Thornton, M., R. Guensler, and P. Schropp (1998). "The Development of an Urban Commercial Vehicles Travel Model and Heavy-Duty Vehicle Emissions Model for the Atlanta Region"; Published in CD-ROM of the Proceedings of the 77th Annual Meeting of the Transportation Research Board; Washington, DC; January.

1. Introduction

Over the past three years, the Atlanta Regional Commission (ARC) has been developing a commercial vehicle travel model. Concurrently, the Georgia Institute of Technology (Georgia Tech) has been working on advanced heavy-duty vehicle emissions modeling techniques. These efforts have been conducted with the support of the Federal Highway Administration (FHWA), the Environmental Protection Agency (EPA), the Georgia Department of Transportation (GDOT), and the contribution of numerous consulting groups. The combined Atlanta model consists of two modules, one used in conjunction with a regional four step travel demand forecasting model to predict truck and other non-home based commercial travel activity (and external truck travel), and the other designed to estimate truck emissions within a GIS framework.

The purpose of this paper is to provide an overview of the development of a commercial vehicles travel model set for the ARC, the Metropolitan Planning Organization (MPO) for the Atlanta Region, and the Georgia Tech emissions model. This is intended to provide a summary of the model development process and in turn provide information for those interested in developing a commercial vehicles model or the issue of the transferability of the results of this project to other urban areas.

The development of the Atlanta commercial vehicle and truck model set was divided into three basic phases. The data collection phase which identifies data elements and formulation of a survey instrument. The second phase consisted of the development of the truck trip generation and the trip distribution models. The final phase, which is still under development, is the integrated heavy-duty vehicle emissions module. Before the specifics of each of these steps are described the context of the model development will be discussed.

2. Context of Model Development

On-road heavy-duty diesel-powered vehicles are major contributors of NOx and SOx, emissions. Because heavy-duty vehicles contribute significantly to NOx emissions, a precursor to the formation of ozone, and because Atlanta is currently in non-attainment for ozone, heavy-duty vehicle activities and emissions are a particular concern in air quality planning.

The ARC commercial vehicles model set was developed in conjunction with a comprehensive regional travel demand model update. To improve the ARC travel demand forecasting model set, the Commission updates their travel models every decade. In anticipation of new Federal transportation legislation, the Intermodal Surface Transportation Act of 1991 (ISTEA), and travel data made available through the 1990 census, the ARC initiated a major travel model enhancement and data collection effort in 1990.

2.1 Travel Demand Model Update

This latest round of model updates was a comprehensive overhaul of the travel demand model set used during the 1980s. In light of Federal legislation including ISTEA and the Clean Air Act Amendments of 1990, it was necessary for the ARC to develop a model set that was significantly more sensitive to changing travel patterns and, vehicle and modal activity.

In addition to addressing issues of changes in urban travel, such as trip chaining, the ARC also wanted to develop a model that was sensitive to fluctuations in time of day activity and variations in vehicle emissions. The primary reason for developing a model of this detail was based in the need to integrate the travel demand models with emissions models (i.e. MOBILE5a) used for air quality analysis and conformity determination in urban areas that do not meet national ambient air quality standards.

Indeed, the Atlanta Region does not meet air quality standards and is a Federally designated serious nonattainment area for ozone. In light of this, it is important for the Atlanta Region, as with many metropolitan areas across the nation, to have a model set that provides accurate VMT estimation and is compatible with emissions models.

It was imperative that this model update include the refinement to the existing model to include truck and other commercial vehicle activity. This was important as it is known that trucks have vastly different travel pattern and emissions rates compared to a typical passenger vehicles. The vehicle emissions elements of the model set were developed with input from and cooperation with the Georgia Institute of Technology (Georgia Tech) and their on going emissions modeling efforts and are discussed in section five.

In addition, this comprehensive model enhancement effort was guided by a peer review panel formed specifically for the model update. The peer review panel was composed of modeling experts from the Denver Council of Governments (DRCOG), METRO Portland, the North Central Texas Council of Governments (NCTCOG) Dallas, and Georgia Tech. This panel played an integral role in the model update, as well as development of the commercial vehicles model.

2.2 ARC Survey Activities

Under the advisement of the review panel, the ARC planned an intensive data collection effort designed to support the model update and supplement the 1990 census data. This data collocation effort was composed of five primary elements: household travel survey, transit onboard survey, establishments survey, external travel survey, and commercial vehicles survey. The household travel survey which was conduced in the fall of 1991 included 2,433 complete households interviews [1]. The transit and external surveys were performed in subsequent years. The establishment survey is planned for the fall of 1997, and the commercial vehicles survey was performed in the spring of 1996.

The Commercial vehicles survey was the primary source of data for the development of the truck activity model, but the external travel survey provided information used in the development of the external portion of the truck model. Supplemental data were used to support the formation of emissions models.

