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Freight Impacts on Small Urban and Rural Areas

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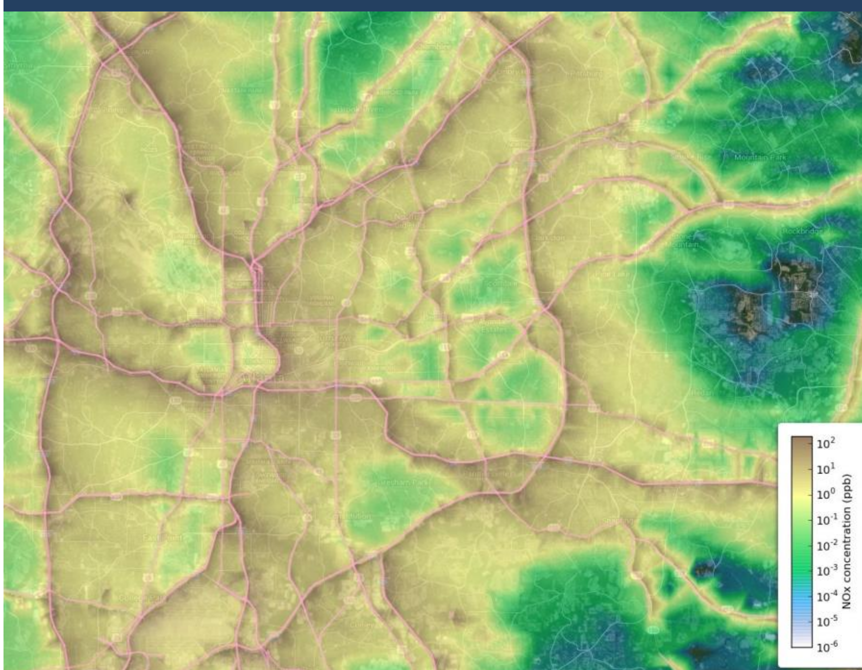
Freight Impacts on Small Urban and Rural Areas



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Freight Impacts on Small Urban and Rural Areas

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About the Center for Quality Growth and Regional Development

The Center for Quality Growth and Regional Development (CQGRD) is an applied research center of the Georgia Institute of Technology. The Center serves communities by producing, disseminating, and helping to implement new ideas and technologies that improve the theory and practice of quality growth.

For more information visit www.cqgrd.gatech.edu.

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EXECUTIVE SUMMARY

Freight mobility is critical for economic activity and vitality of a region. Freight system performance has also a driving influence on the quality of life in communities that experience freight traffic. Freight movement that results in high levels of pollutant emissions decreases quality of life in vulnerable communities.

Federal transportation policy has placed increased focus on the measurement of freight system performance. Freight impacts are often characterized in terms of four performance areas 1) Economic 2) Environmental/Health 3) Infrastructure/Traffic and 4) Social/ Environmental Justice (EJ). EJ considerations are important in communities where racially and economically disadvantaged populations are present. A holistic approach to performance measurement should consider more than just the operational efficiency and effectiveness of the freight -transportation system, but should also take into consideration community impacts, including sustainability and quality of life. However, limited data availability prevents adequate measurement of community impacts of freight, and limited funding availability has challenged local efforts to implement best practices that reduce the impacts of freight. Furthermore, the impact of freight on small urban and rural areas is not well documented, posing a great challenge for mitigation of freight-related impacts.

Freight traffic has many impacts that reduce quality life, including decreased safety and increased noise and vibrations. This study concentrates on one major impact of freight, air pollution from freight emissions. Specifically, the study measures the concentration levels of criteria pollutants monitored under national air quality standards (NO_2 and $PM_{2.5}$). These emissions are often evaluated at the county level, and without differentiation between urban and rural areas. This study uses disaggregate data to estimate current and future freight emissions at local levels along the Georgia Freight Corridor. It then takes the analysis a step further by identifying differing levels of pollutant concentrations for urban, small urban, and rural areas and by evaluating the exposure and health risks to EJ and other vulnerable populations along the corridor.

Freight moves through Georgia using a system of strategic corridors. The most significant freight corridors in the state include the interstate system (I-16, I-20, I-75, and I-85), select U.S. Routes (U.S. 84 and U.S. 441). It also moves through the state on the small urban and rural freight network. Many areas of the state are subject to pass-through freight, that is, freight that does not have an origin or destination within the state. However, the negative impacts of the freight traffic still affect communities bisected by freight corridors, while the economic benefits of the freight movement end up elsewhere.

While many areas affected by freight traffic are urban areas, little attention has been paid to the small urban and rural areas that also experience freight traffic. Georgia's rural and small urban areas are home to over 1 million and 1.5 million residents, respectively. Rural and small urban populations tend to be proportionally older, less racially diverse, and less wealthy than urban areas. Nearly a quarter of residents in small urban areas are below the poverty line, making them vulnerable to health impacts of freight emissions.

To analyze the health impacts of traffic-induced pollutants on small urban and rural communities along the Georgia Freight Corridor, the study uses a multi-stage process. In the first step, specific air pollution levels and traffic characteristics along the Georgia Freight Corridor were estimated using the C-Line ambient air quality simulation model for five representative urban and five representative rural areas distributed throughout Georgia. These results from C-Line were then used as inputs for the least squares regression analysis to obtain the relationship between NO_2 and $PM_{2.5}$ pollutant concentration levels and nearby freight movement. Next, pollutant concentration levels 400 meters from the freight corridor were estimated at the census block group level for the year 2007 and 2040 using Federal Highway Administration (FHWA) FAF3.4 data. The portions of these block groups included in the analysis are referred to as the “communities” of interest in this report.

In the second step of the analysis, exposure to differing pollutant concentration levels was analyzed for vulnerable subpopulations in the communities near the freight corridor, including children, seniors, racial/ethnic minorities, and individuals below the poverty line. Next, relative health risks of developing certain health conditions such as lung cancer and asthma were calculated and compared to those who are not exposed to freight emissions.

The results of the analysis showed that while urban communities, as expected, were more highly exposed to NO_2 and $PM_{2.5}$ pollutants compared to small urban and rural communities, freight emissions are still a problem in the non-urban areas of Georgia. In both, the present condition and in the future scenario, the 95th and 99th percentile for pollutant concentration levels (high exposure to pollution) for rural communities are often higher than that of small urban communities, implying that some rural residents are exposed to a large amount of freight emissions.

As for the vulnerable subpopulations, the results show that in both 2007 and 2040, minority and below-poverty residents were and will likely be disproportionately exposed to high levels of freight emissions. The vulnerability of these groups should be explicitly addressed in the freight planning process to mitigate impacts. The literature in this domain has shown that children and seniors are also vulnerable to the impacts of air pollution; fortunately, the results of this analysis show that children and seniors living along the Georgia Freight Corridor are not disproportionately exposed to higher pollutant levels. The percentage of the population exposed to the higher pollutant concentration levels is estimated to increase from 2007 to 2040, thus increasing the health risks caused by freight emissions.

The concentrations levels in this study are based on truck volumes and speed data only; the estimated emission concentration levels may be less than the observed/measured levels in the study area that account for other sources of emissions. Due to lack of data and resource constraints, simplifying assumptions such as constant emission factors and constant demographic distributions were made; therefore, the study does not account for technology and demographic changes that could occur by 2040. Despite these limitations, the study makes several recommendations that are important for planners and policy makers.

Based on the results and analysis performed the study makes three recommendation for planners and policymakers. First, traffic-induced air pollution needs to be analyzed at finer geographic scales to evaluate local effects of freight emissions. Second, the freight planning process should take into account the effect of freight movement on small urban and rural communities disaggregated by demographic categories to understand health disparities among potentially more vulnerable groups. Third, there is need to prioritize the mitigation effort and freight planning should mitigate the impact of emissions on vulnerable populations firstly near the freight corridor.

SECTION I. INTRODUCTION

Research Background

Efforts to implement the freight-related portions of MAP-21 are ongoing, but thus far little focus has been placed on the community-related impacts of freight. Under MAP-21 DOTs are required to identify a national freight network, and strategic funding at the state level should be directed towards improving the movement of freight. Additional focus has also been placed on the condition and performance of the national freight network, and the provision of investment for freight related surface transportation projects to include critical rural freight corridors (FHWA, 2013).

According to the Government Accountability Office (GOA), MAP-21's freight policy and goals do not directly address community impacts of freight such as freight-related congestion, but do require DOTs to identify best practices to mitigate the impacts of freight movement through communities (GAO, 2014). Moreover limitations within the wording of MAP-21, primarily the limitation of the national freight network to 27,000 miles, places primary performance focus on the highways and major arterials of the primary freight network, but excludes local roads and rural thoroughfares that provide critical connections between freight hubs and markets (GAO, 2014). Traffic congestion in rural areas and small urban areas may significantly impact performance of the primary freight network while experiencing freight related impacts on their community. The impact of freight on small urban and rural areas is not well documented, posing a great challenge for mitigation of freight related impacts.

MAP-21 recommends that states analyze the economic impacts of freight including analysis of benefits and costs of various improvements. As a result, there is increased focus on evaluating the benefits of investing in freight projects and freight corridor improvements. There is also growing interest in quantifying the return on investment for freight network improvements. Through these efforts some progress has been made towards measuring the economic impacts of freight. However, the scale of this analysis is often at the state or regional level, and rarely at the local or individual project level. Impacts are often considered at the point of origin or destination of freight transportation. But there is growing interest in measuring the impacts of pass-through freight i.e., freight that has neither origin nor destination within a local community but passes through en-route to its final destination. There have been ongoing efforts to measure the performance of the freight transportation system. However, this measurement is mostly freight-centered and is mostly focused on aggregate impacts. Measurement is focused on the operational efficiency and effectiveness of freight movement, and often has limited focus on community impacts. Attempts have been made to capture community impacts of freight in terms of livability, safety, quality of life and sustainability. Key areas of performance measurement include environmental, economic, social, and health-related metrics. Progress has also been made towards identifying best practices to mitigate the community impacts of freight. A well-developed performance measurement system should measure effects and identify best practices for impact mitigation.

Contribution and Significance

This study focuses on three important dimensions. First, the important freight corridors in the state of Georgia is identified using combined data of truck volumes from Freight Analysis Framework version 3 (FAF3) as well as truck location readings obtained from global positioning system (GPS) database of trucks generated by American Transportation Research Institute (ATRI). Second, the small urban and rural areas in the study area are demarcated and their socio-demographic characteristics are analyzed using census data. The study area includes the entire state of Georgia. Third, the emissions concentration are estimated along the freight corridors crossing through small urban and rural areas and their correlation to health disparities are analyzed for different disaggregated demographic categories, including age, race, and poverty level.

Disaggregation by demographic categories was motivated by a need to understand health disparities due to freight emissions in small urban and rural areas in the state of Georgia. Such disaggregated analysis is also necessary as demographic characteristics such as age may result in differing levels of sensitivity towards emission levels. The analysis performed in this study not only helps to identify national ambient air quality nonattainment areas in Georgia but also indicates the effect of freight emissions on a diverse population.

Although the focus of this study was on small urban and rural areas in the state of Georgia, United States, the study insights and the methodology can be useful for conducting similar studies for other geographical regions.

Organization of the Report

The rest of the report is divided into five sections. The section II presents a broad literature review of related past research. Then, section III characterizes the study area. Subsequent sections IV and V present the methodology adopted in this study and results of the analysis. Finally, concluding comments and recommendations of this study are presented in section VI. The focus and the scope of the each section of this report are summarized below.

Section II – Literature Review: The literature review summarizes a broad range of past research that is helpful to understand the issues surrounding rural America and their relation to freight transportation, freight centered community impacts, the pollutants that are most relevant to rural and small urban areas and to areas in close proximity to the freight corridors, various methods for determining the emission factors, and measures for mitigating the community impacts of these emissions.

Section III – Baseline Conditions: The context of the study area (State of Georgia) is presented in this section. Baseline conditions include the geographical spread of the urban, small urban, and rural areas of the study area, along with their socioeconomic and demographic characteristics. This section also presents the spatial location of freight corridors of Georgia and their characteristics.

Section IV – Methodology: This section presents the methodological framework adopted in this study along with the details of its components. The relation between the components of the framework are first explained using a flow diagram and then the specific methods used for the analysis are explained.

Section V – Analysis and Results: This section is devoted to detailed computational results and analysis using the methodological framework presented in previous section. The section not only presents the pollutant concentration levels along the small urban and rural areas but also analyzes the possible health risks related to the estimated concentration levels in the study area.

Section VI – Conclusions: The final section draws together all of the previous sections, presenting concise findings and recommendations for future action. It also identifies the limitations of this study which can guide future research about the impact of freight emissions.

SECTION II. LITERATURE REVIEW

Introduction

Traffic impacts on public health have been studied extensively for the past couple of decades, and there are more than a dozen of highly cited review papers. In this context, this section does not provide a comprehensive summary of all the existing literature. Instead, the sole aim of this literature review was to understand the issues facing rural America and their relation to freight transportation, freight-centered community impacts, and to identify the pollutants that are most relevant to rural and small urban areas, especially those living in close proximity to the freight corridors in Georgia.

An initial scan of the literature suggests there is a knowledge gap related to the overall community impacts of freight. In addition, there is a need for more far-reaching measures that capture 1) local economic impacts of freight, 2) impacts to rural and small urban communities, 3) impacts to roadways that are not included in the primary freight network, and 4) impacts from pass-through freight. This literature review summarizes attempts that have been made to date to quantify community impacts of freight including key performance areas and measures. To inform this discussion this report provides a brief overview of freight transportation planning including jurisdictional responsibilities for freight planning in small urban and rural communities, and discusses emerging issues around freight transportation in rural communities. Finally it identifies different approaches that have been used to measure the impacts of freight along various transportation corridors, and begins to identify measures that can be used to quantify freight impacts.

Rural America at a Glance

Definitions of Rural

Critical rural freight corridors transport 500,000 tons of bulk commodities per year (FDOT, 2013). In the United States, rural areas—which can be considered those outside of Transportation Management Areas (TMAs)—contain 20 percent of the population, nearly 60 million people (FHWA, 2014). Rural areas are defined in a variety of different ways. The Census Bureau's list of places, the Census Bureau's list of urban areas, the Office of Management and Budget and the United States Department of Agriculture Economic Recovery Service (ERS) have identified nine definitions for a rural area as shown in Table 2.1(USDA, 2012).

Table 2.1: Definitions of Rural

Definition	Description	Percent of People and land area considered rural in the U.S. under definition	Source
Rural definition #1	All areas outside Census places with 2,500 or more people	87.7 million people 31% of U.S. population 97% of U.S. land area	Census places
Rural definition #2	All areas outside Census places with 10,000 or more people	115.8 million people 41% of U.S. population 98% of U.S. land area	Census places
Rural definition #3	All areas outside Census places with 50,000 or more people	177 million people 63% of U.S. population 99% of U.S. land area	Census places
Rural definition #4	All areas outside urban areas. This places the upper limit of rural at 2,500 since urban areas have at least 2,500 people	59.1 million people 21% of U.S. population 97% of U.S. land area	Census Urban Areas
Rural definition #5	All areas outside urban areas with 10,000	70.6 million people 25% of U.S. population 98% of land area	Census Urban Areas
Rural definition #6	All areas outside urban areas with 50,000	89.5 million people 32% of U.S. population 98% of U.S. land area	Census Urban Areas
Rural definition #7	All counties outside metropolitan areas in 2003 (based on 2000 census data)	48.8 million people 17% of U.S. population 75% of U.S. land area	Office of Management and Budget (OMB) metropolitan statistical area designation
Rural definition #8	Census tracts with 2000 RUCA codes 4 through 10	5706 million people 20% of U.S. population 81% of U.S. land area	ERS Rural---Urban Commuting Area Codes (RUCAs)
Rural definition #9	Locations outside places of 50,000 or more people and their associated urbanized areas	101.9 million people 36% of U.S. population 98% of U.S. land area	USDA's Business and Industry (B&I) Loan Program Definition

The U.S. Department of Transportation defines rural in two ways. First, for highway functional classification and outdoor advertising regulations, rural is considered anything outside of an area with a population of 5,000. Second, for planning purposes, rural is considered to be areas outside of metropolitan areas 50,000 or greater in population. A good working definition of 'rural' is a non-metropolitan area outside the limits of any incorporated or unincorporated city, town, or village. The Federal Highway Administration defines a rural community in the following three ways (FHWA, 2001).

- *Basic*: These communities have few or no major metropolitan areas with more than 5,000 people; they are often considered real rural or meeting the traditional version of rural.
- *Developed rural*: These areas have one population center with 5,000 or more people or one metropolitan area with 50,000 people. These areas have developed metropolitan areas but a significant portion of the region is still basic rural.
- *Urban boundary rural*: These rural areas are located just beyond the fringe of large urban areas. These communities are heavily influenced by the activities of the metropolitan area.

