **10** show spatial variation in link-based estimates of PM. Again, the thicker links in **Figure 10** are road sections that exhibit large levels of PM as a result of the inclusion of trucks.

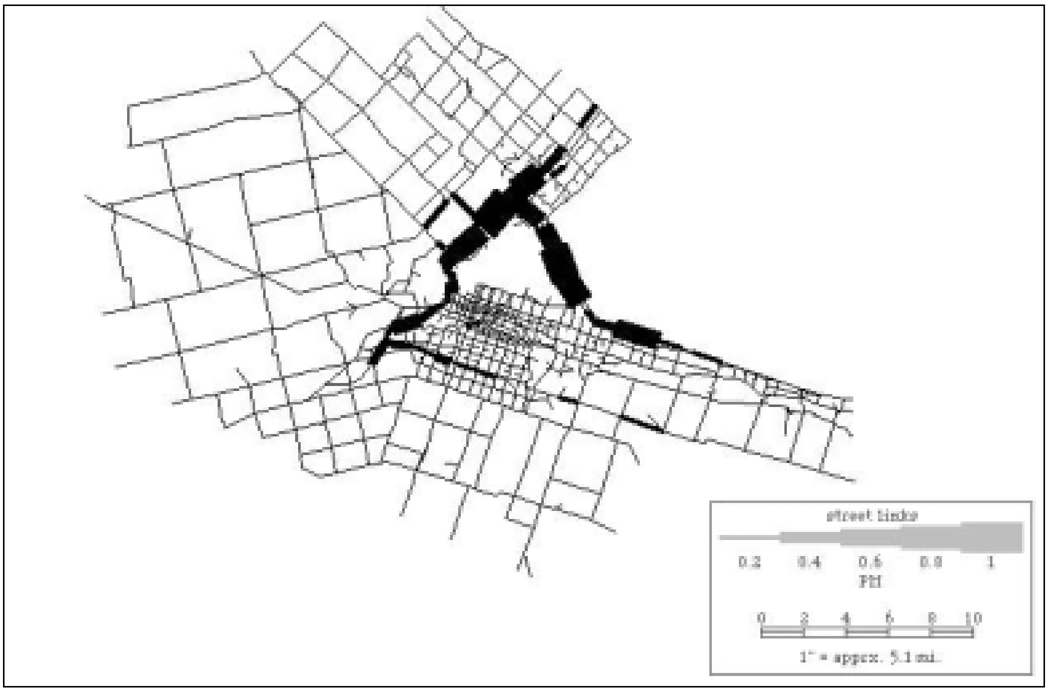

Figure 9: Emissions of PM with trucks at PCE value 0.00

From the PM emission factor (given in grams/mile), it was known that PM would not be as affected by average speed so much as it would by the number of trips taken. With trucks, and the trips they contribute, confined only to certain routes, the effect on PM is more pronounced spatially along truck routes than the other emissions.

