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Use of Geographic Information System Tools for Improving Mobile Source Atmospheric Emission Inventories

Tae-joo Shin

BE&K/Terranext Environmental Company, New York, New York, USA

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Mobile source emissions are important inputs to photochemical air quality models. Since most mobile source emissions are calculated at the county-level, these emissions should be geographically allocated to the computational grid cells of a photochemical air quality model prior to running the model. The traditional method for the spatial allocation of these emissions has been to use a "spatial surrogate indicator" such as population, since grid-specific emission calculations are very labor-intensive and expensive, plus the necessary data are often not available for such grid resolutions.

Accordingly, new spatial surrogate indicators for mobile source emissions(specifically for highway emissions) were developed using Geographic Information Systems(GIS) tools due to the spatially variable nature of mobile source emissions. These newly developed spatial surrogate indicators appear to be more appropriate for the allocation of highway emissions than the population surrogate indicator. It was also revealed that the conventional spatial allocation method underestimates the maximum levels of air pollutant emissions.

Key words : corrosion, potential, anodic, current, Tafel, polarization, degradation.

1. Introduction

Emission sources are broadly classified as either anthropogenic or biogenic sources. Anthropogenic sources can be further sub-classed as point, area, and mobile source emissions based on their source characteristics. Point source emissions refer to emissions occurring at specified locations because of specific processes(e.g., chemical plants, refineries, power plants, etc.). Area source emissions include emissions from sources considered too small or too numerous to be handled individually as point source emissions(e.g., business or residential area emissions). Mobile source emissions are due to non-stationary sources including on-road motor vehicle, aircraft, locomotive, and marine vessel emissions. Emissions from off-road vehicles such as constructional, agricultural, recreational or gardening vehicles are treated as area source emissions1). Biogenic source emissions refer to emissions occurring from natural sources(e.g., vegetative emissions, etc.)2).

Mobile source emissions contribute greatly to ambient levels of both primary and secondary air pollutants. Mobile source emissions are often a major contributor to urban and regional air pollution problems. It is, therefore, very important to develop estimates of these emissions that are both temporally and spatially accurate, that can be used in conjunction with grid-based models of photochemical air pollution systems3-4). Such models are essential in developing rational air quality management strategies and in quantifying pollutant levels of concern.

Air pollutant emissions from mobile sources are typically calculated via5) :

$$M_i = VMT \cdot EF_i \qquad (1)$$

Where,

M = mass of emitted pollutant(grams/day)
i = pollutants(VOC, CO and NOx),
VMT = vehicle miles traveled(miles/day),
EF = emission factor(grams/mile)

Vehicle miles traveled(VMT) represents the total distance traveled by a vehicle fleet. VMT is generally estimated through :

$$VMT = ADT \cdot RSL \qquad (2)$$

Where,

ADT = average daily traffic volume(daily number of vehicles)

RSL = road segment length (miles)

To geographically allocate mobile source emissions, the standard approach is to use a "top-down" method: county-level emissions are calculated, and then disaggregated onto the "grid level", i.e. to the resolution of a computational cell of the grid-based air quality model, by using a spatial surrogate indicator such as the population fraction.[1] However, this spatial allocation methodology employing the population fraction may not be accurate, especially for highway emissions, since highways are not necessarily collocated with residential population concentrations. Therefore, there is a need to develop a more accurate spatial surrogate indicator for highway emissions.

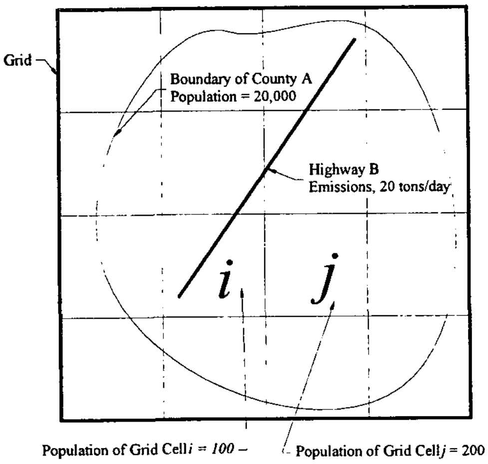
This study discusses the conventional spatial allocation method and the problems associated with estimating the spatial distribution of mobile source emissions. A new spatial allocation method for mobile source emissions is then proposed. Finally, a comparison is made between the standard and the newly developed spatial allocation methods.