Issues Affecting Rural America

The South and the Midwest are considered to be the two most rural regions of America (Turner Gions, G. R., R.; Ham,R. J., 2003). On average, rural America makes up 75% of the country's land area but only 17% of the American population (Carsey Institute, 2006). In recent years rural communities have been characterized by an "aging" phenomenon with the greatest population gains being seen in the over-50 age group, and an out-migration of young adults who relocate to urban areas in search of better economic opportunities (TCHRP Report 136, 2009). Rural populations are generally some of the poorest in the country. Recent labor shifts away from farming and the automation of the farming industry has resulted in a net loss of jobs. A diverse number of industries continue to contribute to the rural economic base but the traditional industries of farming, manufacturing, and mining continue to decline. Less than 6.5 percent of the nonmetropolitan labor force is engaged in farming (Carsey Institute, 2006). A new trend has emerged in rural areas with the emergence of communities centered on natural amenities, recreational opportunities and quality of life advantages (Carsey Institute, 2006). Retirement destination communities have emerged in areas with significant natural amenities suitable for recreational activities therefore attracting a high number of retirees. In spite of the gains observed in rural areas, in 2012 the national poverty rate for a family of four was 15.0 percent and 17.7 percent in non-metro areas (USDA, 2013). Given declining employment opportunities, and the aging of the population, activities that impact economic conditions and the population health are perhaps even more critical issues in rural communities.

Transportation and Rural America

Transportation Planning in Rural America

Rural areas are often found within the boundaries of the Metropolitan Planning Organization (MPO). MPOs are responsible for multimodal transportation planning in large urbanized areas or Transportation Management Areas (TMAs) which are generally areas with more than 200,000 residents. Smaller urbanized areas, which have populations between 50,000 and 200,000, are often referred to as non-TMAs (FHWA, 2014). Transportation infrastructure in rural communities plays a vital role in the movement of goods and people. Eighty percent of national road miles are rural, totaling approximately 3.1 million miles, and 40 percent of vehicle miles traveled happens on rural roads (FHWA, 2001). Rural transportation infrastructure connects metropolitan regions, centers of economic production, and areas of environmental and natural significance.

Transportation planning in rural areas involves several different stakeholders. Stakeholders include Economic Development Councils, State DOTs, MPOs, Regional Development Councils (RDCs), local governments, private sector entities and other public agencies including federal oversight from the Federal Highway Administration (FHWA) (FHWA, 2014). Economic Development Councils develop and implement long-term strategic plans for growth, State DOTs develop and implement statewide transportation plans and programs. MPOs conduct planning for metropolitan areas, but have growing influence over rural and ex-urban transportation planning efforts. Rural transportation planners have varying levels of interaction with state partners. In some instances rural planners participate formally in project prioritization and coordinated outreach efforts and in other instances there is no formal interaction between rural planners and state officials (FHWA, 2014). The local/rural state interaction will be important to consider as further consideration is given to the impacts of freight transportation on local communities particularly in the area of public engagement, communication, and stakeholder involvement.

Freight Transportation in Rural America

Rural freight transportation is characterized by the movement of both people and goods. Transit planning receives significant attention in rural freight planning. The aging community and veterans make up a significant portion of the population in rural areas and these persons rely heavily on transit. Nearly 4 million veterans reside in rural (nonmetropolitan) America, and they make up nearly 10 percent of rural adults (USDA, 2013). Rural transportation is a crucial link between rural communities and metropolitan communities offering direct access to services for rural communities, and access to market for goods produced in rural communities (FHWA, 2014). Rural areas, and particularly urban boundary areas play a critical role in the transportation planning efforts of a region. Infrastructure improvements in rural areas contribute to the efficient movement of goods through a region. State highways move a large proportion of manufactured goods in the U.S., and most highway mileage is located in rural areas (FHWA, 2014). Integrated rural transportation planning processes are therefore critical for freight movement, but economic, demographic, and traffic pattern shifts have begun to impact rural transportation practices.

As discussed, rural areas can be characterized as basic, developed, and urban boundary areas. The challenges faced by basic, developed and urban boundary rural communities are similar but each has unique challenges particularly with respect to the movement of goods and people. In general all rural communities are faced with long distances between population centers, steep grades, and high units of cost for service delivery, operations and maintenance (FHWA, 2001). In basic rural areas the road network outside of the federal aid system is underfunded and poorly maintained, leading to poor support of agricultural activities and general freight movement. In developed rural areas maintenance of the regional network is a challenge yet critical for ensuring access to regional service centers and farm-to-market, while increasing congestion, rapid growth and maintenance needs create challenges in urban boundary rural areas (FHWA, 2001). A primary concern is the lack of mobility and accessibility available to those residing in rural areas.

Transportation System Performance Measurement

The passage of MAP-21 has placed increased focus on the measurement of freight system performance. The measurement of system performance can be conducted at the program level – economic return on freight infrastructure investment; the network level, and the corridor level. The goal of freight system performance measurement is primarily to evaluate how the system is performing, or to conduct an inward-facing review of how freight is performing in spite of its environment. Performance of freight systems is often captured through attempts to measure the effectiveness of investments made in freight system development. This type of analysis is focused primarily on economic measures such as cost benefit analysis and return on investment and is mainly "systems-focused". Measurement is focused inward on the system with little consideration given to the outward community impacts of freight movement. Though freight system performance can take into consideration the impact of freight movement on human activity, often reflected in environmental measures, limited focus is placed on the effect or impact that freight has as it moves through communities. Many communities are challenged by an increase in freight activity and experience impacts including physical, environmental, and economic (Doherty, Wise, Hart, Ivey, & Adams, 2013).

For example, the Florida Department of Transportation (FDOT) uses a macro-economic analysis to quantify the benefits from investments made through its work-program. The goal of this analysis is to show the direct impact on auto and truck travel time, vehicle operating costs and accident costs that highway investment can produce (FDOT, 2009). This analysis is extended to demonstrate savings and direct economic benefit derived from investment in terms of personal travel, and business-related benefit, and increases to personal income for Florida residents and employment. An outward-facing or human-activity focused approach to performance measurement seeks to capture the effect or impact of freight movement on communities and individuals (Browne, Allen, Nemoto, Patier, & Visser, 2012). It is equally important to understand which communities benefit from increased income and employment opportunities.

Performance Areas and Measures for Freight-Centered Community Impacts

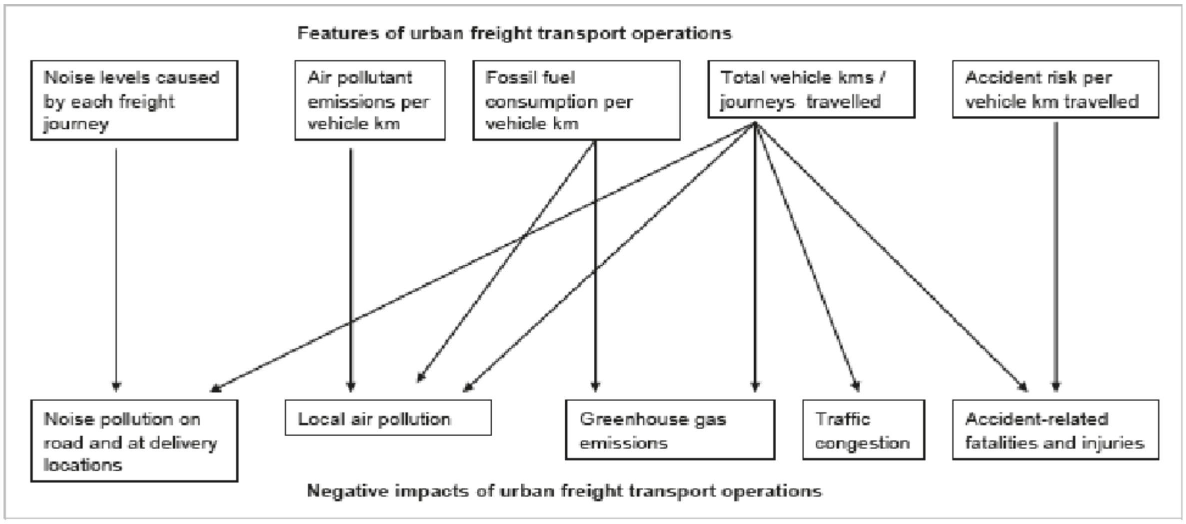
What measures are used to quantify the spillover effects of freight? The spillover impacts or the externalities of a system can be difficult to characterize and even more difficult to quantify rigorously. The use of key performance indicators (KPIs) can make the effort to quantify impacts more relevant to those responsible for planning and programming future freight routes (Balsas, 2004). Key performance indicators are a set of measures that describe a complex social, economic, or physical reality. A measure is one data point that acts as a gauge to tell us how well or poorly we are doing with respect to an indicator. Freight impacts are often characterized in terms of four performance areas 1) Economic 2) Environmental/Health 3) Infrastructure/Traffic and 4) Social/ Environmental Justice (EJ). EJ considerations are also of relevance in communities where racially and economically disadvantaged populations are present. Each performance area can be further classified into sub-areas or dimensions. It is through the sub-area descriptions that the unique characteristics of a community can be captured, and the special considerations of freight impacts can be considered.

Performance measures can then be used to quantify impacts. A review of the literature describing different approaches to measuring impacts of freight movement resulted in the identification of several different performance areas that can and have been measured. In many of the studies there was a discussion about performance areas where impacts could be quantified however no measures were actually listed or identified. There is therefore an opportunity to develop specific measures for quantifying freight impacts that focus specifically on the impacts of freight on human-activity, and more importantly recognize the unique characteristics of rural and small-urban communities.

Human Activity Focused Freight Measurement

A freight-centric community is an area that bears the spillover effects from the movement of freight or goods (Doherty et al., 2013). Freight-centric communities are in close proximity to freight hubs, intermodal centers, ports, airports, major freight corridors, or high traffic generators. Spill-over effects from freight can be characterized in terms of the following impacts: economic, environmental, infrastructure, health, and social. Freight system performance is also measured using these performance areas, but a key difference in the approach used to characterize impacts to freight-centric communities, is the definition of measures and objectives in terms of the impacts to human activity. Economic impacts may also focus on agricultural or tourism, and are often dictated by the local economy. Employment generation and impacts on poverty are also important economic considerations.

A common approach in quantifying the impacts of freight movement is to compare and contrast the conditions along specific corridors. The Atlanta Regional Commission (ARC) in the Freight Mobility Plan Environmental and Community Scan compared conditions along five corridors in the ARC metropolitan region (ARC, 2008). In a study to quantify livability for freight-centric communities located along the Lamar Avenue Corridor in Memphis, TN (Doherty et al., 2013), researchers compared conditions along the corridor to other similar corridors. To identify freight impacts Browne et al. (Browne et al., 2012) connected specific features of freight transport to negative social, environmental and economic impacts produced along a corridor. Negative features included traffic congestion, local air pollution, greenhouse gas emissions, noise disturbance, and safety. Figure 2.1 shows the connections between the features of freight transport and associated negative impacts. Browne's work was limited to those impacts that the research team felt could be impacted by policy, but the scope of this work could go beyond policy impacts.



Source: (Browne et al., 2012)

Figure 2.1: Freight Impacts and Negative Externalities

Freight impacts have also been characterized under the broader themes of livability, sustainability, and quality of life. These efforts are described further below. Freight is one of many factors that may impact the livability, sustainability, and quality of life of a community and attribution remains a challenge in any effort to quantify impacts. However, measuring freight impacts in these terms presents a broad approach. In each approach it is clear that most measures capture the perceptions of community stakeholders who live within the communities being impacted. Surveys are often used to collect stakeholder input during corridor analysis with the goal of capturing changes over time, and stakeholder views about current and projected conditions within the corridor. In addition, stakeholders frequently identify impacts that may be missed by those less familiar with the area.

Freight and Livability

The Federal Highway Administration recognizes the connection between increases in freight traffic and impacts to community livability. As a concept, livability ties the quality and location of transportation facilities to broader opportunities such as access to good jobs, affordable housing, quality schools, and safe streets (Doherty et al., 2013). Freight has an intrinsic tie to many of the principles of sustainability. The Partnership for Sustainable Communities, a partnership between the US Department of Transportation, Housing and Urban Development (HUD), and the Environmental Protection Agency (EPA) (Doherty et al., 2013) identifies six livability principles, shown in Table 2.2 that can help guide the development of performance measures for quantifying the impact of freight movement on community livability.

Table 2.2: HUD/EPA/DOT Six Principles of Livability

Partnership Principles	Associated Performance Measures*
Provide more transportation choices	Walkability rating*
	Multimodal (road) level of service*
	Transit accessibility
	Mode share*
Promote equitable, affordable housing	Jobs/housing balance
	Location efficiency
	Housing and transportation index
Enhance economic competitiveness	Travel time reliability*
	Workforce accessibility
	Job accessibility
	Travel time index*
Support existing communities	Multimodal accessibility to essential destinations (e.g. store, healthcare, schools)
	Safety (crash by mode)*
	Speed suitability*
Coordinate and leverage federal policies and investment	Consistency with local land use and transportation plans*
	Return on investment*
Value communities and neighborhoods	Connectivity index*
	Community character (e.g. resident satisfaction)*
	Partnership and public involvement

*Performance measures with potential application to community impacts of freight measurement

Livability along the Lamar Avenue Corridor

In a study of freight-centric communities (Doherty et al., 2013), researchers summarized an approach for understanding freight impacts on neighborhoods by offering a definition for freight-centric communities and identifying livability priorities for residents. This work focused on Lamar Avenue, a high volume freight corridor in Memphis, TN. The work identified environmental, infrastructure and land use variables that contributed to resident perceptions about the livability, sustainability, and health of their local community. The research team identified baseline indicators for measuring the characteristics of freight-centric communities. The areas measured were population, transportation, health, places/amenities, environmental, economic, livability, and other. Measures defining economic, environmental, and livability measures are most applicable to this work and have been included in Table 2.3 below. The work allows freight planners to think intentionally about impacts to communities from freight, and as a next step seeks to identify best practices for mitigation against the impacts of freight.

Table 2.3: Baseline Measurement indicators for Freight–centric Communities

Community Characteristic	Measure
Environmental	Cost of increased carbon emissions Cost of decreasing carbon emissions Percent change in air pollution Sound level FEMA rating
Economic	Percent GDP from freight Freight legal settlements Percent jobs provided by freight hub Tax revenue generated by freight hub Level of investment in community
Livability	Walkability EPA environmental measures Economic impact studies multiplier effect Percent of commuters who walk or bike Life-space index
Other	Pedestrian danger index

Key Performance Indicators for Town Center Livability

Balsas (2004) defines a livable community as a place that is safe, beautiful, economically vital, affordable, and possessing positive population drivers including efficient administration and functional infrastructure. Balsas was interested in the livability of cities and more specifically city centers. His work focused specifically on quantifying the health of the urban town-center using key performance indicators (KPIs) including population demographics, employment, retail vacancy, performance and sales, car parking, crime and safety, cleanliness, tourism, and evening economy (Balsas, 2004). This work provides an international perspective drawing on North American and European KPIs to characterize redevelopment efforts within urban town centers. This work seeks to evaluate the impact of city-center revitalization efforts, and to monitor the progress of such efforts. The work draws upon urban regeneration literature to quantify a city's ability to improve its viability and vitality. Freight impacts were not evaluated as a specific component of such efforts, but Balsas's work identifies metrics that can be used to measure both positive and negative spill-over effects on city centers, and freight has impacts on many of these town center factors.

Balsas seeks to answer the question, what makes a city center livable? As we consider the impacts of freight on rural communities, this question can be reframed to identify the impacts of freight that make a city center unlivable. City-center livability can by recast in terms of town-center livability in order to quantify livability impacts to small town urban and rural centers. To answer his research question, Balsas utilizes six dimensions of performance: vitality, sense, fit, access, control, and viability. Vitality and viability are used to assess city center health (Balsas, 2004). The two dimensions of vitality and viability refer to whether the city center feels lively to people and whether it has a capacity for commerce. The process of managing the revitalizations of town centers is called town-center management (TCM). The British Association of Town Center Management published Key Performance Indicators to measure town center livability (Balsas, 2004). These indicators are shown in Table 2.4.

Table 2.4: British Association of Town Center Management (ATCM)

Category	Key Performance Indicator
Regional Health	Population demographics Employment
City Center Progress	Visits to town center Car parking Public transportation Crime safety and security Variety and offer Public facilities Street maintenance and cleanliness Facilities for special needs Town center management activity
City-center health	Retail vacancy Retail performance Retail sales
Optional city-specific indicators	Tourism Evening economy

Source: (Balsas, 2004)

Freight and Sustainability

Zietsman (2012) puts forth performance measures to characterize the sustainability of the freight system. Zietsman highlights the diverging views around transportation and sustainability, the first being the transportation- centered or transportation-centric view, and the second being a community-focused or holistic view as described earlier. According to Zietsman, a sustainable transport system ensures the movement of freight from manufacturer to consumer with minimal impacts to the three E's. Sustainable transport is characterized by three dimensions - environment, economy, and equity/society/employment.