3. Commercial vehicles Data Collection

The Commercial Vehicle Survey was conducted by NuStats International for the ARC in the Spring of 1996[2]. The primary objective of the survey was to provide insight into truck movements in the Atlanta Region. Specifically, the goal of the survey was to provide data for the development of the internal truck trip model. Data from the external travel survey was used to support the external truck trip model (trips with one or both ends out side the Atlanta Region).

The commercial vehicles survey was accomplished through a survey of businesses that operate commercial vehicles registered in the planning area for the Atlanta Regional Commission. This includes the counties of Clayton, Cherokee, Cobb, DeKalb, Douglas, Fayette, Fulton, Gwinnett, Henry and Rockdale, and the City of Atlanta.

Like all recent commercial vehicle surveys, this study relied on the willingness of area businesses and their drivers to complete trip logs of their daily travel. Recruitment of businesses was conducted through a “recruitment interview” in which key contact persons were informed of the survey, its purpose and what it would entail for the establishment.

Participating businesses were assigned a travel day, which typically occurred 8 to 10 days after recruitment. Drivers were asked to record all trips made for the specific 24-hour period. Immediately after the travel day, forms were either collected in person by Atlanta staff or returned via business reply mail. In total, 347 firms of the 814 eligible firms contacted, were recruited to participate in the study. Of the 814 eligible firms, 152 firms (19%) provided completed trip logs.

The sample was drawn from a 1993 truck listing of registered vehicles in the 10 county planning area. This included all trucks (small trucks plus tractors) registered in the Atlanta region. This did not include vehicles that may operate in the area or pass through the area, but are registered and/or garaged outside the region. As such, the sample is an estimate of the universe of trucks in the Atlanta Area, but is not exact. Weights were developed using fleet size to expand the sample to the estimated universe. The regional totals of expanded light and heavy truck trips were 843,735 and 274,690, respectively.

The survey effort was composed of the following five major tasks.

Task 1: Development of Survey Instrument
Task 2: Sample selection and Survey Procedures
Task 3: Pilot Test
Task 4: Data Editing and Data Entry
Task 5: Survey Results

A description of these tasks is summarized in the following subsections.

3.1 Survey Instrument Development

The data collection bases for the commercial vehicles survey was to record the vehicle activity of the sampled vehicles for a 24 hour period or a complete typical day. The primary method of collecting these data was through a travel log that the drivers of each survey vehicle would complete. The design of the instrument was to be easily understood so that driver could complete them efficiently with little opportunity for reporting error. A sample trip log is provided in Figure 1. The information gathered through this survey instrument was supplemented by information gathered before the travel day on the vehicle and business characteristic. This included the vehicle make, year, identification number (VIN), vehicle type, engine, fuel type, license number, and the address and business type of the company that owned the vehicle.

These data, as well as the data elements collected from the travel logs comprised the information deemed necessary to support the model development. The list of data elements was determined through a process of discussions between the ARC staff, consultants the ARC had on contract to assist with the model update, the American Trucking Association, the Georgia Motor Trucking Association, and Georgia Tech researchers. The final list of data elements, particularly those included on the trip log, ended up being the data needed to support the travel demand forecasting model and the maximum amount of additional data that could be included to support emissions models and commodity flow models, without overburdening and/or confusing the drivers.

Travel survey development was critical to the success of the study. Identifying the precise data necessary and knowing the needed form of the data for future coding and self coding on the travel log was an important element of developing an effective trip log. Once the data elements were determined and the travel loge was designed, the next step in was to sample companies and ultimately vehicles to participate in the study and implement the survey.

3.2 Sample Selection and Survey Procedures

The procedures used during the survey execution phase of the project are documented in this section. This includes recruitment of firms, site visits, material distribution and collection, and supplying equipment and staff. There are eight stages of field procedures associated with the data collection activities, as shown in Table 1.

Figure 1
Atlanta Commercial Vehicle Survey Form

INSTRUCTIONS	
Use this form to record all trips made today in this vehicle. Please include each stop as a separate trip, **even if only stopping for lunch.** If you have any questions, please call Stacey at 1-800-619-3601. Thanks for your help!	Affix label here

A. Origin Information	**B. Beginning of Day**
At 4am, this vehicle was at: (check one) 1. ☐ Your place of business (go to Section B)⇨ ⇨ 2. ☐ Other location (please provide address) Name of Place: ______ Address: ______ Intersecting Street: ______ City/Zip: ______	1. Departure Time _____ : _____ ☐am ☐pm 2. Beginning Odometer Reading: ______ 3. Cargo at Departure ______ or ☐ Empty 4. License Plate Number ______