2. Methodology

2.1 Development of Highway Fraction

The population fraction has been the standard spatial surrogate indicator for gridding mobile source emissions. An example of this method is illustrated in Fig. 1. In this example, the populations of county "A" and grid cells i and j were assumed to be 20,000, 100, and 200, respectively. The highway emissions within the county were assumed to be 20 tons per day. Therefore, the population fractions of grid cells i and j were calculated as 0.005 and 0.01, i.e. the ratio of each grid's population divided by the county's population. Consequently, the highway emissions of grid cell i were calculated at 0.1 tons per day and those of grid cell j at 0.2 tons per day, even though there was no highway in grid cell j.

For a more accurate gridding of substantially different urban and rural highway emissions, distinct urban and rural highway fractions need to be developed and used as spatial surrogate indicators. The urban or rural highway fraction can be defined as the ratio of the urban or rural highway length in a grid cell to county-level urban or rural highway length. The method can be described by the following equation:



Highway emissions of grid i = 20 (100/20,000) = 0.1 tons/day
Highway emissions of grid j = 20 (200/20,000) = 0.2 tons/day

Fig. 1. Schematic illustration of the standard spatial allocation method for mobile source emissions.

$$M_n = \mu f_v + \upsilon f_r \qquad (3)$$

M = highway emissions in a grid cell(tons/day),

n = pollutant(e.g., VOC, CO and NOx),

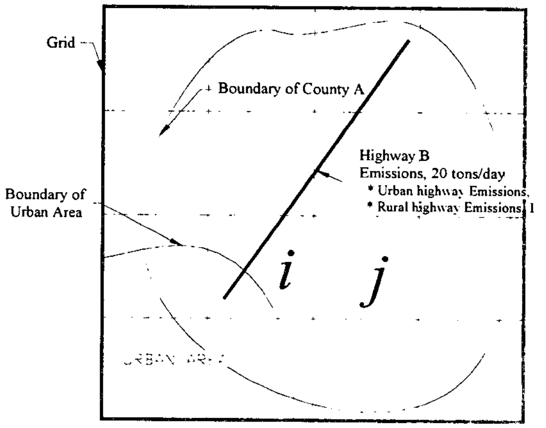
μ = urban highway emissions in a county(tons/day),

υ = rural highway emissions in a county(tons/day),

f_u = urban highway fraction of a grid cell, unitless,

f_r = rural highway fraction of a grid cell, unitless

In this equation, the county-level urban and rural highway emissions are gridded using separate urban and rural highway fractions. For example, if a grid cell includes both urban and rural highway segments, the urban and rural highway emissions are gridded separately for that cell, and then added together to obtain the total highway emission for the cell. Fig. 2 illustrates this method. In this example, it was assumed that 20 tons per day of highway emissions in county "A" were composed of 6 tons per day urban and 14 tons per day rural highway emissions. These emissions were multiplied by the corresponding urban and rural highway fractions. As a result, the highway emissions of grid cell i were estimated to be 9.2 tons per day. No highway emissions were assigned to grid cell j because the highway fraction in grid cell j was zero.



Length of Highway B, 15 km
* Length of Highway B in Urban Area, 2 km
* Length of Highway B in Rural Area, 13 km

Highway emissions of grid i = 6 (2/2) + 14 (3/13) = 9 2 tons/day
Highway emissions of grid j = 0.0 tons/day

Fig. 2. Schematic illustration of the developed spatial allocation method for mobile source emissions.

2.2 Tools and Data

Geographic Information Systems

The development of the new spatial surrogate indicator involved Geographic Information System (GIS) tools. A GIS is a set of computer programs which are able to produce, store, manipulate, retrieve, and display digitized geographical maps and data.[6-8] ArcView and Arc/Info(ESRI, Inc.), MapInfo(MapInfo Co.), and InterGraph(Geomedia Co.) are widely used commercial GIS software packages. A GIS provides the same information as conventional paper maps : that is, how geographic features such as rivers, buildings, and roads are located on or near the surface of the Earth and how far the geographic features are apart from each other. However, the real power of a GIS comes not only from its ability to store geographic data, but also from its ability to analyze this data efficiently and conveniently. One particular GIS function used in this research was the measuring of highway distances in the real world in order to calculate highway emissions and spatially display highway emissions.