Table 2.5: A Holistic View and a Transportation-Centered View of Sustainability in Transportation

	Sustainable Transportation (Transportation---Centered View)	**Transportation from the view of sustainable Development (Holistic View)**
Focus	Single system/sector	Multiple systems/sectors
Advantage	Provides sector-specific objectives And principles that guide the development of transportation policies and programs Does not require a strong external commitment to sustainable development to enact sustainable transportation policies/programs at the regional/local level	Highlights the needs to establish a national framework/policy to address sustainable development that can encourage sectors to coordinate their activities
Disadvantage	Does not explicitly connect impacts from transportation with those from other sectors. Transport tends to be considered in a vacuum	Does not provide detailed sector-specific objectives and principles to guide the development of transportation policies and programs Requires a strong and long-term external commitment to sustainable development that may not be forthcoming in the current political climate

Source: (Zietsman, 2012)

Zietsman developed a framework and methodology to address freight sustainability at the transportation corridor level. Sustainability was defined as providing for environmental stewardship, economic efficiency, and social equity, and performance measures that begin to capture progress towards freight sustainability are identified. Recognizing the differences between urban and rural communities, this research puts forth measures for different corridors and development types. Zietsman's research developed a methodology for evaluating individual performance measures for a specific transportation corridor and combined them into an aggregate sustainability indicator. His work provides a comprehensive literature review of the concepts of sustainability and sustainable development, the dimensions of strong and weak sustainability, key issues surrounding sustainability, and issues related to transportation and sustainability. The final component of the literature review looks at sustainability and the transportation sector including performance measurement in the transport sector. Table 2.5 highlights the differences between a holistic view and a transportation-centered view. Zietsman presents measures for sustainable transport that are mostly transportation-centric. However, some of these measures can also be used to offer a holistic look at the impacts of freight. Performance measurement at both the state and federal levels involves goal setting, identifying objectives, and then defining measures.

Table 2.6: Proposed Measure for Sustainable Transportation Performance Measurement

Goal No.	Sustainability Dimensions	Goal	Objectives	Measure Number	Performance Measure
1	Social	Improve safety of freight movement and of the general public	Reduce freight-related crash rates and crash risk	1a	Annual fatal accidents per truck-mile
			Reduce freight-related Hazmat accidents	1b	Annual HAZMAT accidents per mile
2	Economic	Support freight activity level while ensuring functionality and efficiency of freight operation	Improve road-based freight movement	2a	Truck throughput efficiency TTE = daily truck volumes per lane truck operational speed
			Improve freight movement efficiency	2b	Average cargo weight per truck
			Improve freight movement mobility	2c	Travel rate index
			Improve freight movement reliability	2d	Buffer index
			Improve intermodal activity	2e	Number of intermodal facilities along the section
			Invest in improving freight fleet	2f	Average truck age
3	Environmental	Reduce negative impacts of freight movement on the environment and human health	Reduce criteria pollutant emissions from freight vehicles	3a	Grams per mile of PM. NO_x, VOC
			Improve freight fleet emissions characteristics	3b	Percentage of trucks complying with the second most recent emissions standards
			Reduce GHG emissions from freight vehicles	3c	Grams of CO2 equivalent per mile
			Reduce impact on sensitive population	3d	Number of sensitive areas (schools/hospitals) within 1 mile of the road
			Reduce buffer between road and residential development	3e	Population residing within 1 mile of the road
			Protect natural habitats	3f	Number of Sensitive environmental areas within 1 mile of the road

Table 2.5 identified proposed objectives and measures by sustainability dimensions (social, economic, and environmental). The environmental measures are the most holistic that is they are most concerned with freight impacts to human activity. The social measures take somewhat of a holistic view focusing on the movement of freight but the movement of the general public. The economic measures are mostly transportation focused and present the opportunity for holistic measures. The table above is intended to capture performance measurement for sustainable transportation and therefore the highlighted performance measures are mostly transportation-centered. Some of these measures could also be used in a holistic approach to measurement. However, to truly achieve a holistic outlook, the suggested performance measures should be redirected to assess direct impacts to the community. The sustainability dimension goals and objectives may also change, but Table 2.6 provides a good building block on which to build sustainable development performance measures for community-focused freight impacts (Zietsman, 2012).

Freight and Quality of Life

Another approach used to assess freight impacts on nearby communities is to connect freight to the quality of life within these communities (ODOT, 2010). Quality of life indicators are focused on measuring the health and well-being of a community. Quality of life and livability are sometimes used interchangeably. Quality of life indicators include reductions or increases in noise levels, changes in traffic congestion, improvements or changes in crashes and safety measures. The Ohio Statewide Rail Plan used quality of life measures to emphasize the benefits of freight rail transportation as compared to freight highway transportation. In the Ohio Statewide Rail Plan it is argued that rail service improves quality of life by removing trucks from already congested roads, reducing the freight carbon footprint of the state, and providing businesses and industries with an alternative and often less expensive option to move materials and goods (ODOT, 2010). Freight rail has specific impacts on rural communities because increased congestion, zoning ordinances, public opposition, and inadequacy of land availability has pushed rail operations from within city centers into suburban areas and out even further to rural communities. The rail plan does not offer specific measures for quantifying freight-community impacts, but as shown in Table 2.7 below looks at the following quality of life dimensions and issues related to freight rail movement.

Table 2.7: Quality of Life Dimensions for Freight Rail

Quality of Life Dimension	Community Issues
Economics	Increased competitive edge – shorter cheaper haulage options
Environment	Locomotives produce air and noise pollution
Land Use	Separation of neighborhoods; underutilization of prime development lands for rail operation
Safety	Concerns about at grade crossings, increased congestion and related crashes

Freight and Communities Impacts

NCHRP Synthesis 320 discusses how freight movement and its impacts can be minimized and aligned with community goals. This report does not provide measures for quantifying impacts but it does offer a discussion of best practices that have been used to minimize the impact of these key issues by mode. Being aware of these best practices can help with identifying appropriate measures. NCHRP Synthesis 320 identifies some of the key issues that communities face with respect to freight operations and freight facilities as outlined below (Weider, 2003):

- Communication
- Traffic flow and congestion
- Safety and security
- Economic development
- Air quality
- Noise and vibrations, and
- Land use and value

Table 2.8 outlines the community impact areas and concerns in more detail.

Table 2.8: Freight/Community Impacts

Community Impact Area	Concerns and Impacts
Communication	Key element for reducing conflict and maximizing benefits from freight facilities and operations • First called when there is a problem • First to respond in the event of a policy of medical emergency • Deal with local disruptions
Traffic flow and congestion	Most cited in this study as a concern related to freight facilities and operations: • Volume of trucks and availability of road capacity for other users • Operational characteristics – acceleration and deceleration and other vehicle users • At grade crossing and intersection blockage (number of blockages and time) • Congestion from loading and unloading at commercial sites • Truck parking and roadway operation
Safety and security	This refers to theft and destruction of property as well as vehicular accidents • Safety at---grade rail crossings • Movement handling, and storage of hazardous materials • Loss of life or injury from vehicular accidents

Economic development	It is important to balance economic benefits from increased employment and tax revenue with the community impacts of increased freight traffic: • Retention of existing business activity • Attraction of new businesses • Creation of new job opportunities and opportunities for property redevelopment • Managing additional freight traffic associated with new development
Environmental	Primary concerns involve diesel emissions from idling train engines and vessels. Other concerns include: • Hazardous spills in communities • Impact on minority communities (environmental justice) • Impacts on endangered species and habitats • Light pollution • Noise pollution and vibration from vehicle movement and loading and unloading activities
Land use and value	Land value concerns are centered around real or perceived changes in property values resulting from freight facilities and operations: • Potential better uses for land than current freight operations • The productivity of and economic value generated by the land used by freight

Source: (Weider, 2003)

Freight Transportation Return on Investment

An evaluation of transportation return on investment is focused on identifying the macro-economic impacts of freight transportation. Analysis often includes a cost/benefit analysis. The analysis is undertaken under the assumption that dollars invested in the construction, maintenance and operation of freight facilities result in travel time impacts, accessibility, and other broader user benefits (Cambridge Systematics, 2008). Impacts can be quantified for various user groups including freight, non-freight, business automobile, and non-business automobile.

Benefit scenarios typically compare a build and no-build scenario. Travel time impacts measure the difference in vehicle-miles traveled and vehicle-hours traveled for the build and no build scenario. User benefits are made of factors including – travel time savings, fuel and non-fuel costs, safety benefits, travel time reliability, and reliability benefits. Accessibility benefits measure the improvement to labor, consumer, buyer, supplier, and tourism markets by gauging the additional employment and population that is accessible within one-hour drive time for customer and labor markets therefore attracting and retaining business to an area (Cambridge Systematics, 2008). Another approach to quantifying economic impacts seeks to determine the individual impact of freight investment versus the business impact of freight investment (FDOT, 2009). Individual or personal impacts are quantified in terms of personal auto benefits, time savings, and changes in personal income. Business impacts are quantified in terms of gross state product which is related to personal income, and changes in employment.

The analysis of transportation return on investment is intended to provide a statewide or regional view of economic return and therefore may not provide an appropriate approach to evaluating local community impacts. However, ideas around personal and business benefits can contribute to defining stakeholders for community benefits.

Impacts of Air Pollutants from Traffic on Public Health

As mentioned earlier in this report, impacts of air pollutant from traffic on public health have been studied extensively for the past couple of decades highlighting the growing significance of this issue. But emphasis here is not to list or summarize the literature in this domain but to present those studies that help to find out which pollutants are the most relevant to those who currently live close to the Georgia freight corridor, and to what extent.

An academic literature search engine was employed to find the most frequently cited articles in this field.[1] Then, individual articles are analyzed in terms of their subjects, exposure period, response period, (if any) other pollutants controlled for in regression models, health outcomes, dose of pollutants, , Relative Risk (RR), Odds ratio (OR), non-OR (for those studies that did not use binary regression models), and confidence interval. Among these research papers, we finally selected a small number of articles for each pollutant, which had better research design than others. The selection criteria are below:

1. Exposure periods should precede response periods. This criterion sounds basic and redundant; however, a number of literature did not meet this criterion mostly due to lack of relevant data. A common practice is to assume that exposure levels do not differ much in a short period of time, and thus, later exposure levels can be used in regression models as a proxy for the previous exposure levels. Unfortunately, though this is a testable assumption, we could not find any single literature that focused on testing this assumption. In this report, we chose to be more conservative, and thus, we excluded the literature based on this assumption from our final selection.

2. Health outcomes should be major ones such as cardiovascular, lung, cancer- or death-related. This is partly related to trends in research design. Earlier literature employed research design that measured health outcomes of large groups of participants in multi-year panel surveys, while recent literature tends to focus on relatively short-term effects by different concentration levels by analyzing cross-sectional data sets in many cases. Both research designs have their own merits and shortcomings. One limitation of the latter is that it is difficult to reveal statistical relationships between traffic-related pollution and serious health outcomes, i.e. how can one detect impacts of

[1] Google Scholar in February 2015. We cross-checked other search engines and got similar results.

pollution on death within a few month?[2] Though this transition in the research trend in this field is understanding and a natural development in the research community (i.e. first, focus on serious deceases, then second, move onto less severe or minor deceases), we want to highlight the most serious health outcomes in this report, because we find that still, the most striking results from the literature have not been well communicated into other fields including civil engineering or urban transportation planning.

3. For studies using self-reported questionnaires, any symptoms that are *not diagnosed* by medical service providers such as doctors are *not included* from the final selection. We assume that doctor-diagnosed symptoms are a more reliable measure of negative health outcomes, rather than subjective judgments by individuals in the survey.

4. Odd ratios should be statistically greater or smaller than 1 at 95% confidence level. For research articles that analyzed a multiple number of pollutants using the same research design, it is likely that some pollutants showed statistical significance while others did not. Because we focused on specific pollutants (NO_2, PM_{10}, and $PM_{2.5}$), if these pollutants are not statistically correlated to health outcomes, then that research article is excluded.

Impacts of NO_2 from Traffic on Health Outcomes

Abbey et al. (1999) analyzed 6,338 nonsmoking California Seventh-day Adventists whose data of exposure to pollutants were collected from 1973 to 1992 and health outcomes were measured from 1977 to 1992. Among multiple symptoms, lung cancer mortality for female participants was statistically associated with NO_2 levels due to traffic near their residences. Per the interquartile range of 19.78 ppb (or 37.19 microgram/m3), the relative risk of dying of lung cancer is 2.81 based on Cox proportional hazard model.

Andersen et al. (2011) analyzed 57,053 participants in the Danish Diet, Cancer, and Health cohort survey. These individuals were exposed to traffic-related air pollutants from 1971 to 2006, and their health outcomes were observed from 1993 to 2006. In this study, the researchers tested whether air pollution is statistically correlated to first time diagnosis of Chronic Obstructive Pulmonary Disease (COPD). The survey participants are found to have the relative risk of 1.08 for interquartile range of 5.8 microgram/m^3 based on Cox proportional hazard model.

Beelen et al. (2008) analyzed 120,852 subjects in the Dutch cohort study. These individuals were exposed

[2] There are some exceptions. For example, Friedman and his colleagues (2001) studied impacts of traffic-related pollution on emergency hospital visits by comparing periods during and after Atlanta summer Olympic Games in 1996. There was a voluntary traffic reducing campaign during the Olympic Games. This is sort of a natural experiment research design. Streets and his colleagues (2007) conducted a research using the data in both during and after Beijing Olympic Games in 2012, though this time, the City of Beijing heavily regulated auto use on roads. However, this research design is highly rare, simply because natural experiments do not happen very frequently.

to air pollution from nearby traffic from 1987 to 1996, and their health outcomes were recorded for the same time period. Their respiratory-related mortality is found to be statistically associated with their long-term average NO2 concentration. For 30 microgram/m^3, their relative risk was 1.37 based on Cox proportional hazard model.

Brook et al. (2008) analyzed patients who were over 40 year old and attended two respiratory clinics in Hamilton (sample size 5228) and Toronto (sample size 2406), Canada. Though these individuals' medical records were between 1992 and 1999, their estimated exposure to annual average NO_2 concentration levels was calculated for 2002 and 2004 due to lack of relevant data. For a very small difference in NO_2 such as 1 ppb (or 1.88 microgram/m^3), female patients showed a statistically significant odds ratio of 1.04 based on logistic regression model.

Fusco et al. (2001) collected records of all hospital admissions between 1995 and 1997 in the Lazio region, Italy. Their dataset covered approximately 96% of public and private hospitals in the region. Fusco et al. analyzed the relationship between daily mean levels of NO_2 and percent increases in daily hospital admissions for acute respiratory infections by patients in all ages. The researchers found that for every interquartile range increase of 22.3 microgram/m^3, the percent of hospital admissions for acute respiratory infections rose by 3.9%.

Kim et al. (2004) reported their analysis on impacts of NO_2 on physician-confirmed asthma of elementary school children in the San Francisco metropolitan area in the spring 2001. The subjects were the 3rd to 5th graders in 10 schools, and their doctor-diagnosed asthma in the past 12 months was the health outcome in interest. Kim and the colleagues calculated the annual NO_2 concentration levels by averaging 11 observations in the spring (March to June) and another 8 observations in the fall (September to November) in 2001. They found that for female children who had lived at their addresses more than 1 years at the time of study, the interquartile range of 3.6 ppb, or 6.8 microgram/m^3, is statistically related to asthma diagnosis with the odd ratio of 1.09 based on logistic regression model.

McConnell et al. (2010) analyzed 2,497 kindergarteners and 1st graders who were part of the Southern California Children's Health study. These children did not have any symptoms related to asthma or wheezing at the time of their entry to the study, so any incidences after that time were considered to be statistically associated to air pollution due to traffic when other control variables are accounted for. The Southern California Children's Health study started in 2002, and individual children were enrolled between 2002 and 2003 to this study. The health outcome was parent-reported physician diagnosis of new-onset asthma during three years of follow-up study, and the sample size was 120. The researchers found that 23.6 ppb or 44.4 microgram/m^3 is statistically correlated to asthma incidence with the relative risk of 2.17 based on Cox proportional hazard model.

Rosenlund et al. (2008) studied the relationship between NO2 levels and second time occurrence of coronary heart disease for those who already experienced the first occurrence recently (in 28 days). The research team collected data of all residents in Rome between 35 and 84 year old during the period of 1998-2000. Their exposure period was from 1995 to 1996, which was a few years ahead, and it was assumed that the NO2 concentration levels, to be specific the annual mean levels, did not differ much between the exposure period (1995-1996) and response period (1998-2000). 10 microgram/m^3 difference in the annual NO2 level was found to be statistically associated with out-of-hospital death after the first occurrence of coronary heart disease in 28 days with the relative risk of 1.08 based on Cox proportional hazard model.

