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Integrating Travel Demand Forecasting Models with GIS to Estimate Hot Stabilized Mobile Source Emissions

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Abstract

In a cooperative research effort with the U.S. Environmental Protection Agency, Georgia Tech is developing a regional mobile source emissions model using a Geographic Information System (GIS) framework. The emissions model is designed to improve emission estimates by accounting for the spatial and temporal effects of a variety of vehicle activities, environmental factors, and vehicle and driver characteristics. While a description of the overall modeling approach is given, the emphasis of the paper is to describe the hot stabilized emissions estimation process and the role of travel demand forecasting models. Although travel demand forecasting models were designed for predicting future capacity requirements, they also provide useful information needed for mobile source emissions estimates. Improvements to travel demand forecasting models to more accurately predict hot stabilized emissions are also discussed.

Introduction

For the past three decades, metropolitan areas in the United States have been using a traditional four-step modeling process to estimate future demand for transportation. Although not originally developed for use as part of an air quality modeling package, the four-step process has also become the standard method for providing a key input, vehicle miles traveled (VMT), into the development of a mobile source emissions inventory. However, recent research in mobile emissions modeling suggests that the basic phenomenon being modeled (i.e., emissions from motor vehicles) is much more complex than can reasonably be represented by the aggregate, network-based four-step modeling approach. In particular, transportation activities and resulting emissions vary by location and time of day. These emissions also vary by mode of engine operation (e.g., starts, hot stabilized, enrichment, hot soak evaporation) that clearly have a spatial relationship to characteristics of the transportation network.

For example, high levels of enrichment emissions are likely associated with long, steep grades where additional engine power is needed to overcome higher vehicular load.

In a cooperative effort with the United States Environmental Protection Agency (EPA), Georgia Tech is developing a next generation, mobile source, emissions, research model using a Geographic Information System (GIS) framework. This approach is designed to improve emission estimates by accounting for both the spatial and temporal effects of a variety of vehicle activities, environmental factors, and vehicle and driver characteristics (Bachman et al., 1996). The purpose of this paper is to discuss the hot stabilized component of the emissions model. The following two sections present an overview of the research model and provide a rationale for using GIS as the model platform. The hot stabilized component is presented in detail along with considerations for satisfying the spatial and attribute data requirements necessary to produce a hot stabilized emissions estimate.

Brief Overview of GIS

A geographic information system is a spatial analysis tool that can be used to model spatial relationships between geographic entities. A GIS consists of a data base containing spatially referenced, land-related data as well as procedures for systematically collecting, updating, processing, and distributing these data. The fundamental structure of a GIS is a uniform referencing scheme which enables data within a system to be readily linked with other related data.

A true GIS can be distinguished from other graphical database management systems (e.g., computer aided design, automated mapping systems) through its capacity to conduct spatial searches and overlays that actually generate new information. With its robust set of spatial analysis tools, a GIS can be used to count the number of households that fall within a traffic analysis zone (a point-in-polygon operation), portion a traffic analysis zone's attribute information to 1 kilometer grid cells (polygon-overlay-operation), or calculate total road vehicle mileage traveled within a grid cell (line-through-polygon operation). A vector GIS relies on the topology (the explicit definition of spatial relationships among entities) of its data structures to do spatial analysis efficiently. Thus, the GIS can track the relationships among roadway links and readily identify which roadway links share connections.

Overview of the Model

The model incorporates activity and emission rates associated with specific vehicle operating modes, such as engine starts, idling, hot stabilized operations, enriched conditions (influenced by high acceleration and power demand), and hot soak evaporation. The GIS-based model estimates emissions separately for each operating mode and can aggregate the estimates to a single gridded layer using GIS spatial analysis tools. The grid cells can then be summed across the different modes to come up with an overall gridded emission estimate suitable for input into future air quality modeling systems.