C: Trip Information **Where was this vehicle taken next? (Check box if returned to "home base.")**	**Kind of Place**	**Purpose of Trip**	**Arrival Time/ Route**	**Odometer Reading** (Do not include 10th of mile)	**Cargo Type**	**Departure Time**
Place name ______ Address ______ Cross Street ______ City/Zip ______ ☐ Check if returned to home base	Check one ☐1=Educational ☐2=Industrial ☐3=Medical ☐4=Office/Govt. ☐5=Residential ☐6=Retail ☐7=Home base	Check one ☐1=Delivery ☐2=Pick-up ☐3=Maintenance ☐4=Work-related ☐5=Driver need ☐6=Return to base ☐7=Other	____:____ ☐ am ☐ pm Route used: ☐I-75 ☐I-85 ☐I-20 ☐I-285 ☐Other	______	______ or ☐ check if none	___:___ ☐ am ☐ pm
Place name ______ Address ______ Cross Street ______ City/Zip ______ ☐ Check if returned to home base	Check one ☐1=Educational ☐2=Industrial ☐3=Medical ☐4=Office/Govt. ☐5=Residential ☐6=Retail ☐7=Home base	Check one ☐1=Delivery ☐2=Pick-up ☐3=Maintenance ☐4=Work-related ☐5=Driver need ☐6=Return to base ☐7=Other	____:____ ☐ am ☐ pm Route used: ☐I-75 ☐I-85 ☐I-20 ☐I-285 ☐Other	______	______ or ☐ check if none	___:___ ☐ am ☐ pm
Place name ______ Address ______ Cross Street ______ City/Zip ______ ☐ Check if returned to home base	Check one ☐1=Educational ☐2=Industrial ☐3=Medical ☐4=Office/Govt. ☐5=Residential ☐6=Retail ☐7=Home base	Check one ☐1=Delivery ☐2=Pick-up ☐3=Maintenance ☐4=Work-related ☐5=Driver need ☐6=Return to base ☐7=Other	____:____ ☐ am ☐ pm Route used: ☐I-75 ☐I-85 ☐I-20 ☐I-285 ☐Other	______	______ or ☐ check if none	___:___ ☐ am ☐ pm

Table 1: Stages of Field Procedures

Stage	Description
Sample Selection #1	Operators are randomly sampled from sample frame.
Advance Letter	Personalized advance letters are mailed to listed owner/operator.
Recruitment	Recruitment calls are made to owner/operators. The study is explained and participation is secured. Vehicle inventory information is confirmed and trips logs (if used) are obtained.
Sample Selection #2	Vehicles within each fleet are sampled for inclusion in the study.
Material Placement	Customized forms are produced for each company and delivered for internal distribution.
Confirmation Call	A call is placed to confirm receipt of materials and to answer questions. Participation is confirmed and arrangements are made to retrieve the forms.
Travel Day	Companies are assigned a travel day (Tuesday through Thursday).
Form Collection	Completed forms are faxed, mailed, or collected in person.

3.6 Survey Results

The final data set represents the travel of 744 vehicles associated with 152 firms in the Atlanta area. In all, 4,136 trips were recorded. The characteristics of the firms and vehicles are discussed below, along with a summary of trip statistics.

3.6.1 Firm Statistics

A total of 152 Atlanta area firms participated in the study. The most frequent locations included Atlanta (44), Marietta (18), Tucker (7), Alpharetta (5), and Decatur (5). The majority of responding firms had fleets of ten vehicles or less, with 35 percent having only one vehicle. A map showing the spatial distribution of firms can be seen in Figure 2.

3.6.2 Fleet Statistics

A total of 744 vehicle drivers completed and returned trip logs. A majority of the vehicles were light-duty trucks (59 percent). Light-duty trucks were defined as those trucks less than 14,000 lbs. gross vehicle weight rating. Medium-duty trucks were defined as those weighing between 14,001 lbs. and 18,000 lbs. Heavy-duty trucks were those weighing at least 18,001 lbs. The above weight classifications are based on the definitions used by the state of Georgia for vehicle registration and do not conform to the weight classifications used by EPA. These data elements were attached to the vehicle records through a post processing of tag numbers, as vehicle weight was difficult to collect at the time of the survey. Ideally the federal standard with a cut point for heavy - duty vehicles at 8,500 lbs. would have been preferable. The fleet represented in the data is fairly young, with the majority of vehicles (57 percent) manufactured in 1990 or later.

3.6.3 Trip Statistics

The 744 vehicles recorded a total of 4,136 trips. The types of trips recorded, including average number of daily trips, trip purpose, time of day of travel, and trip length are summarized below.

Table 2 shows the average number of trips by vehicle type. As indicated, medium-duty trucks made more trips on average than any other vehicle class. Table 3 compares the trip rates for four recent studies including Atlanta. As can be seen the daily trip rate for Atlanta was found to be slightly lower than that found for other cities in recent studies. Although there is no clear explanation for this, it was also revealed through the study that average trip distances for truck trips in Atlanta were longer than those observed in other cities. This may partially explain why trip rates in Atlanta are lower than in other cities (i.e. since trips are longer on average, the frequency of trips is lower).