Impacts of PM_{10} from traffic on health outcomes

Abbey et al. (1999) published a paper analyzing impacts of PM10 concentration around residence on multiple causes of death including nonmalignant respiratory diseases and lung cancer. As explained above, their research included a cohort of 6,338 nonsmoking non-Hispanic white Seventh-day Adventists (SDA) in the state of California. These subjects were enrolled into the study in 1977 when they were between 27 to 95 years old. Again, the exposure period was between 1973 and 1992, and the response period was between 1977 and 1992. The lung cancer death for female had the relative risk of 3.36 in response to an interquartile range of 24.1 microgram/m^3 difference in PM10.

Atkinson et al. (2001) studies the relationship between PM_{10} levels and daily respiratory admissions in 8 European cities in the second phase of Air Pollution and Health: A European Approach (APHEA) project. The researchers classified patients into three age groups, 0-14, 15-64, and over 64, and analyzed asthma related hospital admissions. 10 microgram/m^3 increase in PM_{10} was associated with 1.3% rise in admission for kids under 15, 1.1% for those between 15 and 64, and 0.8% for seniors over 64. It appeared that different age groups were affected in different sizes, implying that more focus should be put on “vulnerable” subgroups of people in the total population.

Barnett et al. (2005) also analyzed percent increase in hospital admissions in response to change in PM_{10} levels. They collected data from five Australian cities and another two cities in New Zealand between 1998 and 2001. The researchers included other pollutants such as SO2 in their model to tease out the specific effects by PM10 on the admission counts. They found that 7.5 microgram/m^3 increase in PM_{10}, which is calculated as an average increase of the current day over the previous day, is statistically correlated to more respiratory hospital admissions of children between 1 and 4 years old by 3.2%, and of children between 5 and 14 years old by 3.6%.

Kunzli et al. (2000) reported their analysis of annual mean PM_{10} levels and their impacts on a few number of health outcomes such as death, respiratory hospital admissions, cardiovascular hospital admissions, bronchitis incidence, restricted activity days, and asthma attacks. The subjects in the dataset were in Austria, France, and Switzerland in 1996. The researchers found that a 10 microgram/m^3 increase in the annual PM10 level is associated with a higher chance of death (RR=1.043), a higher chance of respiratory hospital admissions (RR=1.013), a higher chance of cardiovascular hospital admissions (RR=1.013), a higher chance of chronic-bronchitis incidence for adults over 24 years old (RR=1.098), a higher chance of bronchitis episodes for children under 15 (RR=1.306), a higher restricted activity days per person and per year (RR=1.094), a higher chance of asthma attacks for children under 15 (RR=1.044), and a higher chance of asthma attack for adults over 14 (RR=1.039). It is very common to see a higher risk of exposure to traffic-related air pollution for children under 15, compared to all other age groups or the middle age group between 15 and 65.

Kunzil et al. (2009) analyzed the relation between temporal changes in traffic-inducing PM_{10} and their impacts on asthma incidence during the same time period. The subjects were 2,725 never-smokers without asthma in SAPALDIA cohort study at their entry in 1991, and their asthma incidences were collected up to 2002. The research revealed that a 1 microgram/m^3 change in PM_{10} between 1991 and 2002 is associated with a higher chance of having asthma in the study period (RR=1.30). In other words, those whose neighborhood air quality worsened in 2002 were found to have more asthma than those whose air pollution levels were the same as 1991. This is another evidence supporting the association of traffic-induced air pollution and public health outcome.

Impacts of PM2.5 from traffic on health outcomes

Barnett et al. (2005) tested whether $PM_{2.5}$ affected respiratory hospital admissions in five cities in Australia and two cities in New Zealand. The 24 hour $PM_{2.5}$ levels were calculated for the period from 1998 to 2001, and respiratory hospital admissions by young children under 5 were analyzed in this research. The interquartile range increase in a daily $PM_{2.5}$ levels over its previous day is correlated to a 3.1% rise in hospital admissions by children under 1, and a 2.9% rise by children between 1 and 4. This research clearly shows young children and in particular infants are much more vulnerable to air pollution than any other age groups.

Boldo et al. (2006) conducted a meta-analysis of the 23 European cities that are part of Air Pollution and Health: A European Information System (APHEIS). According to their findings, a 10 microgram/m^3 increase in the annual average $PM_{2.5}$ level is associated with a higher chance of mortality (RR=1.06), a higher chance of cardiopulmonary death (RR=1.09), and a higher chance of dying of lung cancer (RR=1.14). Note that the closer a specific type of mortality seems related to traffic-induced air pollution, the higher its relative risk, or its (more) chance of occurrence, is. In other words, though air pollution from traffic induces lung cancer, and pulmonary and cardiovascular diseases (direct health effects), it also affects general mortality in a nontrivial size (indirect health effects).

Brauer et al. (2006) analyzed a rich and unique data set of 3,700 children in the Prevention and Incidence of Asthma and Mite Allergy (PIAMA) study in the Netherlands. In the study, pregnant women were recruited during their 2nd trimester in 1997 and 1998, and their children had follow-up surveys for the next eight years. When these children turned to age two, parents were asked about a variety of health issues with their children, and any otitis and respiratory infections diagnosed by physicians were reported. The research found that the interquartile range increase of 3.2 microgram/m^3 in the long-term average $PM_{2.5}$ level is correlated to an odds ratio of 1.13, implying higher chance of having these health outcomes for the young children.

Brauer et al. (2007) reported another analysis using the same data set, but with a difference focus of asthma incidence by the age of four. The interquartile range increase of 3.3 microgram/m^3 in annual $PM_{2.5}$ level at the birth address is associated with an odds ratio of 1.32, implying higher chance of experiencing asthma in their first four years of life.

Gehring et al. (2010) analyzed the same data set, and they used the full set of 8 year follow up. The subjects were 3,863 children in the PIAMA study in the Netherlands, and the results were comparable in terms of the size of health impacts to the previous two studies conducted by Brauer and his colleagues. During the first 8 years of life, prevalent asthma had a higher chance of occurrence (OR=1.26) for those who children who were exposed to a higher $PM_{2.5}$ levels at their birth addresses by 3.2 microgram/m^3, incident asthma had an odds ratio of 1.28, and asthma symptoms had an odds ratio of 1.15.

Laden et al. (2006) followed the 8,086 Caucasian participants who lived in the six US cities from 1974 to 1998, and enrolled in the so-called Harvard Six Cities study (Watertown, MA; Kingston and Harriman, TN; St. Louis, MO; Steubenville, OH; Portage, Wyocena, and Pardeeville, WI; and Topeka, KS). Their causes of death were analyzed in relation to their exposure to $PM_{2.5}$ (annual average for individual cities). A 10 microgram/m^3 difference in the annual city-level $PM_{2.5}$ level is statistically associated with a relative risk of 1.16 in total mortality, and a relative risk of 1.28 in cardiovascular-related mortality (statistically significant at the 95% confidence level). Again, air pollutants from automobiles appear to have indirect (overall mortality) and direct (cardiovascular mortality) effects.

Literature Review on Emission Factors

This section covers the review of the recent literature on the emission factors of freight and passenger vehicles that were actually driven on roads. The emission factors reviewed in this section may be different from the ones that some transportation-induced air pollution simulation models use. Simulation models use the emission factors that were estimated based on vehicles being operated in experiment facilities, not in real road conditions. These emission factors have been critiqued for tending to underestimate actual amounts of air pollutants that are emitted when the same vehicles are driven on local road networks. For this reason, this section reviews recent findings on this topic, and suggests to use a specific set of emission factors that were estimated by employing better research design. Selection criteria for better design is explained below.

First, only recently published research articles were selected, because the regulations for traffic-related emissions (both in terms of vehicle technology and fuel standards) have become stricter over time. For example, in the US, authorities are finalizing a PM emissions standard for new heavy-duty engines of 0.01 grams per brake-horsepower-hour (g/bhp-hr), to take full effect for diesels in the 2007. These NO_x and NMHC standards will be phased in together between 2007 and 2020, for diesel engines. The new standards will result in substantial benefits to the public health and welfare through significant annual reductions in emissions for NO_x, PM, NHHC, carbon monoxide, sulfur dioxide, and air toxins (EPA, 2000).

Second, it is better to have a research design that directly compares near-road air pollutants concentration levels against background levels. There are a number of recently published articles that uses a research design by analyzing different air pollution levels between the entrance and the exit of a tunnel, when the tunnel has one-way roads (Ban-Weiss et al., 2008; Gillies, Gertler, Sagebiel, & Dippel, 2001; Kirchstetter, Harley, Kreisberg, Stolzenburg, & Hering, 1999; Kristensson et al., 2004; Lough et al., 2005; Martins et al., 2006; Sánchez-Ccoyllo et al., 2009). However, this research design is criticized because it does not capture actual "dilution" processes of air pollutants. In other words, the pollutant concentration levels at the exit of a tunnel are likely to be higher than the levels that are observed simply based on distance from line sources when there are no tunnels.

Third, having different traffic conditions in the same article is desirable: e.g. urban versus rural roads, and trucks versus non-trucks. This is because individual researches adopted different methods of observing traffic counts and estimating air pollutants levels, and there are often debates over which measurement methods would be the most accurate. Given that these methods may influence estimated levels of pollutants, it is difficult to directly compare one emission factor from an article to another emission factor from another article. For this reason, researchers often claim that their estimated emission factors are "within" the range of reports by other scholars, but do not attempt to find "the" most exact emission factors.

Note that it is assumed that emission factors in different countries would not differ much, especially among developed countries, because vehicle technology and fuel standards have been advancing in similar manners over time. However, it has been recognized that different weather and climate conditions do matter, and thus, emission factors can be different based on geographic locations. Yet in the developed countries in the globe, the emission factors are assumed not to differ much, as long as the local weather patterns are not extremely different (e.g. winter in Scandinavian countries versus summer in Florida, US). At least, we can safely claim that variation in emission factors due to varying local conditions would be much smaller than due to different years of study, research design, and measurement methods.

We reviewed the 41 recent journal articles that have been highly cited, and found that emission factors do differ by vehicle type (heavy-duty versus light-duty), average speed of the roads under study, traffic volume, fuel composition at the time of study, vehicle technology (e.g. having catalytic converters), weather (month of a year), and so forth. Among these, there is a single article that reports all the emission factors of NO_x and $PM_{2.5}$ for urban and rural roads by freight and passenger vehicles using the research design of near-road versus background comparison. Table 2.9 introduces three published journal articles that employed the most appropriate research design based on our criteria, and among them, this report chose to use the emission factors from the Wang et al. (2010).

Table 2.9: Literature with the most reliable research design

Citation	Country	Site	Time of a year	AADT	Average speed	AADDT	Vehicle Type	EF-PM2.5	EF-NOx
(Imhof et al., 2005)	Switzerland	Birrhard, Humlikon, & Weststrasse	June-August 2001, October 2001, & August-October 2002	62,000/day, 25,000/day, & 22,000/day	120/85, 85/75, & 0-50/-50 (km/h)	9.6 %, 12.5%, & 6.1%	HDV		8.7, 8.2, & 12.3 (g/km)
							LDV		0.59, 0.37, &0.35 (g/km)
(Jones & Harrison, 2006)	London, UK	London-Marylebone Road, LMR (urban street canyon)	2002-2003	80,000/day	<50 km/h	No info	HDV	0.179 (g/km)	
							LDV	0.01 (g/km)	
(Wang et al., 2010)	Copenhage, Denmark	Highway & Urban	March-April 2008	55,600/day & 60,000/day	110km/h (all) & 90 km/h (HDV), 40-50 km/h	8% & 5%	HDV	233 mg/km & 628 mg/km	9.8 g/km & 11.9 g/km
							LDV	11 mg/km & 20 mg/km	0.70 g/km & 0.46 g/km

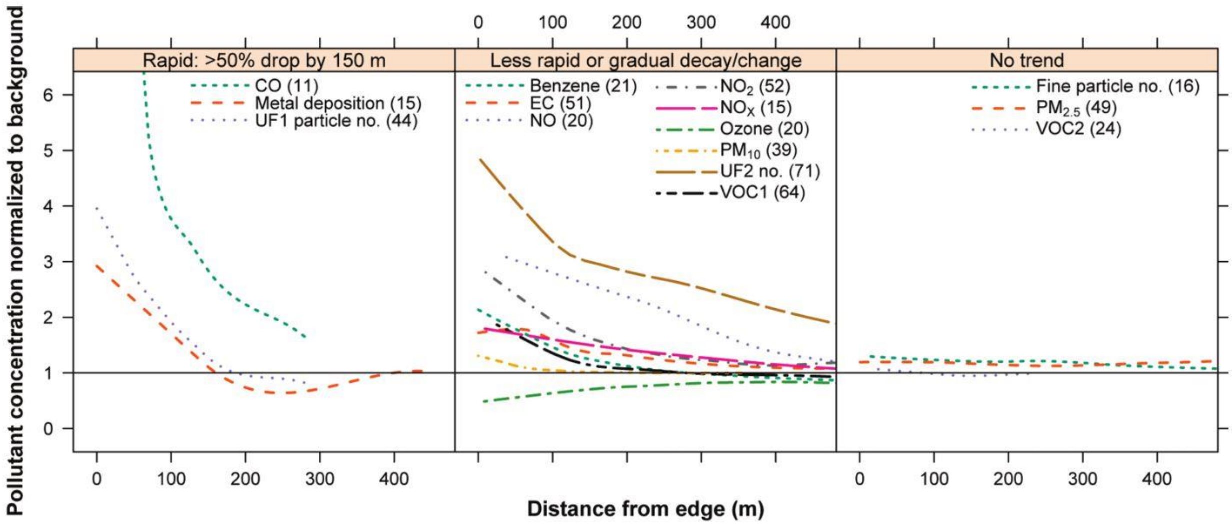
Imhof et al. (2005) estimated emission factors from a data set of pollutants levels and nearby traffic that were observed in 2001 to 2002 on Birrhard, Humlikon, and Weststrasse at the area of Zurich, Switzerland. They studied a four-lane motorway (two lanes for each direction) surrounded by flat agricultural lands without slope, buildings, and trees, a two-lane highway also surrounded by agricultural lands with slope less than 0.5%, and a one-way two-lane roadway in an urban canyon surrounded 10-to-20-meter buildings with frequent stops due to traffic signals and congestion. Their emission factors were within the range of what previous researchers published; however, their research did not include emission factors for $PM_{2.5}$ specifically, though PM_{10} and particle numbers were their main focus.

Two researchers at UK estimated emission factors by light- and heavy-duty vehicles on highly congested urban roads in London, UK, whose average speed fluctuated over a short distance of the roads (Jones &

Harrison, 2006). In doing so, firstly they calculated the total amounts of emissions of individual pollutants from vehicles (unit: $km^{-1}hour^{-1}$) by multiplying observed traffic counts (by type) and reported emission factors in the literature. Then, they regressed these total emissions on the numbers of heavy- and light-duty vehicles. In this process, it was assumed that other pollutants would disperse at the same rate as NO_x, and thus, the amounts of other pollutants were calculated based on their road-side concentration levels and sort of conversion factors related to NO_x. In other words, the authors did not use emission factors for other pollutants including $PM_{2.5}$ and PM_{10}. Though the research design used in this article is reliable, the researchers only estimated emission factors on a single place, urban roads, but did not include any suburban or rural counterparts.

In their paper, Wang and his colleagues analyzed traffic volume and pollutants concentration levels on two Danish roads, one highway and one urban road, and estimated emission factors for NO_x, $PM_{2.5}$, and PM_{10} (Wang et al., 2010). For the highway, they limited observations whose wind directions were between 105° and 225° to make sure that background levels are not affected by traffic on the roads, and they controlled the wind directions for the urban roads in the same manner. Their estimated emission factors for heavy duty vehicles are 9.8g/km·veh and 11.9 g/km·veh (NO_x for highway and urban), 233mg/km·veh and 628 mg/km·veh($PM_{2.5}$ for highway and urban). Their emission factors for heavy-duty vehicles are greater than light-duty vehicles including passenger vehicles by 20 times, and this has been supported by the literature. In this report, those emission factors are used due to their desirable research design, consistent with the literature, and completeness of their estimations for both urban and rural and trucks and non-trucks.

Another issue related to emission factors is to set a maximum distance from individual communities to the nearest roads, beyond which traffic-induced air pollution is diluted up to the background levels. Therefore, we also searched for the literature containing information on critical buffered areas that are severely affected by air pollution emitted from nearby traffic. This report uses a review paper by Karner and his colleagues, which synthesized findings from 41 empirical studies that had been conducted since 1978 (Karner, Eisinger, & Niemeier, 2010). Figure 2.2 shows that pollutants concentration levels near roads decreased gradually over the distance from the roads, and beyond 400 meters from the line sources of pollutants, the concentration levels became very close to background levels. In other words, a critical buffer along the Georgia Freight Corridor in terms of the key air pollutants in this report, NO_2 and $PM_{2.5}$, would be within this distance limit, and beyond it, it may be difficult to claim their pollutants concentration levels are due to traffic-induced air pollution (there can be other polluting sources such as power plants and manufacturing firms).