The framework for the mobile emissions model is shown in Figure 1. The figure illustrates how the characteristics of the fleet composition, vehicle activity, and emission rates are used to produce on-network and off-network emissions estimates. Implementing this framework within a GIS is expected to provide the following benefits:

- Efficiently manage spatially referenced parameters that affect emissions;
- Provide manipulation tools to calculate emissions from the modal parameters;
- Aggregate emission estimates by mode into separate grid cell layers using topologic overlay capabilities;
- Combine the individual modal grid cell layers to obtain an overall mobile emissions estimate for input into regional air quality models;
- Provide visualization and map-making tools; and
- Link to other software packages (such as statistical analysis software or travel demand forecasting software).

Considerations for Estimating Hot Stabilized Emissions

Several factors affect hot stabilized emission rates: vehicle attributes, environmental conditions, and vehicle operating modes (Guensler, 1993). Vehicle attributes include engine size, accrued mileage, emission control equipment type (such as catalytic converter type) and condition, fuel delivery technology, engine monitoring and control strategies (integrated into the electronic control module), gear shift ratios, and vehicle weight and shape (for aerodynamic drag). Environmental conditions include ambient temperature, altitude, and humidity. Vehicle operating modes include cruise, acceleration, deceleration, idle, and induced vehicle loads (e.g., number of passengers, trailer towing, grade, and air conditioning).

Current models account for some but not all of the factors listed above. Instead, surrogate factors, which are correlated to the factors of interest, are used because they are much easier to obtain for a regional fleet of vehicles. For example, in the EPA MOBILE5a model (USEPA, 1993) and the California Air Resources Board EMFAC7F models (CARB, 1992), the effects of acceleration, deceleration, cruise and idle are currently represented by a single surrogate factor: average operating speed, which is correlated with different proportions of the vehicle operating modes. Vehicle attributes are model year, fuel delivery technology, catalytic converter type, accrued mileage, and vehicle condition, and are relatively easy to obtain or estimate for a regional fleet of vehicles.

In the mobile emissions model under development, new and improved surrogate variables are employed (beyond those used in current models) to estimate hot stabilized emission rates. The model will include additional vehicle operating modes (e.g., the proportion of activity in certain acceleration regions), additional vehicle attributes (e.g., the percent in acceleration > 3.0 mph/sec), and similar environmental conditions (e.g., the load distributions and grade). Only those factors that can be obtained and are correlated with the actual causal variables are selected for inclusion in the hot stabilized emission rate algorithms. Thus, the model strives to find a balance between optimizing the accuracy of modeled estimates and using only as many variables as necessary to achieve a functional model.

The hot stabilized portion of mobile emissions is estimated at two levels: a road network level (major roads) and a mini-zone level (minor roads). The major road network is developed to coincide with a metropolitan area's travel demand forecasting network. The minor road zones are areas bounded by major roads. Hot stabilized, emission estimates from both layers are allocated to grid cells and summed to produce an overall hot stabilized, gridded, emission estimate. Figure 2 shows an example of an overall hot stabilized emission estimate for Atlanta, Georgia. Darker areas represent grid cells which have higher portions of hot stabilized emissions.

For each road segment in the major road level, information is stored regarding traffic volume, subfleet composition, speed/acceleration profile, and other data important for hot stabilized emission estimation. Road segments modeled at the major road level are not determined by standard road classifications but by the metropolitan area's travel demand forecasting model's network. This road segment definition allows travel data produced by the existing planning models to be used in emission estimation. Use of the travel demand forecasting network indicates that agencies with more extensively modeled networks could have more accurate spatial emission estimates using this technique, given that other sources of inaccuracies are equal. Road segment data are used to determine the quantities and number of seconds of operation of vehicles operating in hot stabilized mode. The portion of vehicle activity (seconds) for the fraction of fleet operating in hot stabilized mode is linked to hot stabilized emission rates (grams/second) for each pollutant. Baseline emission rates will be developed from the EPA MOBILE5b model. To improve model accuracy, activity and emission rates are tracked for various technology-related fractions of the subfleet rather than for the subfleet as a whole.