Table 2: Average Daily Number of Trips by Vehicle Type

Vehicle Type	N	Mean
Light-Duty Trucks	991,233	4.99
Medium-Duty Trucks	91,060	9.96
Heavy-Duty Trucks	231,112	4.83

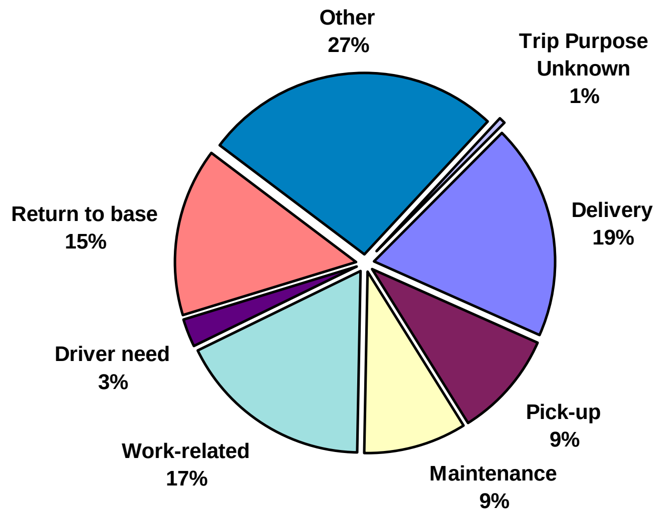
Base: All trips, including vehicles that made no trips on travel day (weighted).

Table 3: Comparison of Weighted Daily Truck Trips.

City	Mean
Atlanta	6.88
San Antonio, TX [3]	8.27
Phoenix, AZ [4]	7.70
Winston-Salem / High Point / Greensboro, NC [5]	7.40

One-fifth of all trips (19 percent) were for the purpose of making deliveries, while only 10 percent were to pick-up cargo. Seventeen percent of all trips were work-related. A complete summary of trips by trip purpose is shown in Figure 3. The high number of "Other" trips include those made to provide a service at that location rather than making a pick-up or delivery.

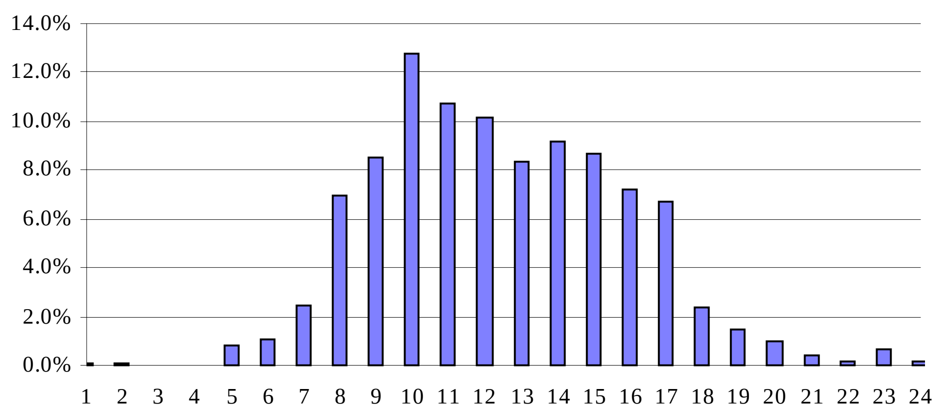
Figure 3: Trips by Trip Purpose



Base: All trips (weighted).

As shown in Figure 4, the majority of these trips began off-peak, during mid-day. In Atlanta, the morning peak period is defined as 6:30 a.m. to 9:00 a.m. The afternoon peak period is from 4:00 p.m. to 6:30 p.m. or from 1600 to 1830 in military time.

FIGURE 4: TRIP DEPARTURE TIME BY TIME OF DAY



Base: All trips (weighted).

Average trip length by vehicle type are shown in Table 4. As expected, heavy-duty trucks had the longest average trip lengths (22.78 miles).

Table 4: Average Daily Trip Length by Vehicle Type

Vehicle Type	N	Average Trip Length	Median Trip Length
Auto	29,308	13.00 miles	7.00 miles
Light-Duty Truck	825,098	14.97 miles	10.00 miles
Medium-Duty Truck	82,659	19.86 miles	7.00 miles
Heavy-Duty Truck	191,837	22.78 miles	6.00 miles

Base: All trips reporting mileage (weighted).

4. Model Formulation

The formulation of the commercial vehicles model set was split into two primary parts--the internal truck model and the external truck model. Post Buckley Schuh and Jernigan and Cambridge Systematics collaborated on the development of these model sets for the ARC [6]. Cambridge Systematics focused on the internal models while Post Buckley Schuh and Jernigan developed the external model.