Note: The horizontal line indicates background concentration. A loess smoother (alpha=0.75, degree-1) is fitted to each pollutant which is placed into one of three groups. The regression sample size, n, is given in parentheses after each pollutant. (Karner et al., 2010)

Figure 2.2: Local Regression of Background Normalized Concentrations on Distance.

Though this report does not contain the analysis result, initially we added 150-meter buffer as "more" seriously affected communities, and then compared it to 150-400-meter buffer and 400 buffer (including both 150-meter buffer and 150-400-meter buffer). However, given that the Census block groups, the smallest geographic unit with estimates of subpopulations, are much bigger than the 400-meter buffered areas contained by those Census block groups, we did not find any significant differences between these small and large buffers, so this report only contains the analysis results for 400-meter buffers.

Mitigation of Community Impacts from Freight

NCHRP Synthesis 320 provides a comprehensive review of best practices used by freight operations companies and local governments to mitigate against the community impacts of freight (Weider, 2003). The recommendations offered in this report are multimodal focusing on both truck and rail freight movement. An alternative approach to quantifying the impacts of freight movement through communities could therefore involve measuring the extent to which communities are equipped to deal with key freight concerns. This approach would measure a community's resilience to freight impacts. A community that implements a larger number of best practices to solve or mitigate freight issue areas would therefore be more resilient to freight impacts and would potentially experience fewer negative effects. This approach, however, should not be based solely on quantity of practices but also on quality and fit of practices. For example, if the citizens of a community are most concerned about air quality impacts, the implementation of a policy to modify rail hour operations would improve concerns about noise and vibration but would not address the primary concern - air quality. The first step undertaken by community leaders should therefore be an inventory to identify key citizen concerns. Table 2.10 summarizes the past literature on mitigation strategies of freight impacts on communities.

Table 2.10: Freight Community Impact Mitigation Strategies

Issue Areas	Concerns	Examples of Mitigation Practices
Traffic Flow	Negative impacts of freight movement on overall traffic congestion	• Replacing and or closing at grade rail crossings • Developing separate truck access routes • Modifying rail hours of operation to minimize conflicts • Ban or limit trucks on certain routes
Safety and Security	The interaction between freight equipment and passenger vehicles and pedestrians The safe movement of hazardous materials Crime Terrorist acts	• Public education • Create a truck-based Highway Watch Program • Install updated rail barriers and no trespass signed • Install pedestrian barriers • Strengthen cargo inspection
Economic Development	Leveraging a region's freight transportation system to create economic value for the area, Adjusting the freight transportation system to permit the development of other types of property uses, and Increasing the efficiency of the freight system to in- crease the competitiveness of the area to attract and retain businesses.	• Relocating rail yards • Hiring locally • Creating neighborhood investment funds • Reuse of dredged materials
Air Quality and the Environment	Practices that reduce emissions or other impacts Reducing congestion and delays. Practices that promote the redevelopment of environmentally contaminated properties, facilitate the cleaning and re-use of contaminated material, and encourage continued use of industrial properties in urban areas	• Using lower emissions locomotives • Promoting the use of clean fuels • Encouraging the use of alternative fuel vehicles • Reducing truck idling times through policy and technology advances
Land Use and Value	Freight policies that support/increase property values rather than create blight and decreases values	• Modify hours of rail operation • Invest in Brownfield initiatives • Focus on maximizing the value of non-freight related land uses
Noise and Vibrations	Reduction of noise and vibrations from the movement and operation of freight facilities	• Modify hours of operation • Create no-whistle zones • Use low-emission locomotives and trucks reducing the need for idle times
Communication	The design of transportation facilities and solutions that incorporates the concerns, values, and views of all affected groups, with the goal of improving transport services for the most people while minimizing the project's impacts on the local communities and environment.	• Public education • Hire locally • Public Charrettes • Continuously engaging the public

Source: (Weider, 2003)

Funding is a major obstacle in this approach to dealing with the impact of freight movement. Communities that have taken steps to reduce the impacts of freight have done so using local funds. Private funds often contribute 1% to 2% of project budgets (Weider, 2003). There is little involvement from state or federal entities. Recommendations for improving funding availability include (Weider, 2003):

- Creating a dedicated funding source for freight projects at the state level
- Developing a coalition of freight funding consisting of state, local, federal and private sources of funding
- Pursuing the development of a freight transportation improvement program

Summary

The performance areas most often measured to quantify the community impacts of freight are economic, environmental, social, and health. These areas can be further broken down into subareas including land values, safety and security, traffic congestion, economic development and public involvement and communication. With the passage of MAP-21 there has been increased focus on defining a holistic approach to measuring freight performance. A holistic approach considers more than just the operational efficiency and effectiveness of freight-transportation but also takes into consideration community impacts. Limited data availability continues to hamper steps towards measuring community impacts of freight, and limited funding availability has challenged local efforts to implement best practices that reduce the impacts of freight. Measuring the impacts of pass through freight has also proven challenging. Ironically, rural and suburban communities that provide needed connection between major freight hubs and corridors often have the most vulnerable populations, benefit the least from freight movement that passes through their communities, and have the least amount of financial resources to minimize these impacts. Moving forward continued focus should be placed on holistic measures of performance, and added attention should be placed on not only roads within the primary freight network, but also on local rural, small urban, and suburban roadways that provide much needed freight connections.

SECTION III. BASELINE CONDITIONS

Geographical Spread of Rural and Small Urban Areas in Georgia

The Census Bureau defines two types of urban areas as Urbanized Areas (UAs) with population of at least 50,000 and Urban Clusters (UCs) with a population of over 2,500 but less than 50,000. All other areas are classified as rural (Census Bureau, 2015). Unincorporated areas containing a settled concentration of population are defined as Census Designated Places (CDPs). CDPs may be located inside or outside of UAs and UCs, and have no population requirement (Census Bureau, 2012).

Of Georgia's sixteen UAs, seven including Atlanta are clustered in the northwestern area of the state. Georgia's 106 UCs are more evenly distributed throughout the state. Out of Georgia's 626 CDPs, roughly 16% are contained within or overlap with the Atlanta UA, and the rest are more evenly distributed throughout the state.

To define the study area, census block groups were classified as urban, small urban, or rural according to classification scheme in Table 3.1. A designation of "1" indicates that the block group intersects a UA, UC, and/or CDP boundary, and the value 0 indicates no intersection. Block groups fully or partially contained within a UA and/or UC and/or CDP were classified as urban. Including partially contained block groups whose areas extended beyond UA, UC, or CDP boundaries lead to the consolidation of urban block groups into ten major urban areas. Block groups located outside of UAs but overlapping with UCs or CDPs were classified as small urban. All other block groups, including those outside of UAs and UCs but overlapping with CDPs were classified as rural. The geographic distribution of these areas in Georgia is shown in Figure 3.1. Urban block groups are much smaller than rural block groups, resulting in denser block boundaries. Therefore, for clarity of presentation, urban block groups have been aggregated.

Table 3.1: Logic Table for Urban, Small Urban, Rural Classifications

	UA	UC	CDP
Urban	1	1	1
	1	1	0
	1	0	1
	1	0	0
Small Urban	0	1	1
	0	1	0
Rural	0	0	1
	0	0	0

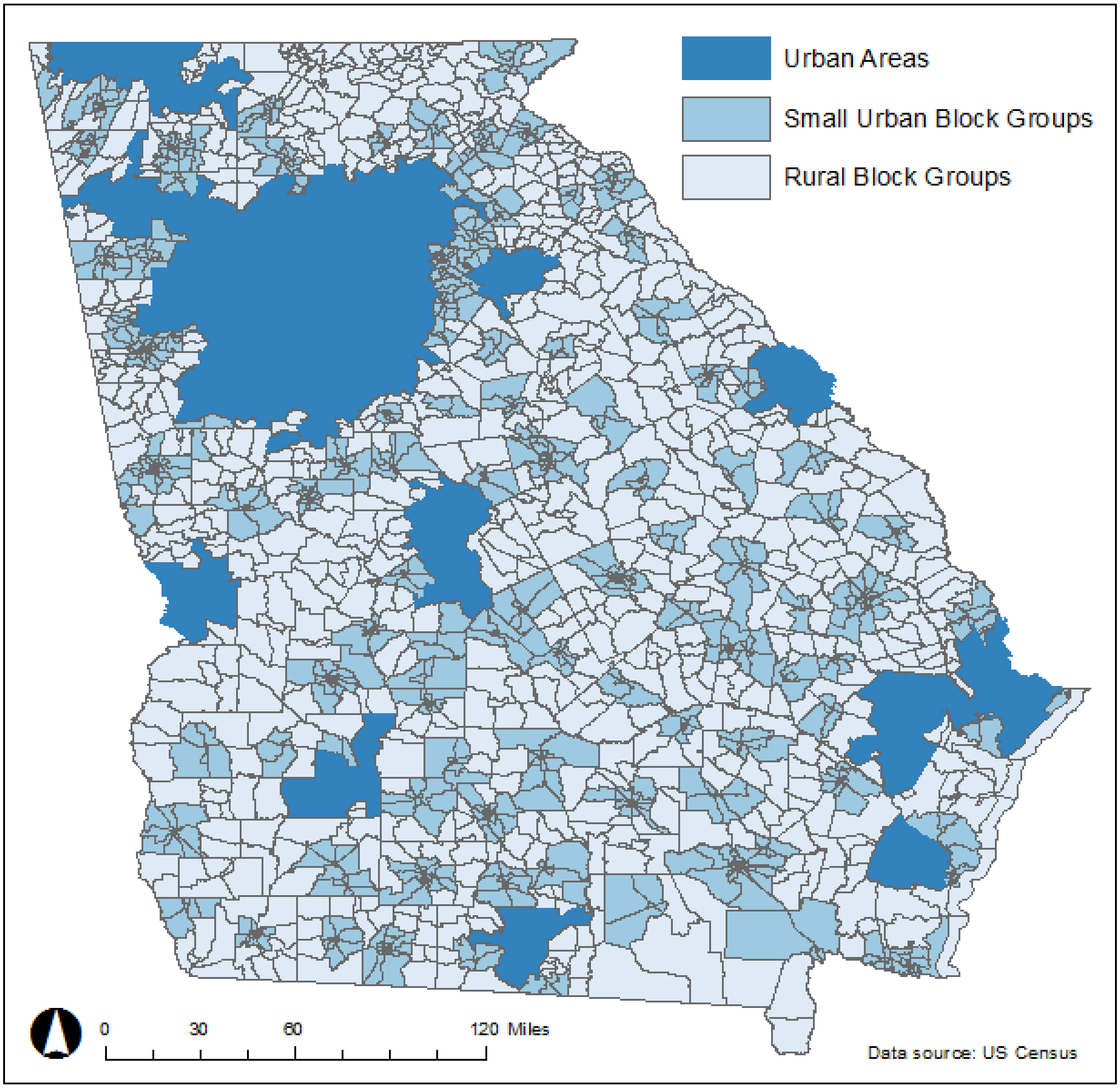


Figure 3.1. Urban Areas, and Small Urban and Rural Census Block Groups

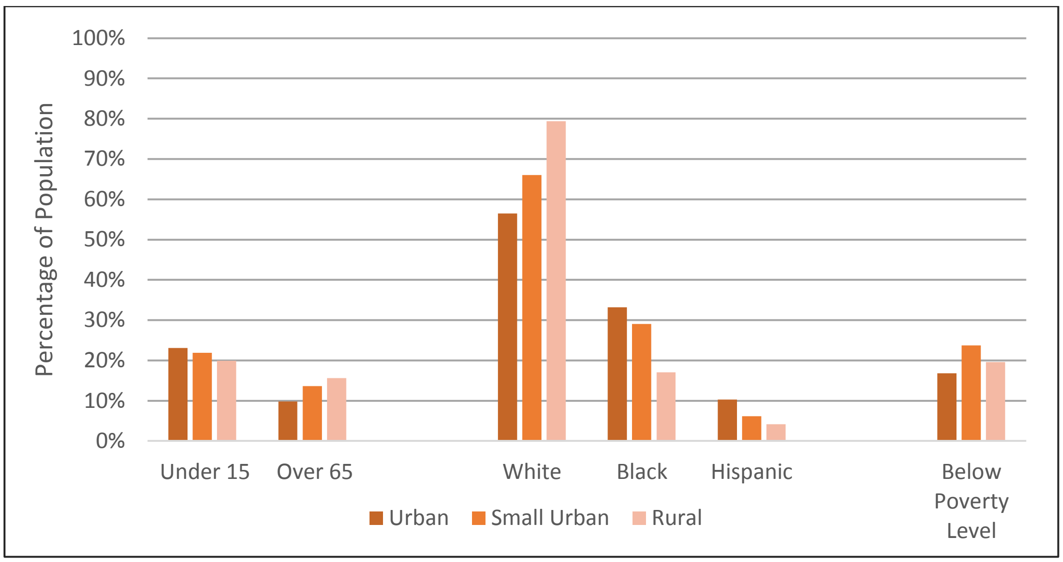
Demographic and Socio-Economic Characteristics of Small Urban and Rural Areas in Georgia

Georgia's rural and small urban areas are home to over 1 million and 1.5 million residents, respectively. Rural and small urban populations tend to be proportionally older, more white, and poorer than in urban areas. Table 3.2 summarizes and Figure 3.2 visualizes the demographic characteristics of Georgia. Rural areas have the lowest proportion of residents under the age of 15 and the highest proportion of residents over the age of 65. The proportion of the population that is white increases by 22% from urban to rural areas; likewise, the proportion of the population that is black and Hispanic decreases by 16% and 6%, respectively. Small urban areas have the highest proportion of individuals (24%) living below the poverty line.

Table 3.2: Age, Race, and Poverty Level by Urbanization Class

	Age (Percentage of Population)		Race/Ethnicity (Percentage of Population)			Poverty (Percentage of Population)
Urbanization Class	Under 15	Over 65	White	Black	Hispanic	Below Poverty Level
Urban	23%	10%	57%	33%	10%	17%
Small Urban	22%	14%	66%	29%	6%	24%
Rural	20%	16%	79%	17%	4%	20%

Source: U.S. Census Bureau



Source: U.S. Census Bureau

Figure 3.2. Age, Race, and Poverty Level by Urbanization Class

Freight Transportation in Georgia

Understanding the impacts of freight on small urban and rural populations requires an overview of freight movement across the state. In Georgia, freight goods are moved by three primary modes of transportation: highway, rail, and air. Freight transportation is an important component of Georgia's economy. In 2007, freight related industries were responsible for 25% of Georgia's $380 billion gross state product (GDOT, 2011). Freight flows in Georgia consist of over $634 million tons per year, and nearly one-third of the tonnage travelling through Georgia has neither origin nor destination in Georgia (VLMPO, 2009). Communities within Georgia are therefore highly subject to pass-through freight; which is freight that moves through a community without origin or destination within that community. In 2035, nearly 29 percent of the freight tonnage and 33 percent of the value of freight moving on the transportation network in Georgia is forecasted to have neither an origin nor a destination in the State (GDOT, 2006). Freight moves through Georgia using a system of strategic highway corridors. These highway corridors play a critical role in supporting freight industries and in freight mobility – movement of goods from suppliers to customers. The most significant freight flows into the State can be categorized under one of the seven following classifications categories (a) Savannah-to-Atlanta corridor, (b) Atlanta-to-Tennessee Corridor – Gateway to the Midwest, (c) Atlanta-to-South Carolina Corridor-Gateway to the Mid-Atlantic and Midwest (d) Macon-to-Florida Corridor – Connection to the U.S.'s fourth largest economy (e) Atlanta-to-Alabama Corridor (f) Through Freight Corridors, and (g) Small Urban and Rural Freight Corridors (GDOT, 2013b). Figure 3.3 shows the system of significant highway corridors used to move freight throughout the state. All of the interstates function both as strategic corridors (a–e outlined above) and as through corridors.