Local roads are modeled on a zonal basis. Each transportation analysis zone (TAZ) is disaggregated by land use to provide improved spatial resolution of trip origins and destinations. The trip generation algorithms already employed by the forecasting model can be used to estimate the number of trips produced by residential neighborhoods (and/or other land use categories) that lie within a TAZ. The number of trips is multiplied by the estimated average travel time to the closest major road segment to estimate the vehicle operation within a zone. The output of the local road component of the hot stabilized module is reconciled with the output from the engine start module to estimate the portions of vehicle activities before the trip reaches the major road network. The portion of travel time allocated to each activity will depend on travel times from disaggregated zone centroids to the major roads via the local road network.

The individual estimates are aggregated to grid cells using the GIS's spatial analysis capabilities. Figure 3 shows the spatial allocation technique used to transfer road segment emission estimates to corresponding grid cells. Grams of hot stabilized emissions are estimated and stored as a rate per road segment length or zonal area. The spatial entities are subdivided by the grid cell boundaries and the rates applied to the new spatial structure. All the estimates lying within a grid cell's boundaries are summed together to produce a grid cell emission estimate.

To estimate light-duty vehicle emissions, the model first estimates the amount of activity (seconds of operation) on each link and then estimates the fraction of that activity occurring in hot stabilized enrichment modes. Traffic volumes and speed acceleration profiles are used to estimate the number of seconds of vehicle activity for links in the system. As research continues at Georgia Tech, it has become evident that the fraction of hot stabilized activity on any road segment is a function of subfleet composition and engine load (which is in turn a function of vehicle mass, speed/acceleration profile, and other load-inducing factors such as grade and accessory operation).

Traffic Volume: Hourly traffic volumes by roadway link will be developed from a calibrated regional four-step travel demand model. Additional data sources, such as historical Highway Performance Monitoring System records and real-time data from traffic monitoring systems, will be used to adjust volumes into hourly volumes throughout a given day. The forecasting model outputs also provide initial estimates of level of service conditions on the roadway links that are used in predicting representative speed/acceleration profiles for roadways on the network. The Georgia Department of Transportation's advanced traffic management system (ATMS) will also provide real-time traffic volumes and speed acceleration profiles for the monitored freeway and arterial system so that predicted and monitored conditions can be compared.

Local Fleet Distribution: The composition of the vehicle fleet on any given road segment is important for two reasons: 1) a small fraction of high-emitting vehicles (super-emitters) must be correctly represented in the fleet for emissions estimates to be accurate, and 2) the on-road vehicle/engine combinations determine which fraction of the fleet will be operating under enrichment conditions for any given speed/acceleration profile, grade, and other influencing factors. The model aims to group vehicles that are likely to be behave similarly (in terms of basic emission characteristics and emission response characteristics). Model year and engine size are examples of factors that are important for characterizing emissions of a vehicle. Clear spatial patterns of vehicle ownership exist in Atlanta which indicates that on-road subfleet distributions vary as well. Given that on-road fleet distributions are correlated to the local, sub-regional, and regional registration mix, it is important to predict various on-road vehicle subfleets for improved spatial resolution. The relationships between on-road vehicle fleet composition and registered local, sub-regional, and regional fleet composition are currently being developed through the use of license tag monitoring studies (and translation to vehicle identification numbers from the department of motor vehicles). Surrounding land use information will also be used to aid in developing empirical relationships.

Traffic Modal Activity: An engine load module of the modal model employs local subfleet composition and speed/acceleration profiles (along with grade, and accessory operation assumptions) to estimate the fraction of vehicles per link operating in enrichment and in hot stabilized mode. The speed/acceleration operating profile for each roadway is based upon statistically derived relationships between measured speed/acceleration profiles, level of service conditions for each roadway class, and physical roadway characteristics. Empirical studies are currently underway to develop modal profile relationships for freeways and expressways. Work begins this summer on similar arterial and local road studies. Roadway grades are coded in the model as link attributes and are measured in the field using a global positioning system array (Awuah-Baffour, et al., 1996).