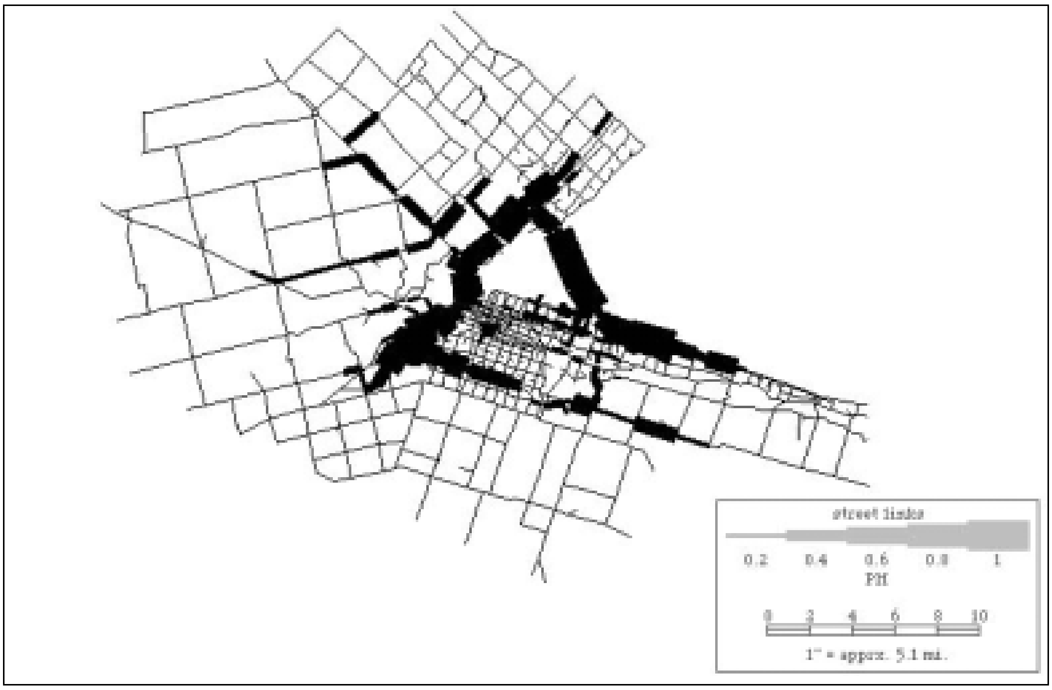

Figure 10: Emissions of PM with trucks at PCE value 1.00

4. Conclusion

A procedure for evaluating the contribution of trucks to mobile source emissions within urban areas has been presented and tested. The procedure has been applied to the CMA of Hamilton, Ontario. The results suggest that the procedure is effective. The contribution of trucks to mobile emissions of HC, CO, NOx, and PM has been addressed at the aggregate and link levels. Emission estimates demonstrate sensitivity to passenger car equivalency values. The presence of trucks, as modeled in this study, is shown to increase the aggregate level of all pollutants and affect changes in link-based estimates.

While the results are encouraging it has been recognized that the potential of this procedure for generating accurate estimates is limited by the resolution of the observed truck data. The vehicle kilometers traveled, and hence the PM results, are understated due to the sparse nature of the original truck matrix and the aggregate nature of the vehicle classification. Another limitation of the present study 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, but warrants futures work. Also, the reported results refer only to the morning peak period. The contribution of truck emissions during the rest of a typical day is expected to be significant since most freight trips avoid the morning peak period.

Appendix

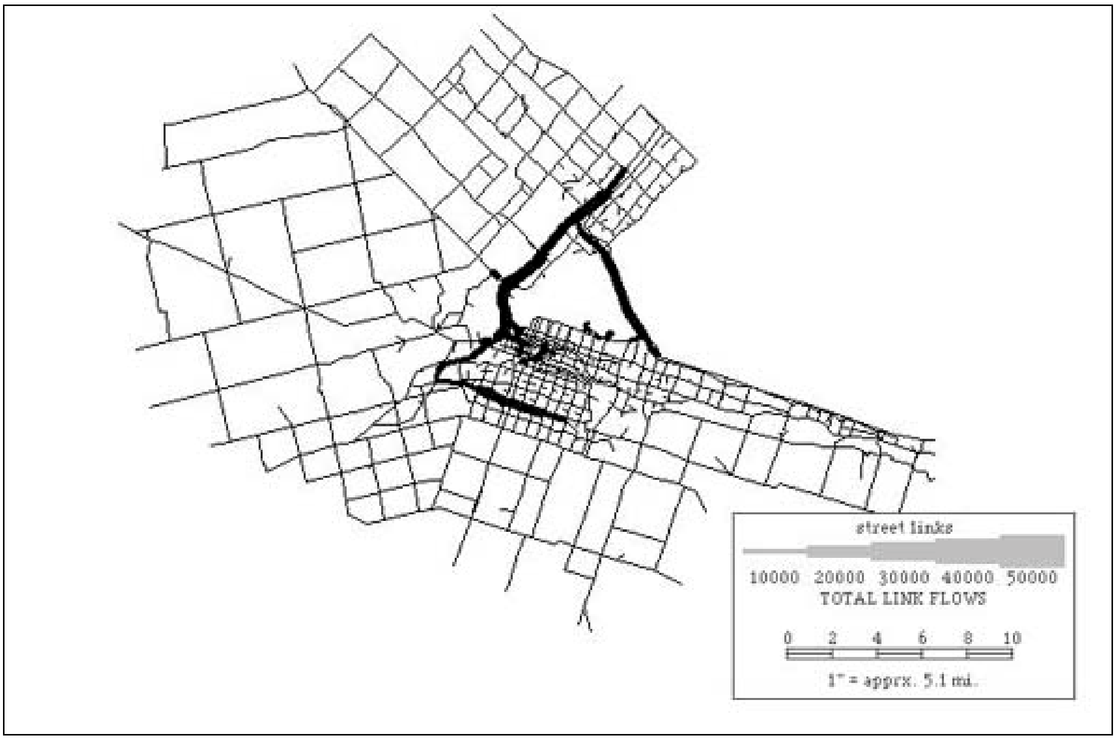

Figure 11: Total link flows from 1996-2001 for cars only (PCE 0.00)