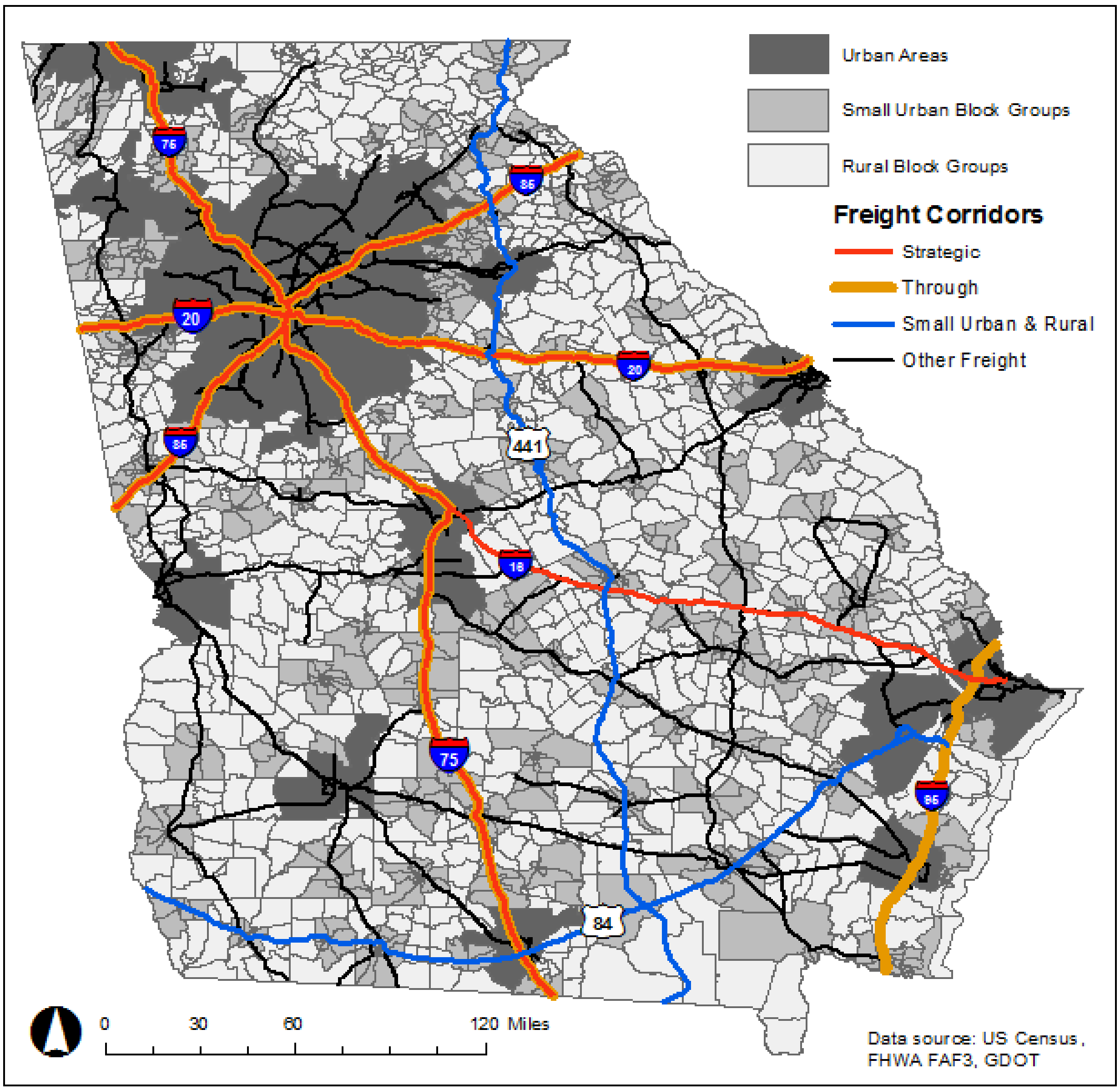


Figure 3.3. Major Georgia Freight Corridors

The strategic, through, small urban and rural, and other freight corridors pictured in Figure 3.3 comprise the Georgia Freight Corridor used in this study.

Traffic and truck volumes and truck tonnages vary by type of freight corridor, with the interstates (five strategic corridors and the through corridors) carrying the largest volumes and tonnages. Table 3.3 below shows volumes and tonnages for each corridor type. The Atlanta-to-South Carolina and the Atlanta-to-Alabama corridors are composed of two routes that diverge as they leave the Atlanta metropolitan area but head in the same east or west direction. The Savannah-to- Atlanta Corridor is composed of two continuous routes, with northbound I-16 feeding into I-75. In addition to the Florida-to-South Carolina through corridor, the combination of strategic corridors such as the entire lengths of I-20, I-75, and I-85 in Georgia serve as through corridors. Small urban and rural corridors along U.S. Routes also carry freight, but trucks makes up a smaller proportion of total traffic volumes (see Table 3.3).

Table 3.3: Traffic Volume, Truck Volume, and Truck Tonnage on Georgia Freight Corridors (For the Year 2007)

		AADT (volume/day)			AADTT (trucks/day)			YKTONS (annual truck tonnage in Kilo Tons)		
Corridor	**Route**	Average	Min	Max	Average	Min	Max	Average	Min	Max
Strategic Freight Corridors										
Atlanta to South Carolina	**I-20**	67,791	21,740	180,900	11,472	3,568	32,890	34,748	3,214	49,883
	I-85	138,043	37,570	247,172	23,628	7,337	46,725	50,555	44	108,870
Atlanta to Alabama	**I-20**	95,096	31,520	162,924	17,365	7,550	28,597	29,876	4,961	61,489
	I-85	67,008	24,357	122,174	12,001	5,066	22,361	38,779	1,154	136,624
Atlanta to Tennessee	**I-75**	106,733	53,228	250,037	16,018	5,808	38,102	93,765	59,496	148,712
Savannah to Atlanta	**I-16 to I-75**	77,813	15,100	284,100	13,765	3,245	48,347	43,051	47	114,342
	I-16	26,278	15,100	68,542	5,565	3,245	16,035	30,364	10,739	46,515
	I-75	135,017	36,059	284,100	22,867	6,089	48,347	59,055	47	114,342
Macon to Florida	**I-75**	47,317	34,507	75,670	8,943	5,769	15,636	66,056	14,641	92,357
Through Freight Corridors										
Florida to South Carolina	**I-95**	51,284	40,050	69,775	8,696	5,664	15,716	41,125	33,485	50,216
Small Urban and Rural Freight Corridors										
Savannah to Alabama	**U.S. 84**	11,911	1,400	36,708	1,653	140	3,810	2,503	31	4,958
Florida to Tennessee	**U.S. 441**	10,234	863	39,700	1,189	125	3,282	2,418	24	11,299

Source: FAF3 Network Database, GDOT Statewide Freight & Logistics Action Plan

Figure 3.4 shows the variation in total traffic volume on the Georgia freight network. Most congested parts of these corridors are concentrated in the Atlanta urban area carrying an average of 50,000 to nearly 300,000 vehicles per day. These interstates also bring an average of 20,000 to 50,000 vehicles per day through small urban and rural areas as they cross to neighboring states.

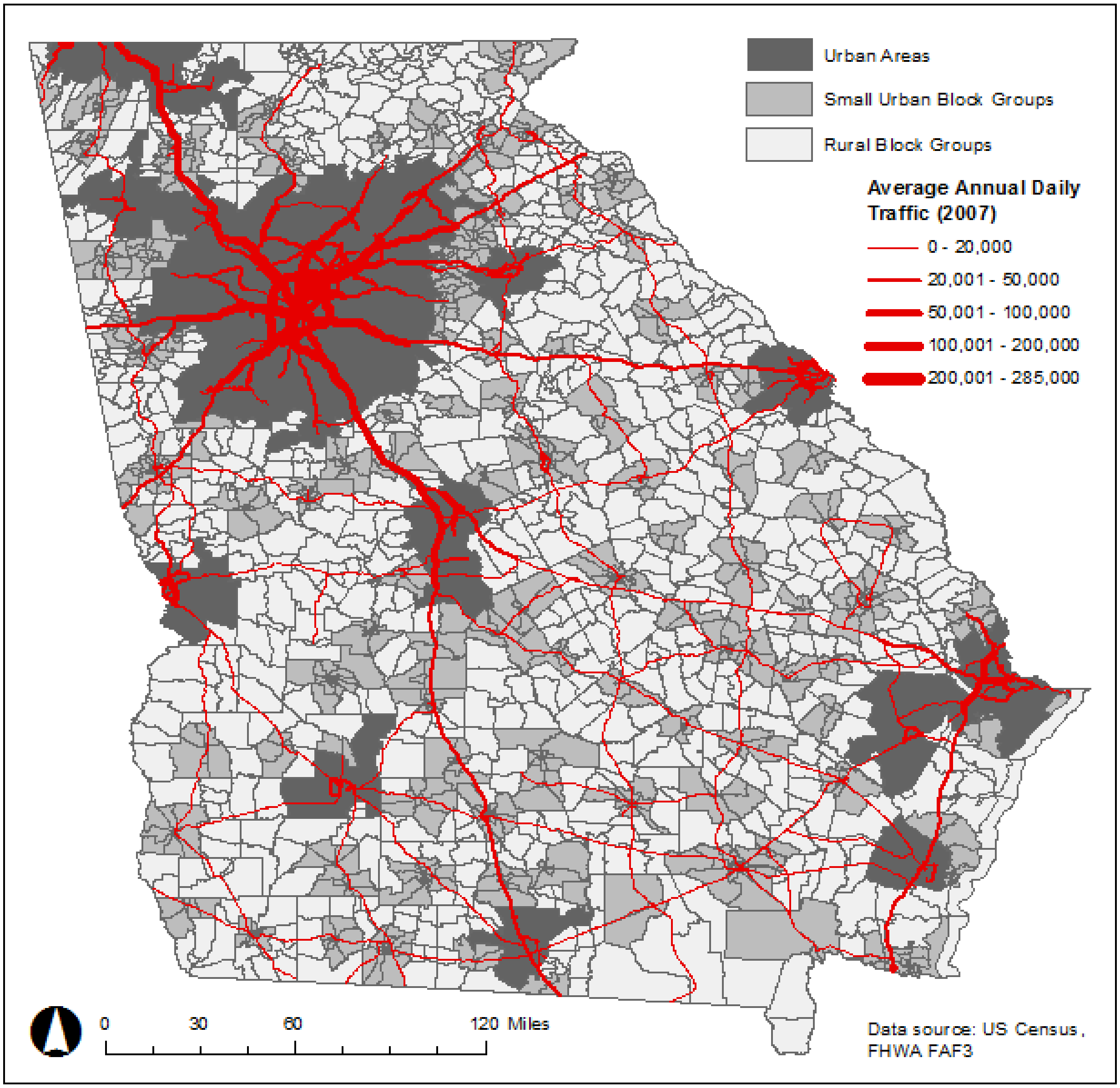


Figure 3.4. Traffic Volume (AADT)

Figure 3.5 shows truck volumes on the Georgia freight network. As evident from this figure, the truck volumes are also highest in the Atlanta urban area, reaching an average of 50,000 trucks per day. An average of 15,000 to 25,000 trucks move not only through Atlanta, Macon, and Savannah urban areas, but also through small urban and rural areas on the way to all neighboring states.

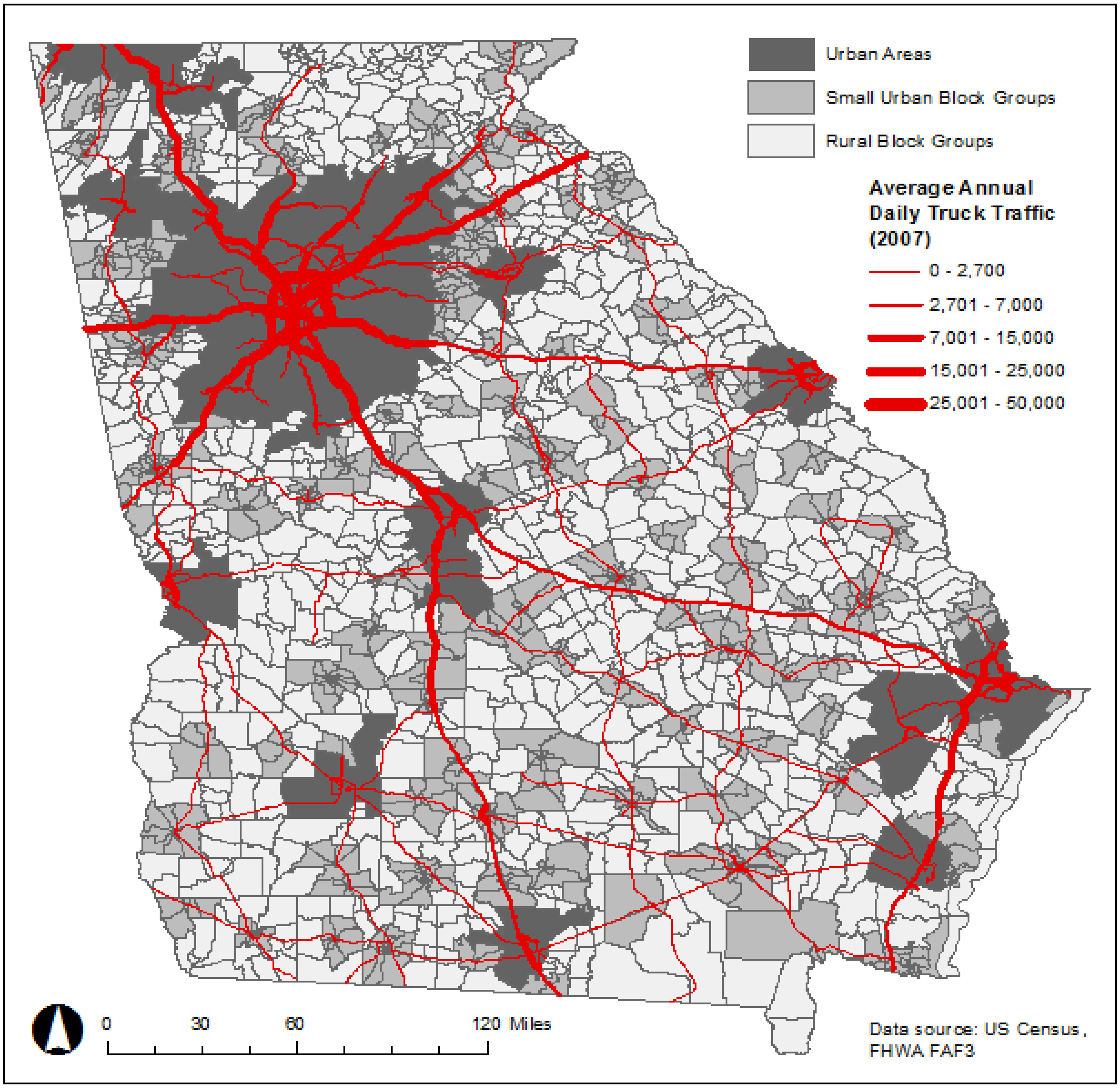


Figure 3.5. Truck Volume (AADTT)

Table 3.4: Volume to Capacity Ratio, Speed, and Delay on Georgia Freight Corridors (Year 2007)

		VCR (volume to capacity ratio)			SPEED (miles/hour)			DELAY (peak period link delay in hours)		
Corridor	**Route**	Average	Min	Max	Average	Min	Max	Average	Min	Max
Strategic Freight Corridors										
Atlanta to South Carolina	**I-20**	0.66	0.40	1.36	59.19	0.06	73.06	0.02	0.00	0.36
	I-85	0.93	0.41	2.077	45.52	0.00	73.07	0.11	0.00	1.08
Atlanta to Alabama	**I-20**	0.82	0.53	1.212	56.43	0.36	72.92	0.01	0.00	0.21
	I-85	0.67	0.41	1.107	59.22	4.22	73.06	0.00	0.00	0.11
Atlanta to Tennessee	**I-75**	0.70	0.47	1.12	56.65	0.93	73.06	0.00	0.00	0.12
Savannah to Atlanta	**I-16 to I-75**	0.61	0.20	1.21	59.81	0.04	78.08	0.01	0.00	0.21
	I-16	0.44	0.20	0.97	65.60	45.80	78.08	0.00	0.00	0.00
	I-75	0.79	0.40	1.21	53.38	0.04	73.03	0.01	0.00	0.21
Macon to Florida	**I-75**	0.54	0.30	0.92	62.18	54.16	78.08	0.00	0.00	0.00
Through Freight Corridors										
Florida to South Carolina	**I-95**	0.64	0.34	1.18	60.12	1.82	73.06	0.01	0.00	0.18
Small Urban and Rural Freight Corridors										
Savannah to Alabama	**U.S. 84**	0.20	0.04	1.18	44.62	2.20	55.44	0.01	0.00	0.23
Florida to Tennessee	**U.S. 441**	0.24	0.03	0.95	44.09	23.50	53.20	0.00	0.00	0.16

Source: FAF3 Network Database, GDOT Statewide Freight & Logistics Action Plan

Table 3.4 presents three important characteristics of important Georgia freight routes namely, volume to capacity ratio (VCR), speed, and peak period delays. As evident from Table 3.4, the interstate highway system experiences the highest speeds and are near to reaching capacity compared to small urban and rural routes.