The internal truck model was developed with the intent of replacing the existing truck model and utilizing the newly collected travel data. The new model was designed to be a separate model set that would be more sophisticated and allow for easier integration with emissions models by estimating truck trips by different weight classes or technology groups. The expanded survey data indicate that there were over 1.1 million commercial vehicle trips in the Atlanta area in 1995, illustrating the importance of trucking activity in the economic well-being of the Atlanta region and the importance of an enhanced truck model.

The previous ARC truck model was imbedded in the trip generation sub-model used for the calculation of region-wide person-trips. Not only was this model more simplistic than the new truck trip model and lacking in sophistication, it was calibrated on 1972 truck activity data.

The external truck model, which addressed all trips that had at least one trip end out side the Atlanta Region, was developed as a sub model to the complete external model set for the ARC. The specifics of this model are discussed in following sections.

4.1 Trip Generation Model

Based on considerations of air quality modeling and differences in trip characteristics, the most important means of segmenting total commercial vehicle trips for the Atlanta truck model was by vehicle weight class. Ideally, this would have been three classifications based on the EPA truck definitions, but the survey sample size did not support this level of disaggregation and the model was ultimately based on two classes of commercial vehicles. The two classes were light-duty vehicles including pickups and commercial automobiles, and heavy-duty vehicles including most medium-duty trucks (i.e. all those truck in excess of 8,000 pounds) [6].

Three different methodologies were tested to develop a model that would produce the best fit for the Atlanta data. Development of trip rates by vehicle type, multiple linear regression of total truck tips, and multiple linear regression of truck trip rates were all considered. A simple cross-classification trip rate model by vehicle type for four land use /employment categories (industrial, retail, office, and population) based on tabulations of trips by land use at trip ends divided by total regional employment /population was selected [6].

Trip Rates were developed for four generalized employment/population categories based on the reported land use at the trip ends. These rates are summarized in Table 5. This method did not prove to result in less error than the multiple regression methods, but did conform to intuitive relationships of commercial vehicle activity and was therefore the current favored method [6].

Table 5: Simple Truck Trip Generation Rates

Sub Model	Ind. Emp.	Retail Emp.	Office Emp.	Population
Light Truck	0.4823	0.6426	0.2315	0.0559
Heavy Truck	0.1439	0.2463	0.0829	0.0147

4.2 Trip Distribution Models

Following the development of the trip ends for the base year 1995 in the trip generation process, a trip distribution model was developed. The trip ends were used to develop gravity models for both the light and heavy trucks. In addition, to the trip ends the formation of the gravity model also required the zone-to zone highway travel times from the ARC highway network and observed trip length distribution from the expanded survey trip file. Most truck trips occurred during the mid-day, therefore an off-peak or uncongested highway travel times were used for the truck distribution model. The most important consideration toward making the gravity model reasonably reflect actual travel behavior was making the estimated trip length distribution consistent with the observed travel times survey trip file [6].

The TRANPLAN Calibrate Gravity Model procedure was used to obtain friction factors which would replicate the average trip length of the data and also match the observed distribution as closely as possible. This procedure produced an estimated average trip length for light trucks with in 1.2 % of the observed average, and with in 3.1% of the observed average for heavy trucks [6].

4.3 External Truck Trip Model

The external (trips where one trip end lies outside of the region) truck trip model was developed in a similar fashion as the internal model. The trucks were stratified into two classes as they were with the internal model, but data used to support this model was taken from the external travel survey conducted the ARC in 1994 [7]. Unlike the internal truck model, the external model trip generation was based on a standard multiple liner regression analysis. In addition, adjustments were made for interstate and non-interstate trips.

The external truck model estimates internal to external truck attractions for light and heavy truck sub-models using socioeconomic data, external truck activity survey data, and minimum travel times. It was found that the best correlation between socioeconomic data and observed trips occurred when the socioeconomic data was factored by minimum travel times between external stations and traffic analysis zones. This method of socioeconomic weighting essentially added an accessibility factor to the data. The final regression equations used for each sub-model are included in table 6.

Table 6:
External Truck Trip Regression Equations

Model		Constant	pop emp (xT^{-x})	gov emp (xT^{-x})	ind emp (xT^{-x})	retail emp (xT^{-x})	R^2
Light	w/const	7.27	0.081	0.146	0.342	-	0.14
	final		0.088	1.039	0.596	-	na
Heavy	w/const	15.14	0.0002	0.0126	0.0487	0.0439	0.36
	final		0.0013	0.0570	0.0570	0.0461	na

Light truck time exponent is -1.15
Heavy truck tile exponent is -0.35

The variables used for this trip generation model were population, government employment, industrial employment, and retail employment all scaled by an accessibility factor. The correlation coefficient R^2 for both the sub-models indicate a poor fit of the models to the data. Despite this these models were chosen as they were the best that could be developed with the given data set. If the models were being applies to the prediction of trips other than external trips additional effort to improve the models may have been warranted [6].