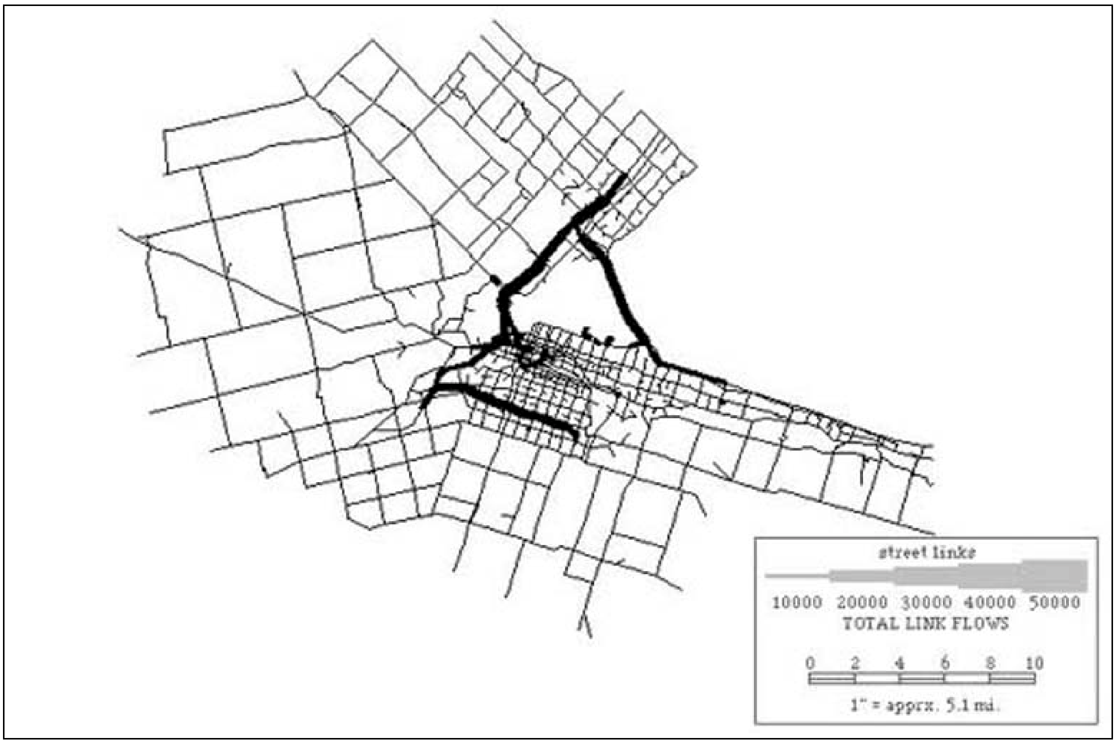

Figure 12: Total link flows from 1996-2001 with trucks at PCE value 2.48

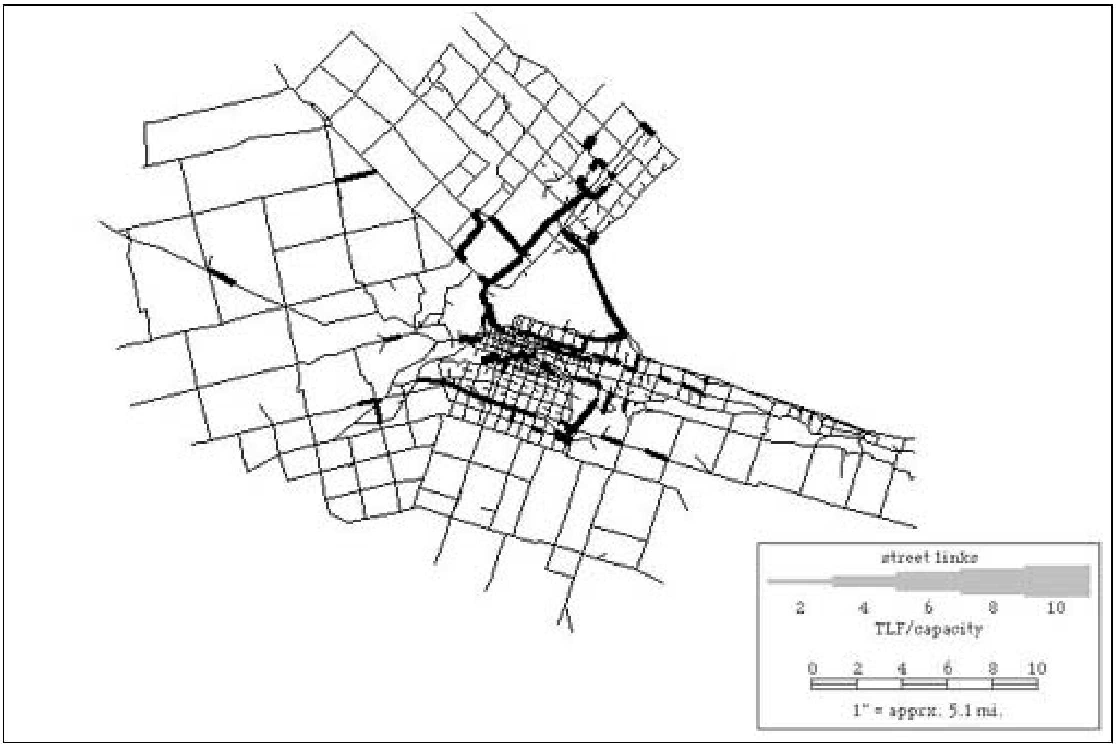