TIGER/Line Files and New Jersey Road Network Data

The term TIGER is an acronym for Topologically Integrated Geographic Encoding and Referencing. TIGER/Line files are important GIS data in that they provide geocoded roads, railroads, and rivers within county boundaries, covering the entire United States. Moreover, demographic data(e.g., population, income, and housing) generated from a 1990 census has been integrated with GIS data to develop TIGER/Line files[8-10]. Since the first TIGER/Line files became available through the Census Bureau in 1990, they have subsequently been updated in 1992, 1994, and 1995. TIGER/Line files are one of the principal sources for digital highway maps.

The New Jersey Department of Transportation (NJ DOT) has developed its own digital road network data. The data are derived from a comprehensive inventory of the state's major roadways(e.g., average daily traffic volume, speed, number of lanes, etc.). The data are able to provide such information as lengths and geographic locations of highways in addition to TIGER/Line files, which are all necessary to develop highway spatial surrogate indicators. The data can be obtained from the NJ DOT's Bureau of Geographic Information Systems.

New Jersey Integrated Terrain Unit Map (NJ ITUM)

NJ ITUM is a land use/land cover database(e.g., residential, industrial, commercial & business areas, etc.) used for GIS applications for local projects in New Jersey. The database was developed by the New Jersey Department of Environmental Protection(NJ DEP) by interpreting aerial photographs taken in 1987 for Camden county and in 1986 for all other New Jersey counties. The spatial resolution of the land use/land cover of NJ ITUM is 1.5 acres that are equivalent to a minimum width of 85 feet. The database provide

134 categories of land use/land cover for the state of New Jersey[11]. In this study, this database is used for dividing highways into urban and rural highway segments.

3. Results and Discussion

Two digital highway maps were extracted from the 1992 TIGER/Line files and NJ DOT's road network data, as shown in Fig. 3 and 4. The two extracted highway maps were compared with a commercial map to determine which of the two highway maps provided more accurate highway information. From the comparison it appeared that the digital highway map extracted from the road network data of the NJ DOT provided more accurate highway information on the state of New Jersey than the 1992 TIGER/Line files. This result was anticipated as the TIGER/Line files were primarily developed as a national database, whereas the NJ DOT's road network data were developed as a state-specific database for the state of New Jersey and were, therefore, more detailed and accurate.

Some major problems identified in the highway map extracted from the 1992 TIGER/Line files were as follows:

1. The Census Feature Class Codes(CFCC) of
2. Some segments of highways were missing or inaccurately digitized, some streets and avenues were incorrectly coded,

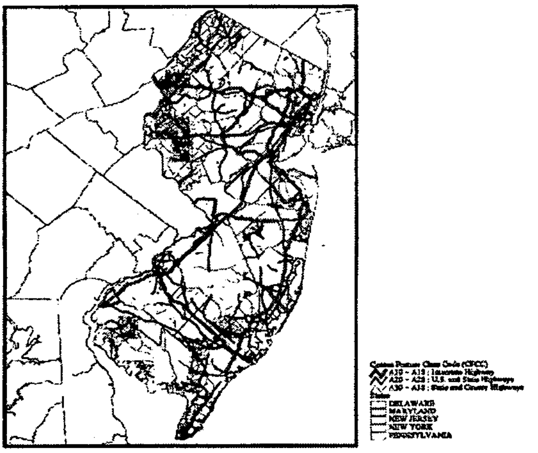


Fig. 3. Digital highway map of New Jersey derived from the 1992 TIGER/Line files.