The t-statistics for each variable coefficient used in the two models, shown in table 7, indicate that for both models the industrial employment variable has the most influence in the model. For the heavy truck model the retail employment variable also performed well. Although the t-statistics for industrial and retail employment indicate a strong relationship with truck trip activity the other variables in the model do not perform as well, as indicated by this measure. Despite this, these variable combinations were chosen as they were found to provided the best model for the given data set.

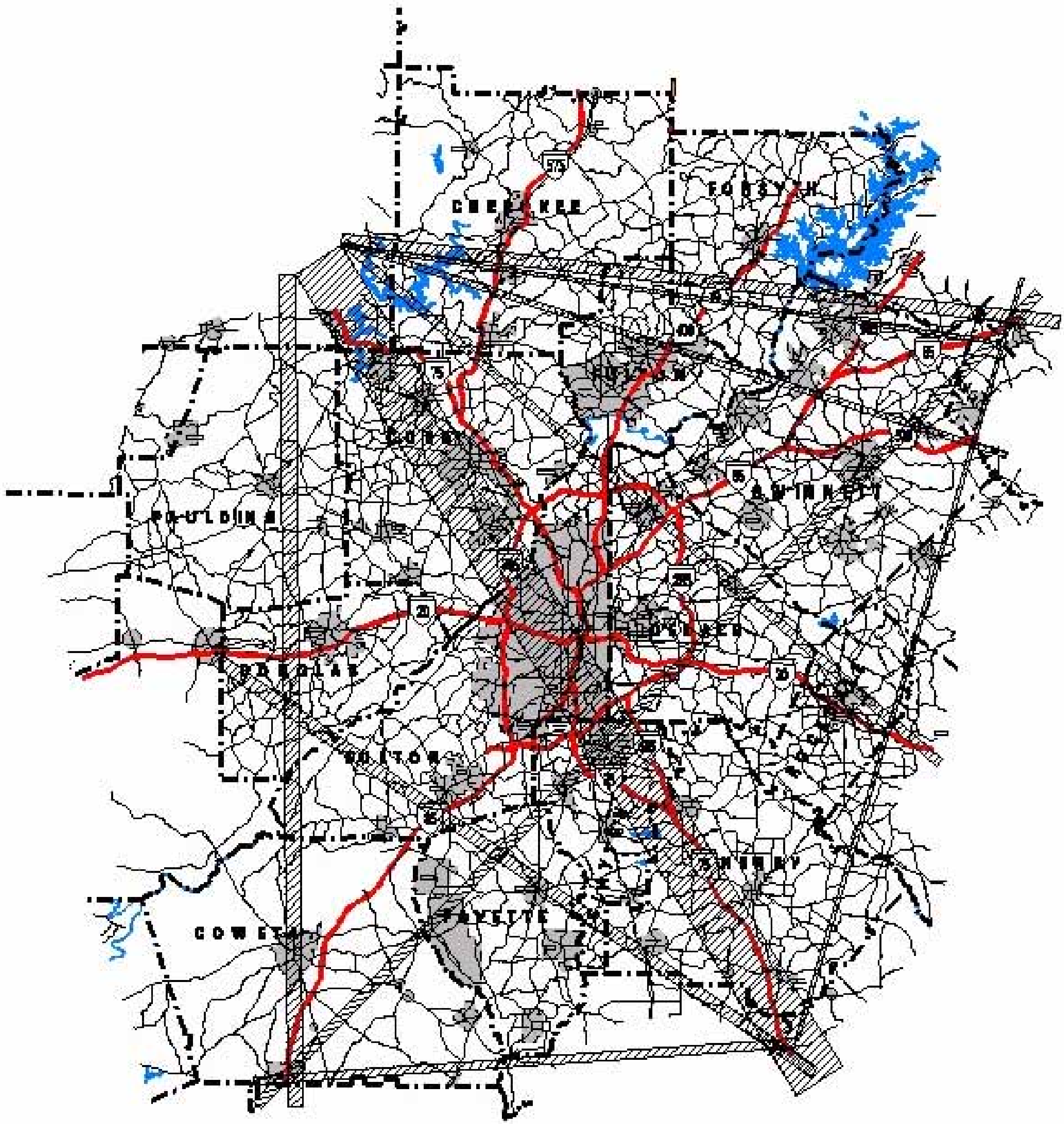
Table 7:
T-Statistics for External Truck Trip Regression Model

Variable	Light Truck Model	Heavy Truck Model
Industrial Emp./Time	2.29	5.9
Gov. Emp./Time	1.13	0.99
Population/Time	1.16	-
Retail Emp./Time	-	2.99

The external truck trips distribution model was developed using the TRANPLAN calibrate gravity model function in the same manor as for the internal trips [6].

The through truck trips (those with both trip ends outside the region) were developed separately and expanded directly from the survey data. The relative volume of through truck trip interchange is shown in Figure 5.