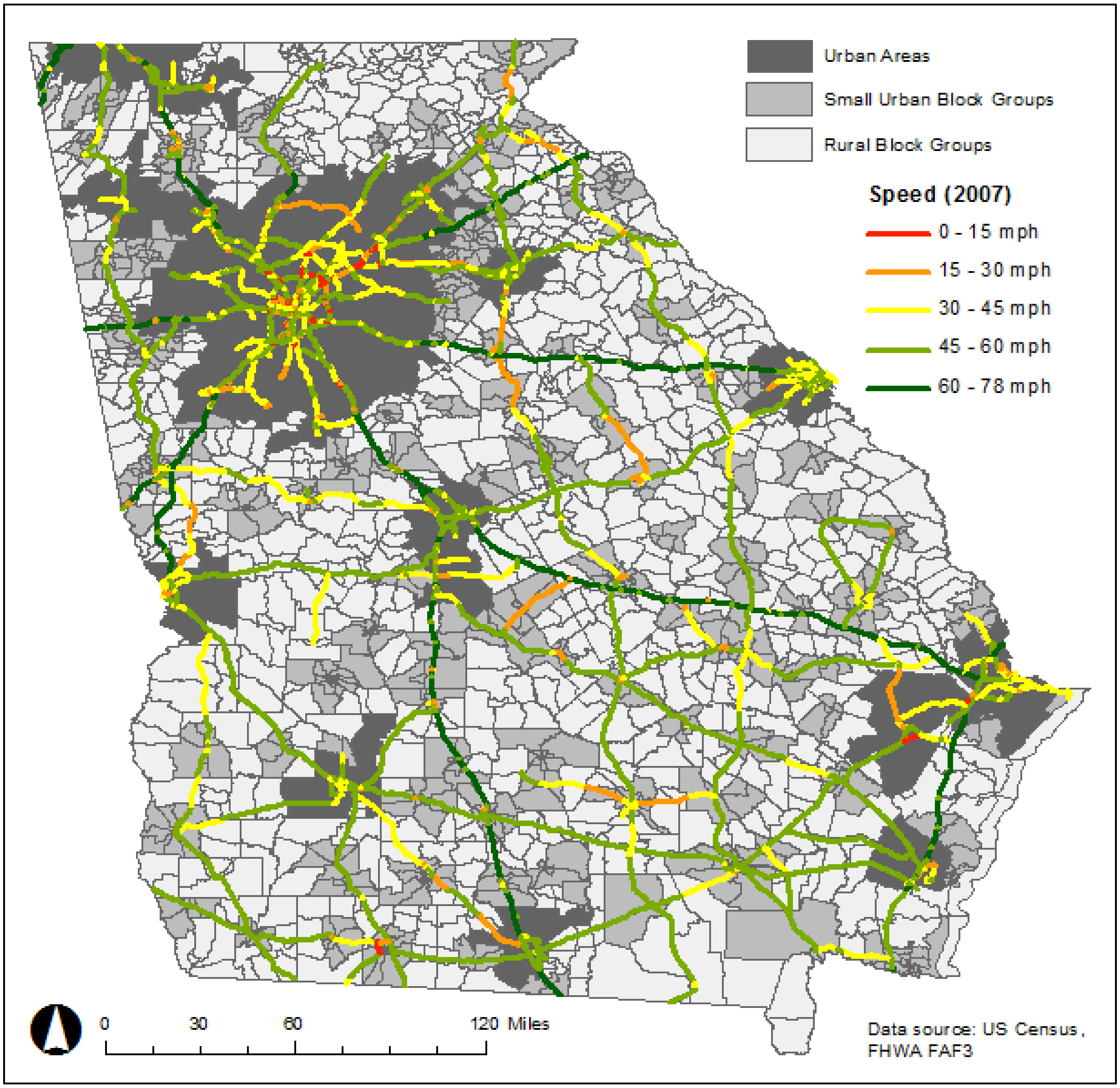


Figure 3.6. Average Truck Speed

Small urban and rural areas experience interstate traffic moving at the highest average truck speeds relative to other areas of the state as shown in Figure 3.6. Some small urban and rural areas also experience slower truck speeds, whether due to congestion or smaller roadways, but speed is less variable compared to the hotspots of congestion visible in the Atlanta urban area.

Figure 3.7 shows the spatial pattern of volume to capacity ratio along fright network in Georgia. The figure depicts that nearly all corridors moving through small urban and rural areas are not at full capacity, with the exception of certain interstate segments. Urban areas, in contrast, exhibit greater variability in volume to capacity ratio and have more corridor segments that are overcapacity.

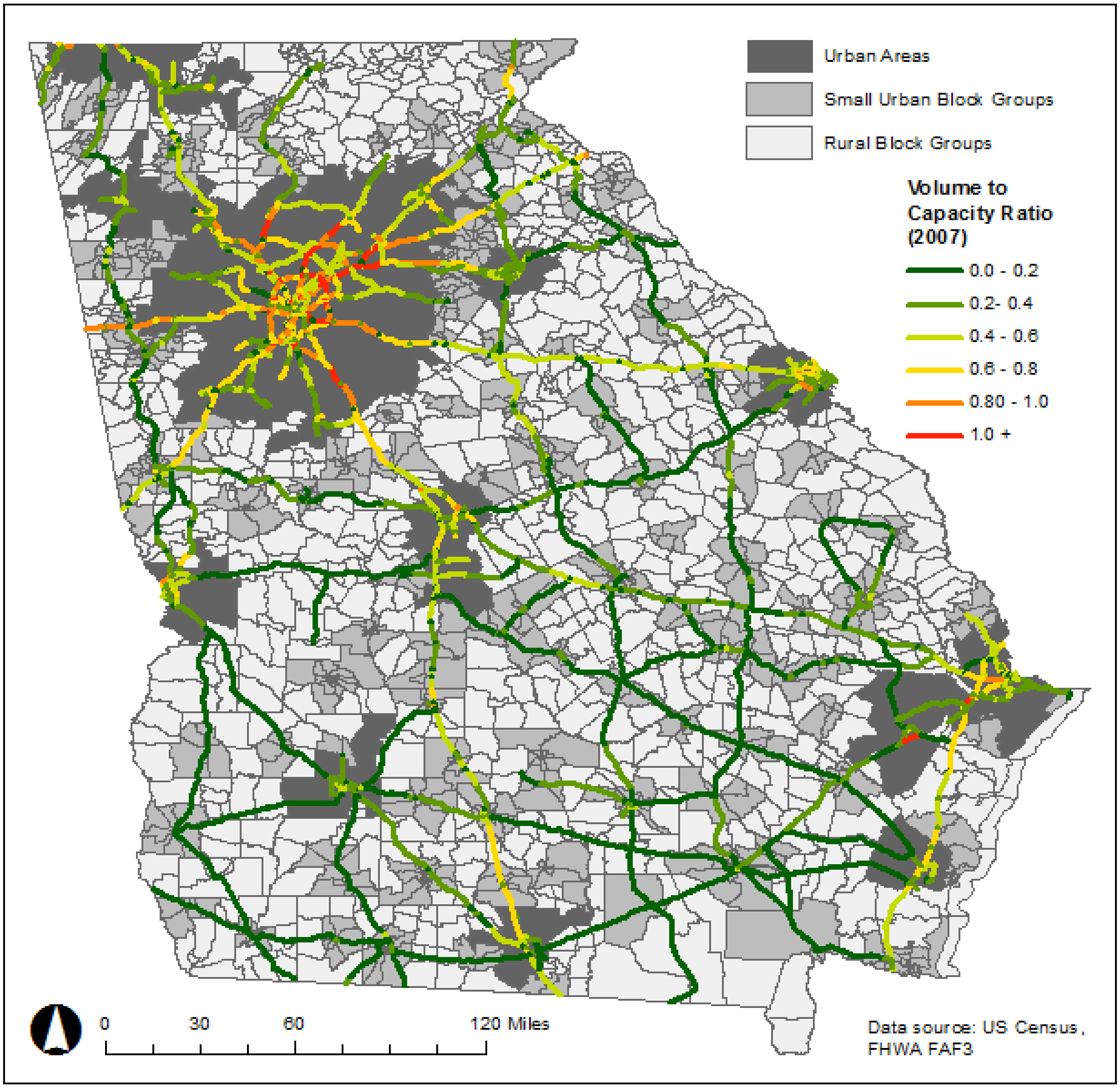


Figure 3.7. Volume to Capacity Ratio

In addition to the major corridors identified by GDOT, freight also travels through the state using a network of collectors, arterials, and urban and rural local roads (but not included in this study due to lack of data). For example in the Valdosta MPO planning area, U.S. 41/GA-7 or the Inner Perimeter Highway runs parallel to I-75, carrying freight through local communities (VLMPO, 2009).

The Governor's Road Improvement Program (GRIP) has supported rural economic development by improving connectivity of state highways since 1989. Roadways improvements through GRIP benefit trucks with origins or destinations in rural areas (GDOT, 2013a). The two small urban and rural freight corridors, U.S. 84 and U.S. 441, both have active GRIP projects to replace 2-lane highways with four lanes, and they were 91% and 53% completed, respectively, as of January 2015 (GDOT, 2015). While road improvements may increase safety, they could also lead to higher truck volumes and resultant air quality issues.

SECTION IV. METHODOLOGY

Introduction

The major goal of this study was to analyze the health impacts by traffic-induced pollutants on small urban and rural communities in the State of Georgia. This goal has been achieved by completing a set of tasks sequentially; first, specific air pollution levels of those communities along Georgia Freight Corridor were estimated (step I through III in Figure 4.1), and second, health risks associated with those pollutants concentration levels were evaluated for all the residents in the communities and for particular subgroups; e.g. children, seniors, racial/ethnic minority, and people under poverty (step IV in Figure 4.1).

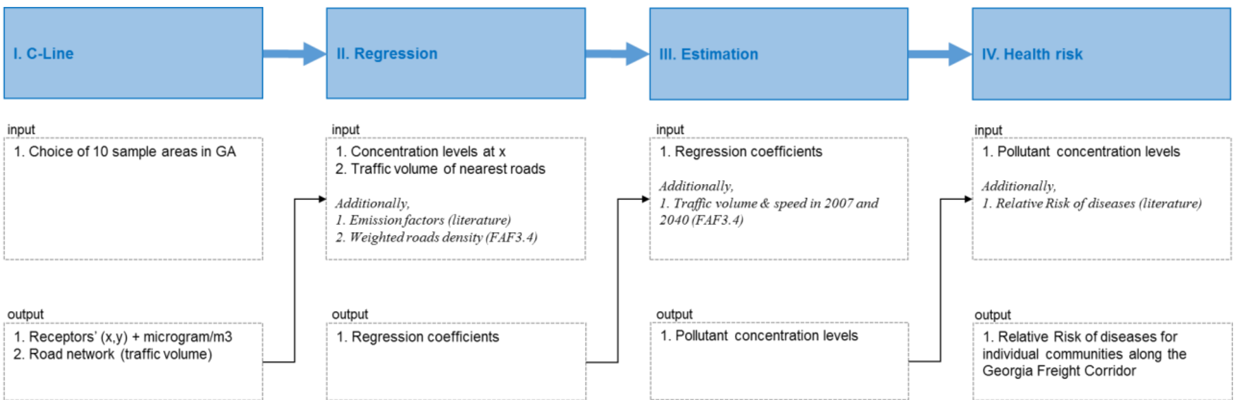


Figure 4.1 Methodological Framework

To estimate the concentration levels of the key pollutants, NO_x and $PM_{2.5}$, this study uses a multi-stage approach while overcoming obstacles due to limited resources and data. At the stage I, a specific air quality model, called Community Line Source Model, or C-Line, is employed to obtain a basic data set of pollutants concentration levels and nearby freight movement. At the stage II, the least squares regression is run to obtain the statistical relationship between total air pollution emitted from certain road links and air pollution levels of nearby communities. At the stage III, this relationship (to be specific, the regression coefficients) is used to estimate pollutant concentration levels along Georgia Freight Corridor for the year 2007 and to forecast pollutant concentration levels for the year 2040. This allows for analysis of any temporal changes in air pollution in individual communities.

This sequential process may seem more complicated than a process using only a single technique, either simulation or statistical modeling; however, given the complexity of the research goal, this integrated process is necessary. First of all, regional air quality simulation models require a different kinds of input, among which traffic characteristics such as traffic counts and average speed on individual road segments are essential. Given that air quality models use an external data set for these information, two data sets (each for 2007 or 2040) for the *same* road network are necessary. Unfortunately, the road networks used in C-Line air quality model in this study differs from the FAF3.4. However FAF 3.4 data set is chosen as the key input to analyze the temporal changes in community-level air pollution between 2007 and 2040. Without the traffic volume and average speed in FAF3.4, which are estimated by FHWA for 2007 and 2040, a separate travel demand model needs to be employed for the State of Georgia (at least, for the freight corridor), and this requires substantial resources that are beyond the scope of this report. This is why this report runs the least squares regression using the outcome from an air pollution simulation model to find the relationship among key variables. Though the road networks are different between the simulation model being used and the Georgia Freight Corridor built from the FAF3.4, it is the relationship itself that is critical to estimate air pollution levels of individual communities along the corridor. Once the statistical relationship is analyzed, then the regression coefficients for key variables (e.g. truck volumes, average speed, the distance between individual communities from the road links) are used to calculate NO_x and $PM_{2.5}$ concentration levels along Georgia Freight Corridor for the two years.

There are *at least* three simulation based models which can be used to estimate local air quality at a small geographical scale; smaller than County, the Census tract, and the Census block group. C-Line was originally developed to help community residents better understand local air quality issues, especially when they want to compare different transportation investment scenarios based on the air quality performance. Though this model is not yet being used for regulatory purposes due to its simplified simulation techniques for some procedures[3], researchers have been working on resolving technical issues so that C-Line can be approved by the EPA for official uses. C-Line can be accessed on the CMAS (Community Modeling and Analysis System) website and the simulation model can be run on the server at the University of North Carolina at Chapel Hill. Users can run different scenarios for different pollutants on the website. Once each run is finished, then users can download simulation results for further analysis on their own. In this study, C-Line is primarily used after considering the tradeoffs between efficiency and accuracy between the three models.

The second method is to analyze the EPA National Emissions Inventory (NEI) that provides total amounts of air pollutants from different sources for individual counties in 2011. While using this data set, researchers can distribute the total traffic-based air pollution in a county to individual road links based on the characteristics of those links such as road type. However, this method needs a dispersion model that will convert the amount of air pollution emitted on individual road segments to pollutants concentration levels around those segments. For this reason, NEI provides reliable estimates in terms of total emissions; however, it is not a comprehensive tool to calculate NO_2 and $PM_{2.5}$ levels for individual communities.

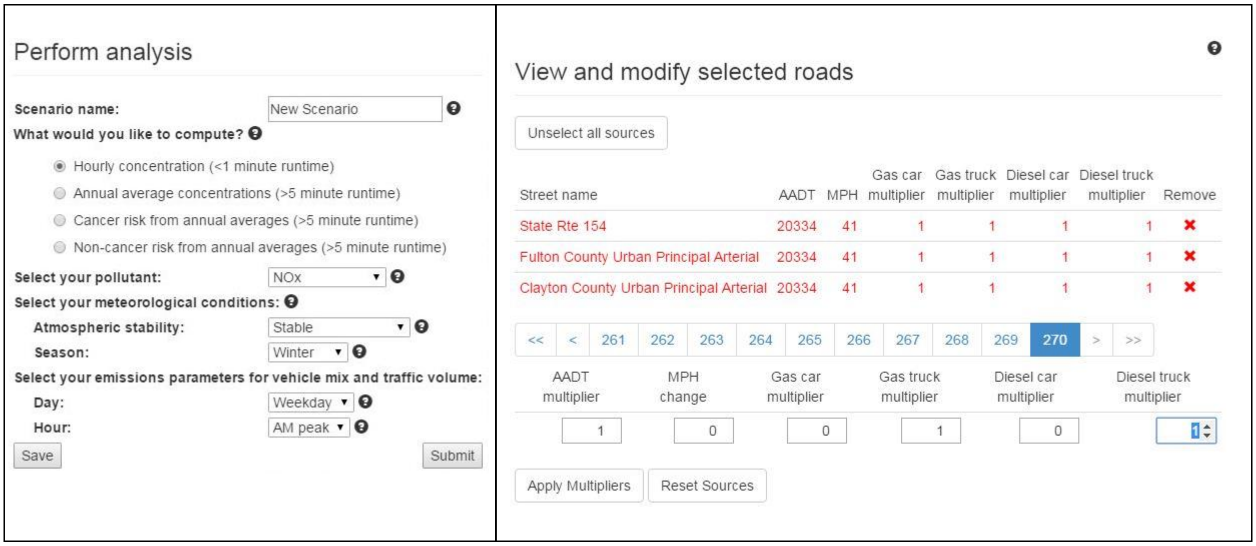
[3] The dispersion algorithm of C-Line is the analytical version of R-Line that is run on using FORTRAN, and provides more advanced modeling techniques. Actually, the R-Line algorithms are currently under review and being revised to get approved by EPA for official use in the future.