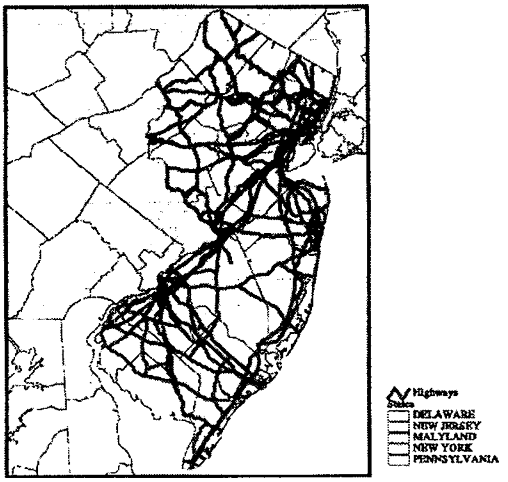


Fig. 4. Digital highway map of New Jersey derived from NJ DOT's road network data.

3. The Garden State Parkway, one of the major highways in the state of New Jersey, was incorrectly coded into two different road categories: interstate and state highway,
4. The Road data were out of date as they were based on road information from the 1980s.

Accordingly, the NJ DOT's road network data were adopted to develop the urban and rural highway fractions as urban and rural highway spatial surrogate indicators.

GIS tools, the extracted highway map from the NJ DOT's road network data, and the NJ ITUM land use/land cover data were all utilized to develop the urban and rural highway fractions as the new spatial surrogate indicators. The population fractions, used as the standard spatial surrogate indicator for mobile source emission allocation, were developed and provided by the United States Environmental Protection Agency(US EPA). The county-level highway emissions for the state of New Jersey estimated using Mobile5a were provided by the NJ DEP.

The emission levels from three major categories of roads(i.e., urban and rural highways, and local streets) as provided by the NJ DEP are presented in Table 1. Table 1 indicates a prominent difference between the urban and rural highway emission levels. Therefore, urban and rural highway emissions must be separately allocated to their appro-

Table 2. Mobile source emissions levels for the counties of New Jersey on July 8, 1988(Source : NJDEP).

FIPS	County	Emissions (tons/day)			
		Rural	Urban	Local	Total
34001	ATLANTIC	50	96	29	175
34003	BERGEN	0	390	109	499
34005	BURLINGTON	81	231	29	341
34007	CAMDEN	22	258	81	361
34009	CAPE MAY	33	8	5	46
34011	CUMBERLAND	17	48	13	78
34013	ESSEX	0	232	86	318
34015	GLOUCESTER	37	88	32	157
34017	HUDSON	0	131	50	181
34019	HUNTERDON	72	0	0	72
34021	MERCER	36	148	40	224
34023	MIDDLESEX	44	397	34	475
34025	MONMOUTH	71	168	62	301
34027	MORRIS	35	165	65	265
34029	OCEAN	76	100	39	215
34031	PASSAIC	9	140	52	201
34033	SALEM	30	20	12	62
34035	SOMERSET	26	143	39	208
34037	SUSSEX	42	8	9	59
34039	UNION	0	198	63	261
34041	WARREN	44	6	5	55

priate urban and rural areas. These emissions should not be simply distributed according to the population density.

Urban and rural highway fractions were developed as new spatial surrogate indicators using the aforementioned method in Section 2.1. County-level highway VOC, NOx, and CO emissions were allocated to grid cells using the standard and newly developed spatial allocation methods to compare the spatial allocation accuracies of the two methods.

Fig. 5, 7, and 9 present the VOC, CO, and NOx emissions allocated to the grid cells, respectively, using the standard spatial allocation method. Whereas, fig. 6, 8, and 10 show the VOC, CO, and NOx emissions allocated to the grid cells, respectively, using the newly developed spatial allocation method. In these figures, the entire state of New Jersey was gridded using a 5 by 5 km^2 cell size. The lines in the grid cells indicate the major highways in New Jersey, and the colors of the grid cells represent specific ranges of air contaminant emission levels.

Several important things were found in common when the gridded VOC, NOx, and CO emission figures of the two spatial allocation methods were compared. When the newly developed spatial allocation method was used, highway emissions were more accurately allocated to grid cells along highways, and more highway emissions were allocated to grid cells that had longer or more highways. Whereas the standard spatial allocation method proportionally allocated higher emissions to grid cells according to their population density, consequently, a considerable amount of highway VOC, NOx and CO emissions was allotted to grid cells where no highway existed.