Figure 13: Total link flows divided by capacity for cars only (PCE 0.00)

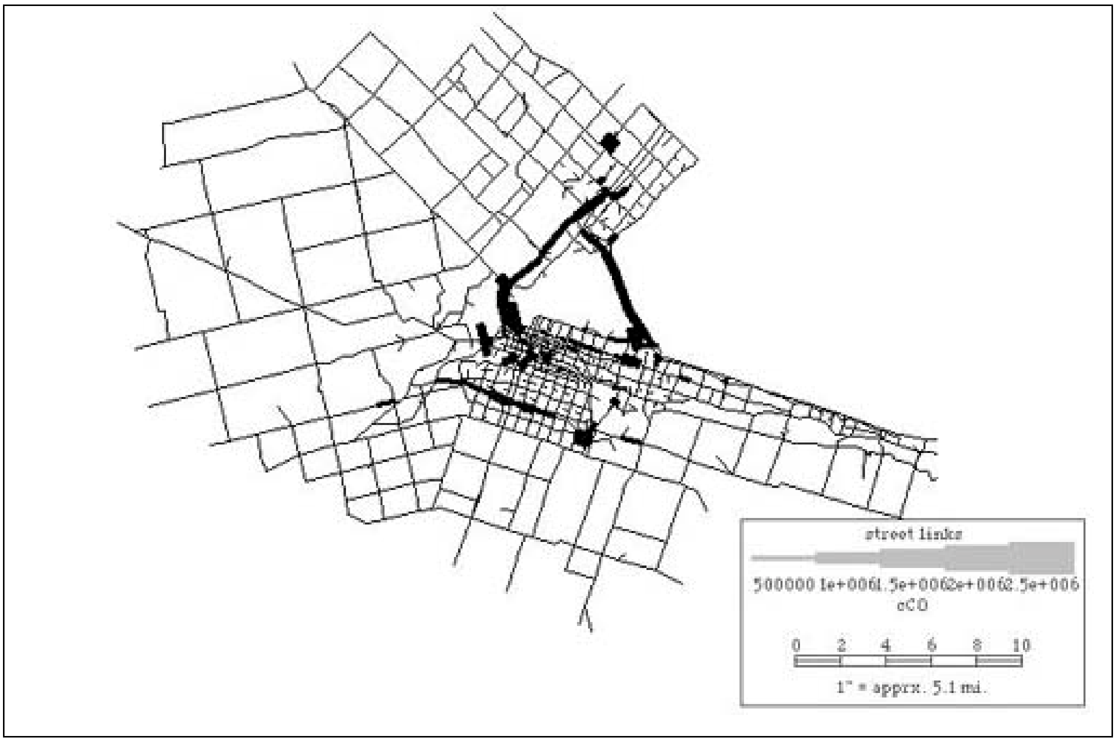

Figure 14: Emissions of CO for cars only (PCE 0.00)