Travel Demand Forecasting Model Integration

A major goal in the development of the GIS-based mobile emissions model is that the resulting model be usable in current planning practice. To the extent possible, the model will make use of existing data sources. Because of this, a linkage to an existing travel model is proposed as an integral component of the emissions model. Although both technically and practically criticized (Suhrbier, 1992, Stopher, 1993), travel demand forecasting models are the most widely used and accepted tools available for providing reasonable forecasts of vehicle activity on a given road network. Most major metropolitan areas are already using travel demand model outputs in their regional air quality analyses. Furthermore, most transportation planning agencies within metropolitan areas have already spent considerable resources developing functional travel demand forecasts using "off-the-shelf" travel demand modeling software. Capitalizing on these initial investments will save organizations from the painstaking effort of recreating information already available. However, there are two challenges to integrating a conventional travel demand model into the GIS-based emissions modeling approach: spatial inaccuracies of the road network and inaccuracies in individual link volume estimates.

The spatial inaccuracies are the result of the travel demand forecasting model's abstract representation of an actual road system. A network containing nodes (representing intersections and shape points) and straight links (representing roadway links) is typically used in travel demand model highway networks. However, some spatial inaccuracies are observed in these networks, depending on the level of model detail and whether or not the network was created following an accurate map base. Because roadway spatial accuracy was not needed for estimating travel behavior, spatial accuracy was not developed in most urban models. The individual links, however, do maintain a measured road distance which proves valuable for estimating link volumes.

An analysis of a modeled network for the Atlanta region was completed comparing the traffic network with estimated traffic volumes of a TRANPLAN model and a spatially accurate digital road network (Figure 4). A sample area of 182 square kilometers was used in the comparison. Conflation (matching links between networks so that attributes can be transferred) techniques were used to allocate the TRANPLAN forecasted volumes to the accurate digital road network. The simplification of using traffic volumes instead of emissions does not affect the findings because hot stabilized link emissions are roughly proportional to the traffic volume on the link. The volumes associated with the TRANPLAN network, and the corresponding volumes associated with a spatially accurate network were aggregated to 1 km grid cells in the GIS using a line-through-polygon procedure. Results show that the TRANPLAN volume estimates by grid cell on average were within 30 percent of the corresponding grid cell estimates using the accurate digital map. Individual cell estimates, however, varied widely. The TRANPLAN link, for example, could be far enough off spatially such that most of its volume could be attributed to the incorrect cell. This error can seriously affect the confidence in a single cell's estimate. The aggregation steps were repeated for a 4 km grid cell aggregation in order measure the sensitivity to grid cell size. As one would expect, a larger grid cell is able to reduce the spatial error. An aggregation over the entire study area showed total volumes to be within 2 percent of the more accurate road database.

As a result, using existing travel demand forecasting model networks in emission modeling reduces the accuracy which can be expected for individual cells. However, inaccurate cell estimates are frequently balanced by an adjacent cell's error. A better test of the sensitivity and level of acceptable inaccuracy would be to develop hot stabilized emission estimates for both the abstract network and the accurate network and input the results into a photochemical model. The emission model and the EPA's future MODELS3 photochemical model are still under development, and this experiment will be run when the models are complete. In the meantime, a test is underway using the sample gridded estimates in an urban airshed model to determine the impacts that counterbalancing spatial errors have on predicted ozone concentrations.

If improvements to the spatial accuracy of the network representation in the travel demand forecasting model are deemed necessary (based upon air quality model sensitivity analysis), two alternatives could be implemented. The first is to improve the accuracy of the highway network by adding shape points and/or more accurately representing complicated roadway configurations such as those at freeway interchanges. This network-editing process would be quite time consuming depending on the size and accuracy of the original model network. The alternative is to conflate the links of the travel demand modeling network to an accurate digital road network. Conflation involves the development of a one-to-one linkage between a model link and a corresponding road segment on the accurate digital road network. Emissions could be estimated for the existing travel demand model network and then transferred by unique identification number to the corresponding segments of the road database for aggregation to grid cells. The disadvantage to this strategy is that conflation can also be a labor intensive process for large urban networks. Conflation tools and techniques are available to make the process less intensive.