Another finding was that the newly developed spatial allocation method provided higher maximum air pollutant emission estimates than the standard spatial allocation method. The standard spatial allocation method estimated the maximum VOC, NOx, and CO emissions at 10.4, 6.3, and 44.4 tons per day, respectively, whereas the newly developed spatial allocation method produced

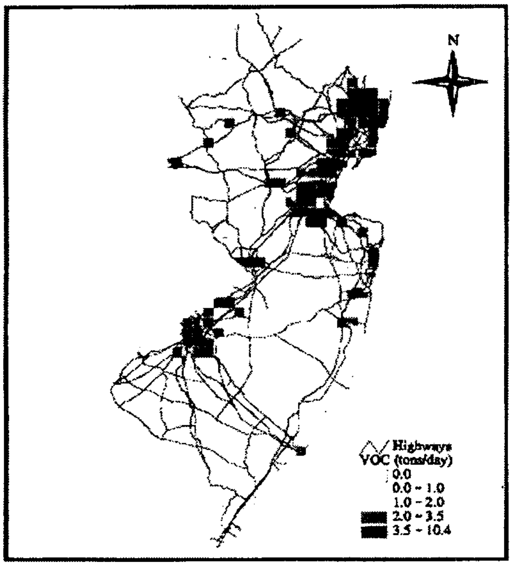


Fig. 5. Plot of gridded highway volatile organic compounds(VOC) emissions using the standard spatial allocation method.

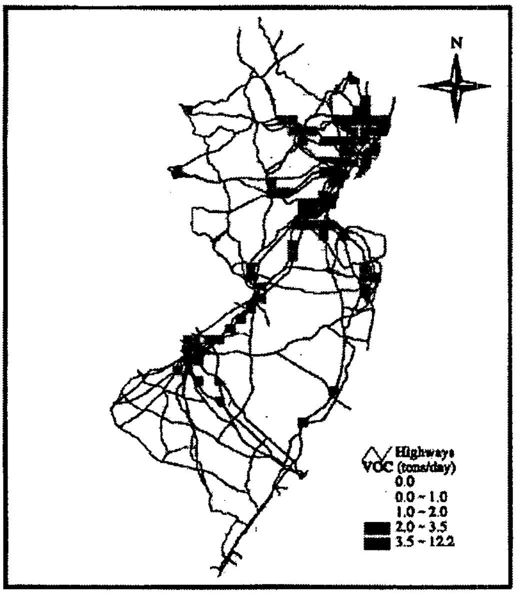


Fig. 6. Plot of gridded highway volatile organic compounds(VOC) emissions using the developed spatial allocation method.

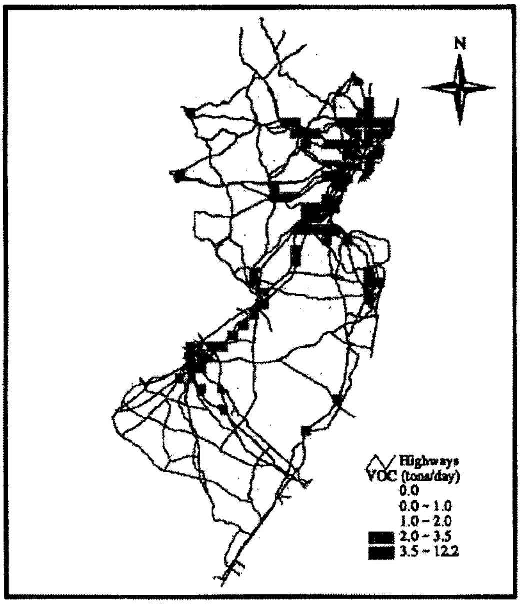


Fig. 7. Plot of gridded highway volatile organic compounds(VOC) emissions using the developed spatial allocation method.