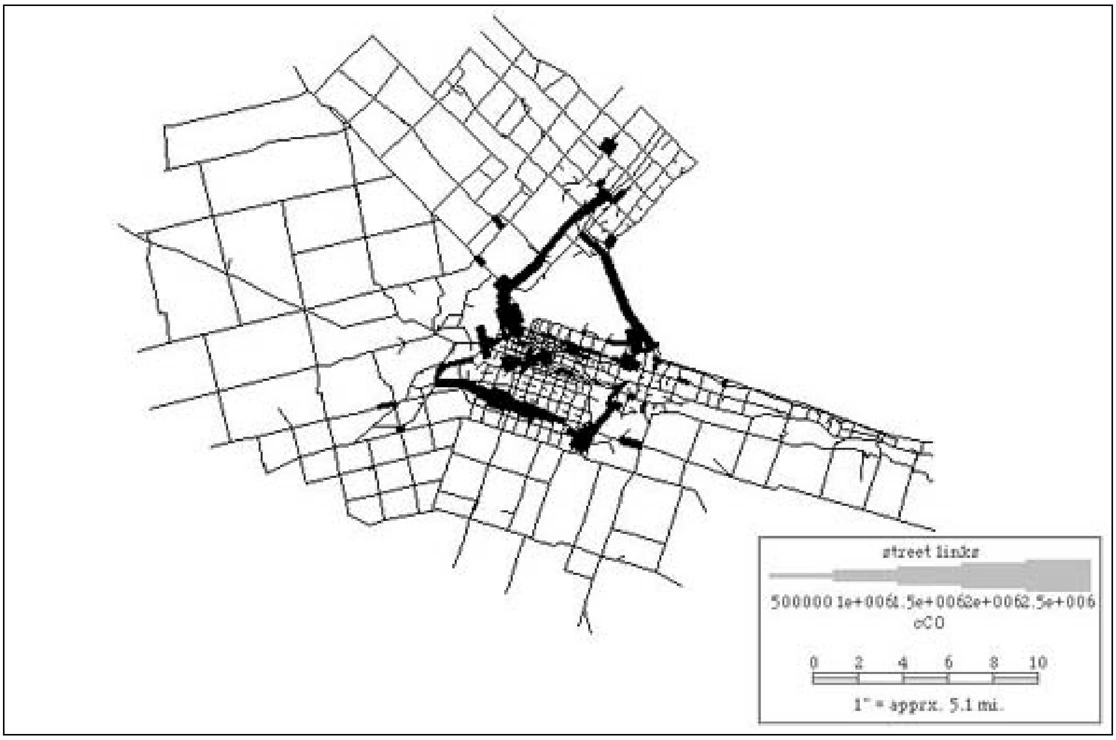

Figure 15: Emissions of CO with trucks at PCE value 2.48

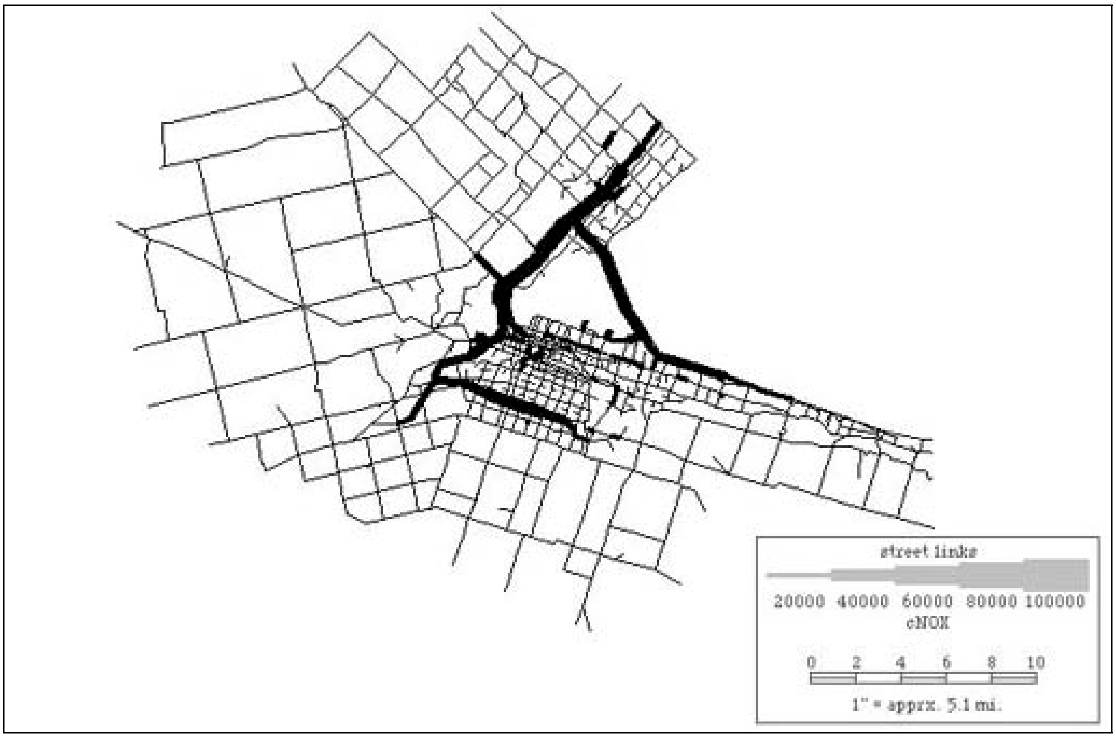

Figure 16: Emissions of NOx for cars only (PCE 0.00)