The inaccuracy of the travel demand model's link volume estimates is another issue that must be considered. Spending a great deal of time and effort to improve a model's spatial accuracy is not justifiable unless the modeled volumes are accurate, which is usually not the case on a link-by-link basis. Travel demand models are best suited for predicting corridor flows among large areas. While total volumes on parallel links in one general direction are usually within 10 percent of actual volumes during a calibration base year, volumes on a link-by-link basis are not nearly as accurate. If base year link volumes predicted by a model are not accurate, it is even more unlikely that forecasted volumes for individual links are accurate.

Conclusion

A next generation research mobile emissions research model is being developed which will increase the spatial resolution of mobile source emission inventory predictions. The hot stabilized portion of the emissions modeling framework relies on the integration of travel demand and emissions forecasting models to provide information regarding travel behavior. Travel demand models contain the spatial variations in travel behavior that allow hot stabilized emissions to be estimated with greater spatial accuracy. Integrating existing travel demand models is advantageous as information already produced at great expense to planning agencies can be used.

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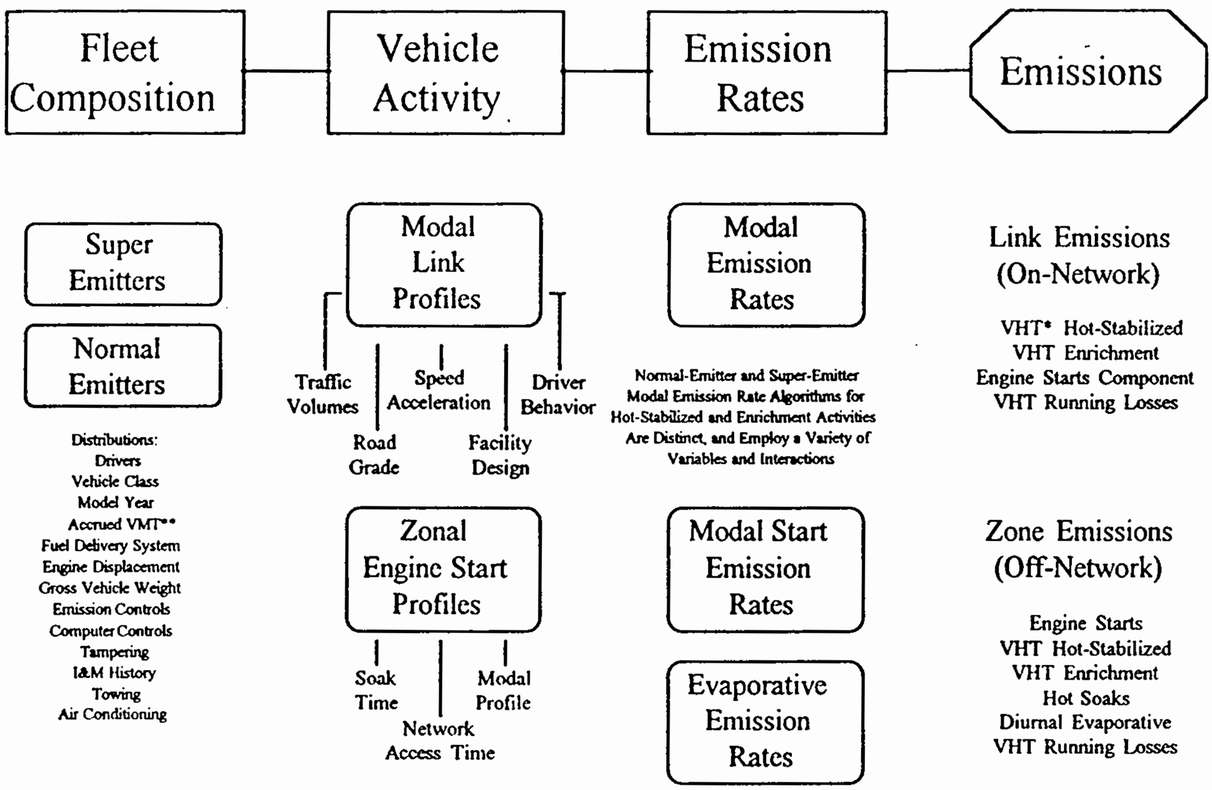

(*)VHT = Vehicle hours traveled
(**)VMT = Vehicle miles traveled

FIGURE 1 - GIS-based emission model framework.