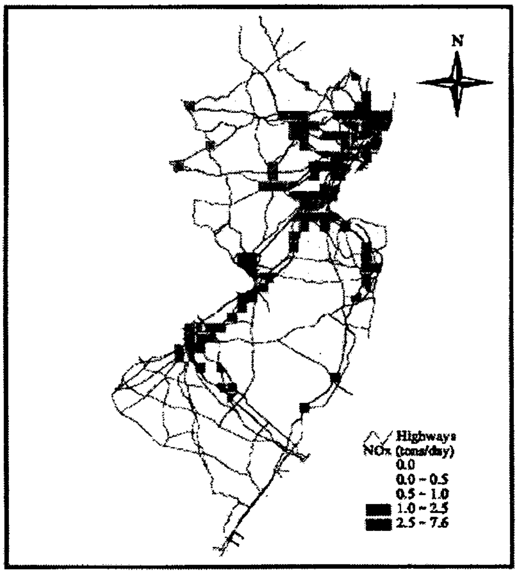


Fig. 8. Plot of gridded highway nitrogen oxides (NOx) emissions using the developed spatial allocation method.

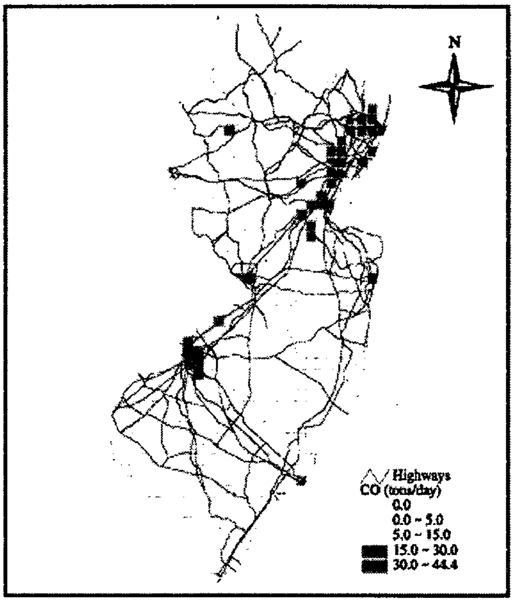


Fig. 9. Plot of gridded highway carbon monoxide (CO) emissions using the standard spatial allocation method.

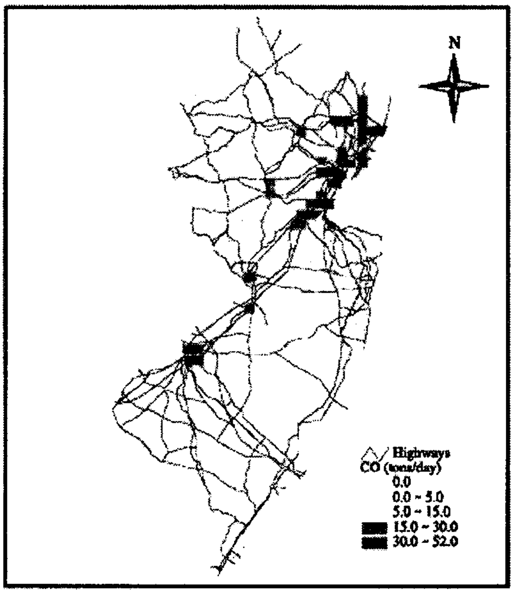


Fig. 10. Plot of gridded highway carbon monoxide (CO) emissions using the developed spatial allocation method.

maximum estimates of 12.2, 7.6, and 52.0 tons per day. The higher maximum air pollutant emissions estimated by the newly developed spatial allocation method are more realistic as higher emission levels are only allocated to grid cells crossed by highways. Accordingly, the underestimated maximum air pollutant emissions using the standard spatial allocation method will lead to inaccurate calculations for maximum air pollutant concentrations. The accuracy of estimated maximum air pollutant emissions and concentrations is very important, since these maximum air pollutant emissions and concentrations determine the compliance with air regulations on ambient air quality standards.

4. Summary

The findings obtained through this study can be summarized as follows :

1. The NJ DOT's road network data appears to be a more accurate source of highway information for the state of New Jersey than the 1992 TIGER/Line files,
2. A separate allocation of urban and rural highway emissions to computational grid cells using the newly developed urban and rural spatial surrogate indicators appears to be more effective as the urban and rural highway emissions are substantially different for each county in New Jersey
3. The use of the newly developed spatial allocation method seems to be more physically plausible than the standard spatial allocation method for highway emission disaggregation,
4. Highway CO emissions are more sensitive to the newly proposed emission allocation method than either VOC or NOx emissions,
5. The standard spatial allocation method underestimates the maximum air pollutant emissions from highways.

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