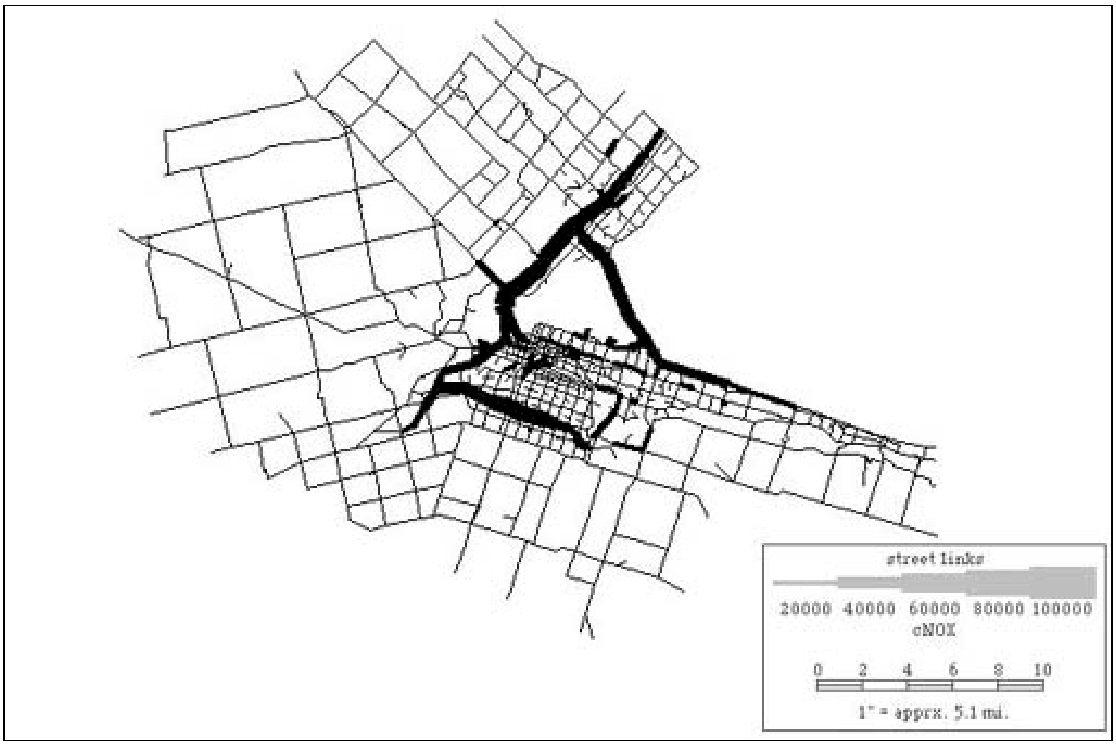

Figure 17: Emissions of NOx with trucks at PCE value 2.48

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