Figure 5: Through Truck Trip Interchanges



5. Heavy-Duty Vehicle Emissions Modeling

The ARC survey and model development efforts have provided a basis for improving the understanding of the activity side of truck modeling, but reliable emissions rates need to be developed to carry the modeling process through emissions estimation. Further development on the emissions modeling side is also underway in Atlanta through a cooperative agreement between the Georgia Tech Research Partnership, the USEPA and the Federal Highway Administration.

Emissions modeling techniques for heavy-duty truck operations have not changed significantly in more than ten years. Vehicle activity and emission rate model deficiencies identified in 1991 still exist in today's urban estimates of truck VMT and within the current version of MOBILE5a, the USEPA's emission rate model. Estimated emissions for heavy-duty diesel trucks are highly uncertain because: 1) the current in-use heavy-duty truck emission rates are based upon a non-statistically-representative numbers of vehicles exhibiting high variance in emissions rates, 2) emission rates in grams/mile are derived using questionable assumptions and correction factors for the truck fleet, 3) vehicle activity estimates are based upon limited sampling, questionable surrogates, and highly aggregated data (e.g., traffic counts used to estimate vehicle miles of travel), and 4) a number of critical vehicle activities are omitted from the models [8] .

5.1 Activity

Heavy-duty truck activity estimation methodologies used in almost every metropolitan region differ significantly from those for light-duty vehicles. Light-duty vehicle activity is estimated using the Highway Performance Monitoring System and modeled using 4-step travel demand models. Heavy-duty vehicle activity is generally not modeled using a stepwise process for generating and distributing vehicle trips. Such goods movement models are rare and require a significant amount of data to implement. Heavy-duty truck activity is usually only estimated through surrogate indicators (such as traffic counts or fuel consumption studies). The ARC commercial vehicles survey and trip generation algorithms discussed earlier in the paper are a first cut effort at an enhanced goods movement modeling framework for the Atlanta Region and should provide more certain estimates of truck activity than is available through surrogate measures.

For light-duty vehicle activity, regional emission models generally rely upon vehicle registration data in estimating mobile source contributions. However, heavy-duty truck registrations are not terribly useful in developing emissions estimates. Trucks are rarely registered in the county in which they are used (and often are registered in entirely different states). To develop truck registration mixes and VMT operating fractions, some urban areas rely upon Polk truck data and the Census of Transportation and Truck Use Survey [9]. These areas often then assume that the truck VMT can be reliably estimated by multiplying registration numbers by an assumed annual truck VMT value. Most urban areas today rely upon specialized truck survey programs coupled with Highway Performance Monitoring System (HPMS) data. The VMT estimates are then based on traffic counts and surveys of truck fleet operators. Information gained from the commercial vehicles survey and trip activity models developed from the data will provide an improved basis for estimating truck VMT in the Atlanta Region. This is of particular importance in light of the accuracy and quality assurance problems related to HPMS truck VMT estimates.

Engine idling activity is another source of vehicle emissions. Heavy-duty trucks are frequently idled for extended periods while picking up or delivering goods to provide air conditioning or heating for driver comfort [9]. However, idling emissions are not included in the emission inventory because idling activity has never been quantified [8]

5.2 Emission Rates
Emission rate models provide estimates of mass emissions per unit of vehicle activity for carbon monoxide, hydrocarbons, oxides of nitrogen, and particulate matter. For trucks, the EPA's MOBILE5a model provides truck emissions rate estimates in grams/vehicle-mile of travel. These emission rates are determined through laboratory testing programs, using test methods established by the USEPA in 40CFR86 and a number of conversion equations.

Light duty vehicles are tested on a chassis dynamometer, or a computerized treadmill that allows the vehicle emissions to be collected while the drive shaft and wheels are actually rotating. In contrast, heavy-duty vehicle emissions are determined through testing of the engines on an engine dynamometer. The emission rates in the MOBILE model were developed through a one-time engine testing program of 30 in-use heavy-duty diesel engines conducted in 1983/84 as a cooperative effort between the USEPA and the Engine Manufacturing Association (EMA) [10]. Unfortunately, with the limited number of in-use engines tested, it is not possible to establish reliable statistical relationships between emission rates, engine size, and accumulated mile traveled. The average engine emission rates were determined as a function of the average brake-horsepower load applied to the engine during the transient cycle test (grams/brake-horsepower-hour), and were converted to grams/mile emission factors using assumptions and conversion factors [8] Emission rates were converted to grams/mile values using average brake-specific fuel consumption data (grams of fuel/BHP-hr) from the same tests and average fleet fuel economy data (miles/gram of fuel). Fuel economy estimates were derived from the 1982 nationwide Truck Inventory and Use Survey [11].