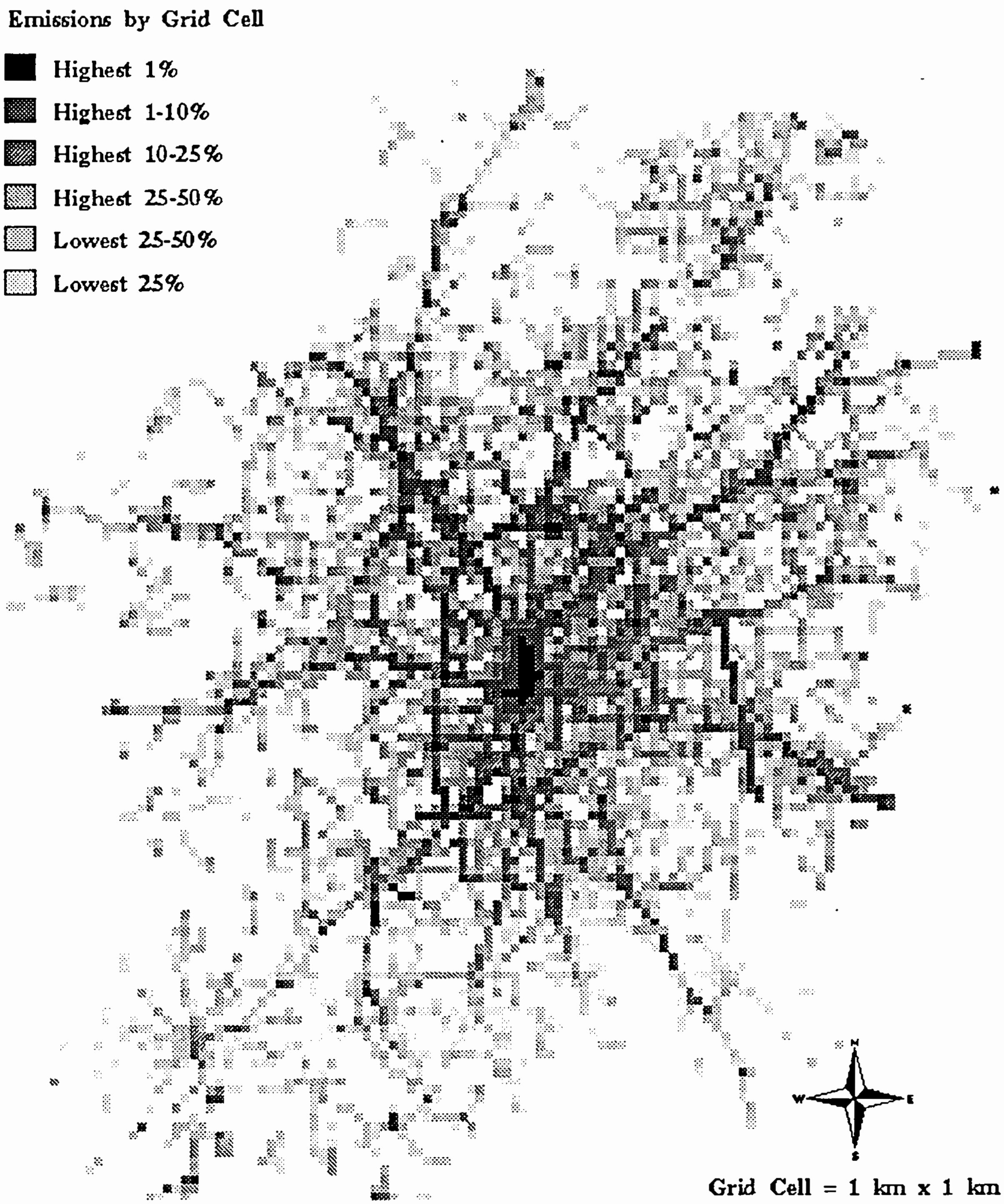

FIGURE 2 - Estimated carbon monoxide produced by hot-stabilized emission activity during a mid-week AM peak hour