To project future emissions rates, USEPA staff adjusted the baseline grams/bhp-hr emission rates downward, assuming emission control would improve in proportion with decreased new engine certification standards. In addition, fuel economy values were adjusted upward to project the effects of such factors as: decreased drag coefficient, use of advanced radial tires, weight reduction, new drivetrain lubricants, etc. [12]. Each of the conversion factor assumptions (use of the 22 measured BSFC rates from the 1984 tests, use of average fuel efficiency factors, and projections of new engine technology, control, and fuel economy improvements) yield uncertain emissions rates.

5.3 Enhanced Modeling Efforts

For the past three years, the Georgia Tech Research Partnership has been developing a modal emissions model within a GIS framework [13]. Modal models are based on the premise that emissions are better modeled as a function of specific modes of vehicle operation than they are as a function of average vehicle speed. For light-duty vehicles, the model predicts mobile source emissions as a function of vehicle and engine operating mode across a spectrum of modal activities, including cruise, acceleration, deceleration, idle, and the power demand conditions that lead to enrichment, or high fuel-air ratios. The model employs specific vehicle fleet characteristics and speed/acceleration profiles in predicting emissions from the onroad operating modes.

In developing emission rates for heavy-duty engines, the USEPA has historically assumed that emissions are relatively constant in grams/bhp-hr across all operating ranges. Onroad emissions testing conducted recently by the USEPA in Research Triangle Park using instrumented trucks has tended to support the assertion that the grams/bhp-hr emissions rates are fairly constant across the majority of vehicle operations (emission rate deviations have been noted under extreme rpm and load combinations and these secondary effects will be added in later model enhancements).

Until recently, the USEPA modeling approach was thought to be the only viable alternative and that gram/bhp-hr emission rates had to be converted to gram/mile emission rates to be employed. However, truck activity can be translated into bhp-hr loads and coupled directly with the emissions rates. New data are becoming available from weigh-in-motion stations and advanced traffic management systems that will make load modeling practical. Once grams/bhp-hr emissions rates are established for each engine family, the onroad engine loads for these vehicles can be estimated using a basic power demand equation:

$$BHP = ([(W)/32]a + (Ra) + (Rr) + (Rg) + (Ru) + (Rc))(v/550)$$

Where:

- BHP = engine brake horsepower demand (horsepower)
- [(W)/32]a = force to overcome inertia
  - W = vehicle weight (pounds)
  - a = acceleration (ft/sec2)
  - 32 = correction from pounds to slug-ft/sec2
- Ra = resistance due to aerodynamic drag (pounds)
- Rr = rolling resistance due to road surface friction (pounds)
- Rg = resistance due to grade (pounds)
- Rc = resistance due to consumer equipment such as air conditioning (pounds)
- v = velocity (ft/sec), relative to wind velocity
- 550 = conversion factor for ft-lb/sec to horsepower

The basic load equation can be simplified so that only vehicle weight, velocity and acceleration, grade, frontal area and drag coefficient, air density, and consumer equipment load are needed for modeling. For any given link in the transportation network, the distribution of vehicle classes and engine load for each vehicle class can be coupled with hours of vehicle class operation (based upon the onroad speed/acceleration profiles) to yield bhp-hr activity. The Georgia Tech Research Partnership is in the process of integrating these basic power demand equations for various truck classes into the GIS-based model. Once complete, the emission rate module will be linked to the ARC-developed activity estimates to enhance predictions of onroad truck emissions.

To implement the heavy-duty vehicle load-based model, relationships between vehicle class, engine class (horsepower), vehicle weight, and operating conditions must be statistically derived. The three major tasks to be completed for the truck portion of the model are: 1) develop a truck classification format which is consistent with various truck and engine technologies, 2) determine the relationship between weight and horsepower for each truck classification, and 3) provide a method for estimating truck horsepower and weight distributions from existing and future truck data sources. These topics are being explored in greater detail by the Georgia Tech research team [14].

6.0 Conclusions

The last three years have brought significant progress in the development of a commercial vehicles model set for the Atlanta region. New data has provide insight to travel patterns and allowed for the development of demand forecasting procedures routines (internal and external) that have greatly improved the explanatory power of the ARC travel demand models. In addition, this will eventually be used in enhanced emissions modeling, especially when load and engine distributions are added to the picture.

The Atlanta model development experience emphasizes the extensive effort needed to produce a meaningful commercial vehicles and truck model set. The most critical lessons learned from this effort include the following. Although, often difficult the definition of a vehicle universe is imperative to development of useful models, both on the activity and the emissions side. Related to this is the importance of accurate vehicle weight information. Again this is important for both activity forecasting models and emission rate estimations.

The development of improved truck travel and emissions models are critical to continued growth and development of the Atlanta region, as well as, most metropolitan areas in North America. This is particularly important in light of growing constraints in the areas of goods movement, economic development, and air quality. Modeling is important as there is a need to keep goods movement efficiency maximized within the environmental constraints. It is important to determine the relative impacts of trucks in planning for future economic growth and in making emissions control tradeoff decisions.

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