in the Atlanta, GA area.

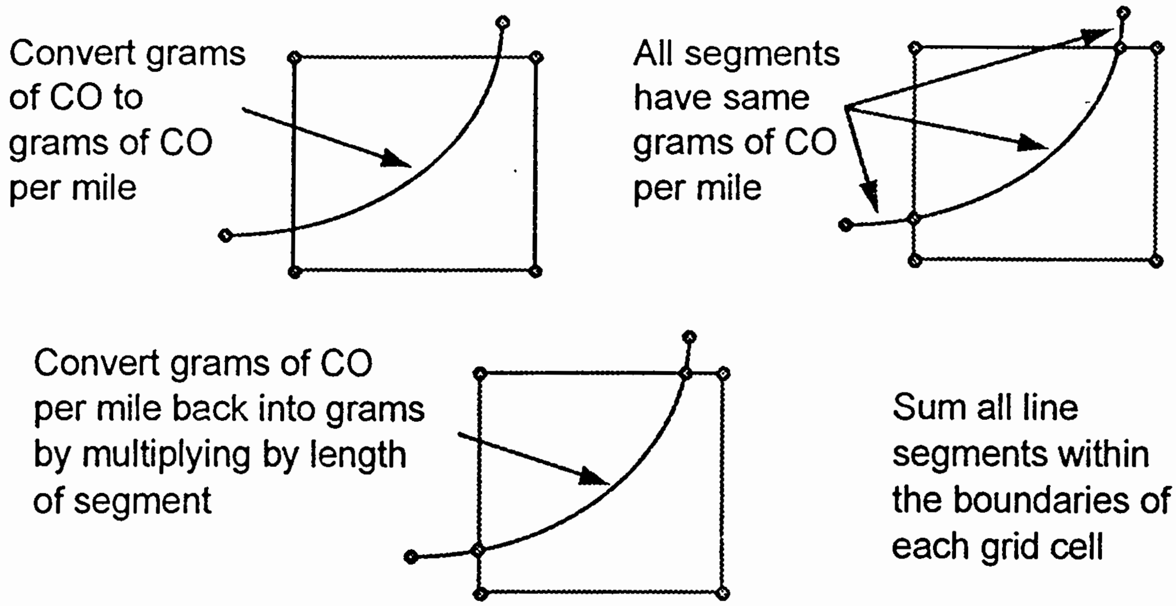

FIGURE 3 - Spatial aggregation technique for moving linear emission data to grid cells.

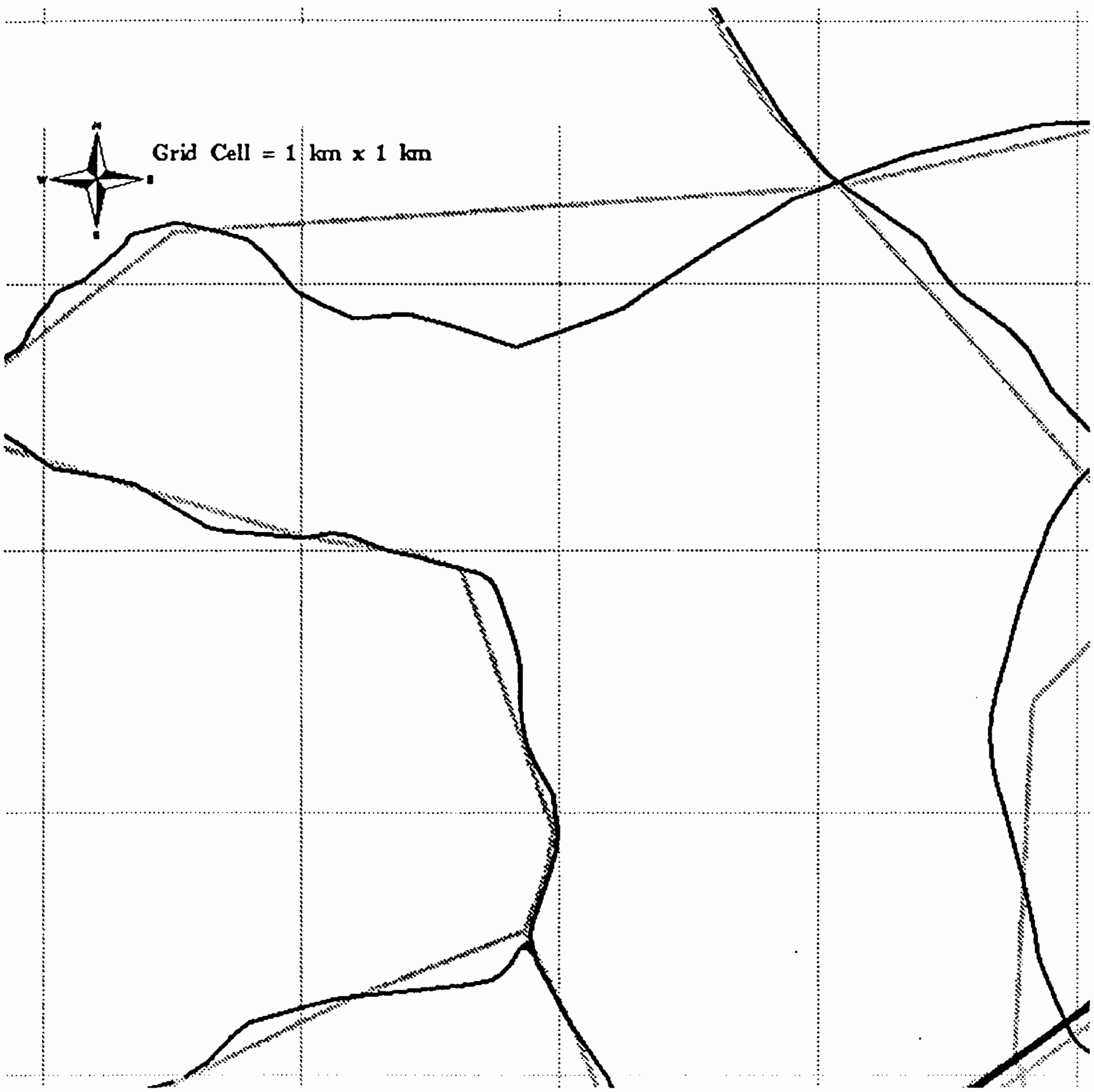

FIGURE 4 - Sample of the TRANPLAN highway network (gray) for Atlanta and the corresponding spatially accurate highway network (black).

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16. ABSTRACT The paper discusses integrating travel demand forecasting models with the Geographic Information System (GIS) to estimate hot stabilized mobile source emissions. In developing a regional mobile source emissions model using a GIS framework, the emissions model is designed to improve emission estimates by accounting for the spatial and temporal effects of a variety of vehicle activities, environmental factors, and vehicle and driver characteristics. While a description of the overall modeling approach is given, the emphasis of the paper is to describe the hot stabilized emissions estimation process and the role of travel demand forecasting models. Although travel demand forecasting models were designed for predicting future capacity requirements, they also provide useful information needed for mobile source emissions estimates. Improvements to travel demand forecasting models to more accurately predict hot stabilized emissions are also discussed.

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Ground Vehicles	Forecasting	Mobile Sources	13F	
Emission	Carbon Monoxide	Automotive Vehicles		07B
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