The third method is to use the EPA MOVES model to estimate total emissions from traffic for individual counties, and then, use the EPA SMOKE model (with the MOVES result as an input) to calculate dispersion from line sources to nearby communities, while taking into account meteorological conditions. This approach can be the most comprehensive, or the gold-standard in terms of estimating air pollution levels in individual communities. However, it requires substantial amounts of modeling experiences, computing power, and run time for different scenarios, so for this project, this approach is not feasible. Moreover, the EPA MOVES model uses the latest local transportation networks with estimated traffic volume and average speed; however, given that this study aims to compare air pollution at two different points in time, i.e. 2007 and 2040, the EPA MOVES model cannot be used because it only contains the latest information and does not predict for future years.

In brief, estimation of the critical pollutants concentration levels along Georgia Freight Corridor requires integration of simulation and statistical modeling tools. We could have used only the C-Line results to analyze geographic distribution of health risks along the major transportation network in Georgia; however, we chose to employ both C-Line and statistical techniques for the following two reasons. First, our final estimates use traffic characteristics in the FAF3.4, which are different from ones that C-Line analyzes (the same data set as MOVES 2011b). Second, traffic-induced air pollution in a future year is also estimated using the same kind of traffic characteristics that were predicted for the year of 2040 in the FAF3.4. Otherwise, a separate state-wide travel demand modeling would need to be employed, which is beyond the scope of this report.

C-Line Analysis

C-Line, or Community line source model, is the analytical version of its full model, R-Line, and can be run on the server at Community Modeling and Analysis System (CMAS), Chapel Hill, NC (for more information on R-Line itself, please refer to (Snyder et al., 2013)). C-line estimates pollutants concentration levels at specific geographic locations at any place in the US. In C-Line, these specific locations are called "receptors", arrayed in a grid, and their density (or the size of a grid) differs by the geographic scope of individual run. The total number of receptors for each run is set to 2,500 in C-Line, and thus, the smaller the spatial size of analysis gets, the denser the receptor density would be. As implied from its name, C-Line estimates NO_x and $PM_{2.5}$ in microgram/m^3 or ppb, based on the total emission from surrounding "line"-sources, which are vehicles on local roads. Note that the road networks used in C-Line are different from actual ones in that C-Line simplifies them to shorten the time for data loading and processing on their server (CMAS, 2015a). C-Line takes Annual Average Daily Traffic (AADT) counts for individual road links from county-level averages of 2013 Highway Performance Monitoring System (HPMS), and then "apportioned to a TIGER 2010 road network by road type"(CMAS, 2015a). In doing so, C-Line only considers road links whose National Functional Classification (NFC) values are "1, 2, 11, and 12 (corresponding to rural interstate, rural highway, urban interstate and urban highway respectively)" (CMAS, 2015a).



Note: left: pollutants, weather, and times (day/hour), right: traffic

Figure 4.2 C-Line Options

C-Line provides a number of options to calculate local pollution levels, such as type of air pollution measures (hourly or annual), specific pollutants (NO_x, CO, SO_2, $PM_{2.5}$, and so forth), meteorological conditions (stability or season), vehicle mix and traffic volume for different days and times (weekday versus weekend, AM peak, Mid-day, PM peak, or Off peak). Among the options shown in Figure 4.2, this study used annual average concentration levels for NO_x and $PM_{2.5}$. Note that once annual average measures are chosen, then other options such as stability, season, days, and times of a day do not apply, because the annual average option averages all different cases throughout a year.

Annual average concentrations were chosen in this study due to two reasons. First, the most literature considered in this report are associated with annual averages with specific health outcomes, and second, EPA regulates NO_2 and $PM_{2.5}$ levels based on annual average concentrations. For NO_2, EPA also regulates the "98th percentile of 1-hour daily maximum concentrations, averaged over 3 years". However, the C-Line modeling does not produce this estimate (EPA, 2015). Since C-Line does not provide the NO_2 level directly, we had to convert NO_x to NO_2 with an appropriate conversion factor. There has been a discussion on how to best convert NO_x to NO_2, and some evidences indicate the conversion factors need to vary by the amount of pollutants (RTP Environmental Associates, Inc, 2013). However, more studies are needed to establish reliable conversion factor that is a function of the amount of NO_x. This study uses a constant conversion factor 0.8; i.e. 0.8 multiplied by the concentration of NO_x yields the concentration of NO_2, which is the same as "EPA tier 3 conversion methods for 1-hr NO_2 dispersion modeling" (RTP Environmental Associates, Inc, 2013).

Another set of options in C-Line are related to characteristics of traffic on individual road links (see Figure

4.2). For all or selected road links in the area being analyzed, researchers can modify traffic volume (AADT), average speed (MPH), and fleet mix in four categories (gas car, gas truck, diesel car, and diesel truck). Since the focus of this report is to analyze freight impacts on communities along Georgia Freight Corridor, all vehicles were set to either gas trucks or diesel trucks, implying that estimated concentration levels at individual communities would be due to freight movement. Though this approach is not realistic, it does not produce biased estimates at later stages, because only the statistical relationship between truck volume and NO_2 and $PM_{2.5}$ levels at nearby communities would be employed in later part of analysis, and not the actual estimates from C-Line.

Note that, at this stage, C-Line was employed to produce data sets that can be used as inputs at the next stage of analysis, namely, the regression analysis. In this context, only a small number of representative areas in Georgia, not all areas along the freight corridor[4], were selected for air quality simulation using C-Line. Ten areas across Georgia were chosen based on their urban/rural category and geographic variance in the State of Georgia, and are shown in Figure 4.3 using overlaid rectangles on the Georgia map. The names of these ten areas are also listed in Figure 4.3. The first five areas are the largest Core Based Statistical Areas (CBSA) in Georgia according to the 2010 US Census, and the next five areas are chosen evenly in rural areas, mostly from the southern part of Georgia. These rural counties have relatively denser freight corridor density than other rural counties. Though 10 appears to be small sample size, each of these ten areas have a few hundred observations of pollutant concentrations, making a good sample size for the statistical models in the next stage.

The C-Line simulation results provide outcomes in a tabular format (*.csv), so users can download these files from their server, and then, conduct additional processing and analysis. These outcomes are the (x,y) coordinates of receptors, the specific pollutants concentration levels at each receptor, and the local road networks being used. Since these all are stored in the specific tabular format, ArcGIS 10.3 was used to geocode receptors and local road networks to extract other key variables for the next stage.[5] For example, the distance from individual receptors and the nearest road links were calculated using an ArcGIS built-in geoprocessing tool, Analysis Tools>Proximity>Near. Later, the spatial join was conducted for a road network shapefile and its matched receptor shapefile in ArcGIS. These processes would produce not just the distance but also the traffic volume (AADT) and average speed of freight on the nearest road links. The Figures 4.4–4.9 illustrate the complete step-by-step process for C-Line analysis. Figure 4.4 shows the interface along with the options that can be chosen on the C-Line website. Figure 4.5 contains a

[4] We found that running C-Line for all communities along Georgia Freight Corridor would require more than 100 runs for each pollutant (i.e. the total runs would be doubled for two pollutants), which is a huge amount of research efforts, while adding only marginal gains to the accuracy of estimation.

[5] The projected coordinate system of C-Line outcomes is a modified version of the USA Contiguous Lambert Conformal Conic, and their geographic coordinate system is North American 1983 (NAD 1983).

visualization of a C-Line simulation result, which is automatically produced once a C-Line analysis is completed on the server. Figure 4.6 depicts how the C-Line output data sets look, and Figure 4.7 gives an idea about how C-Line output appears after being geocoded in ArcGIS 10.3.

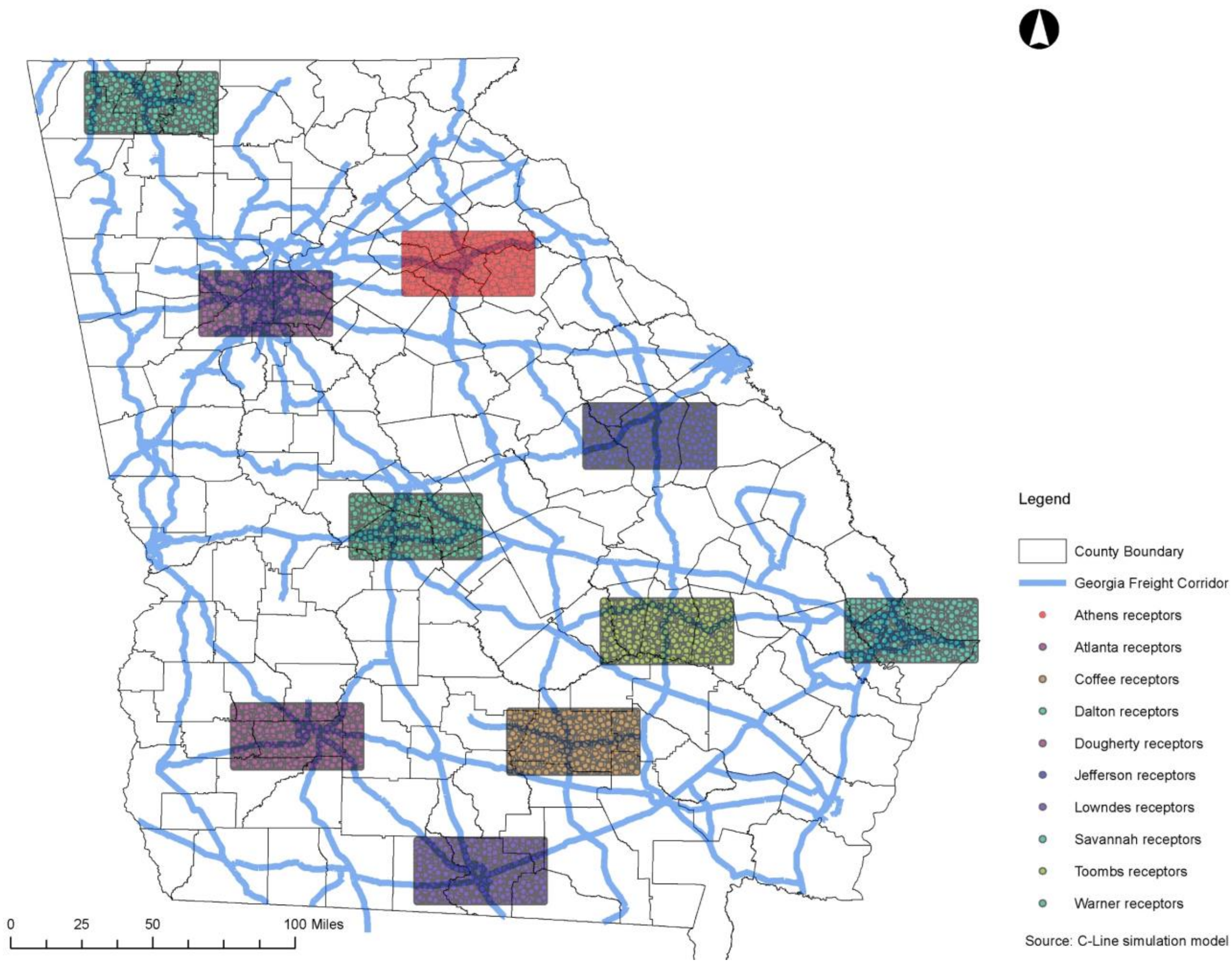
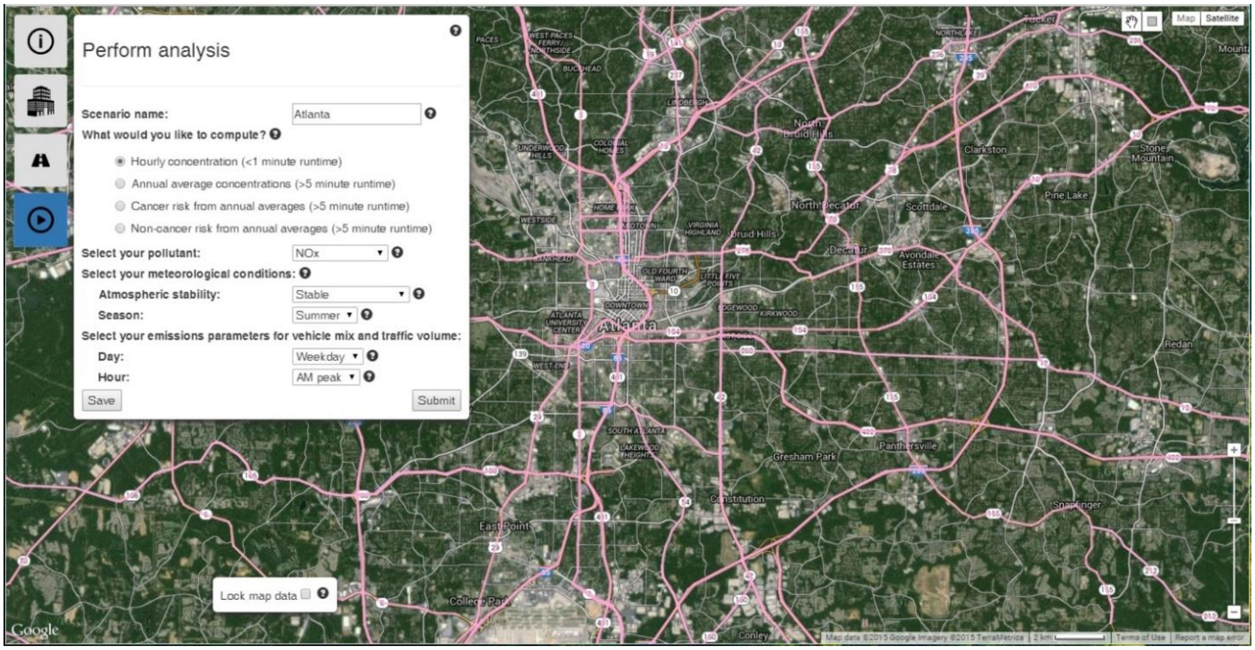
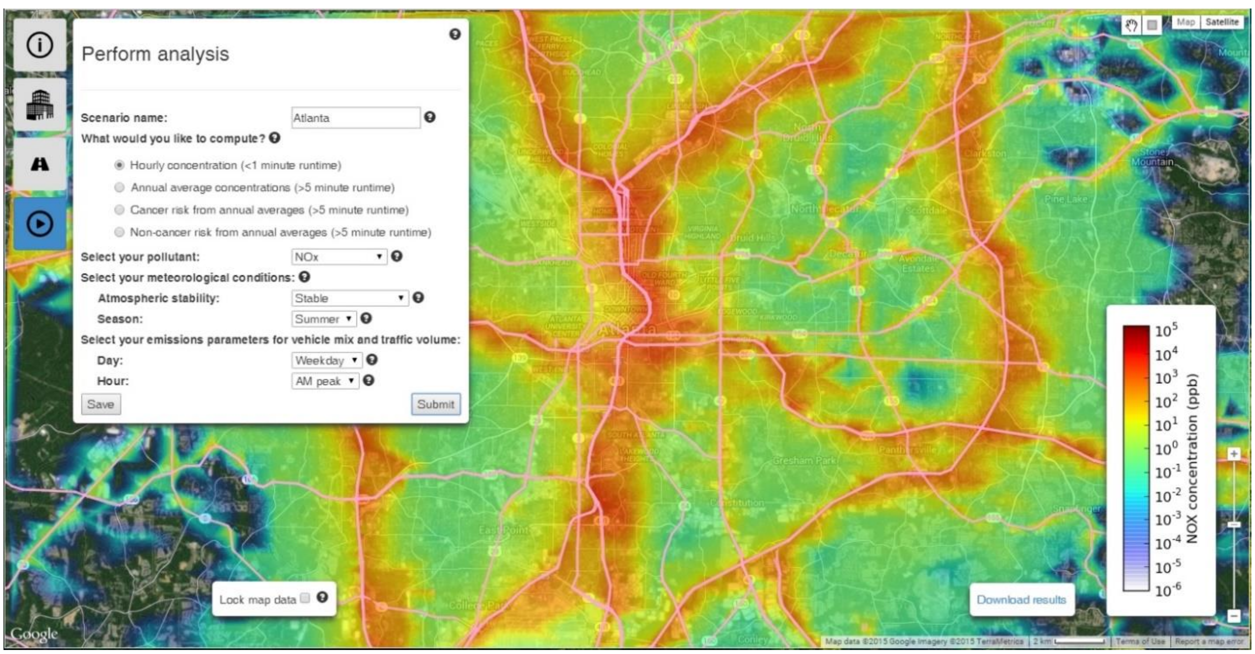


Figure 4.3 Locations of the 10 Sample Areas in Georgia



Note: Pink lines are local roads being used for analysis.(http://ctools.its.unc.edu/ctools/cline/)

Figure 4.4 C-Line Website



Note: options: Atlanta, NO_x, summer, Week day, and AM peak

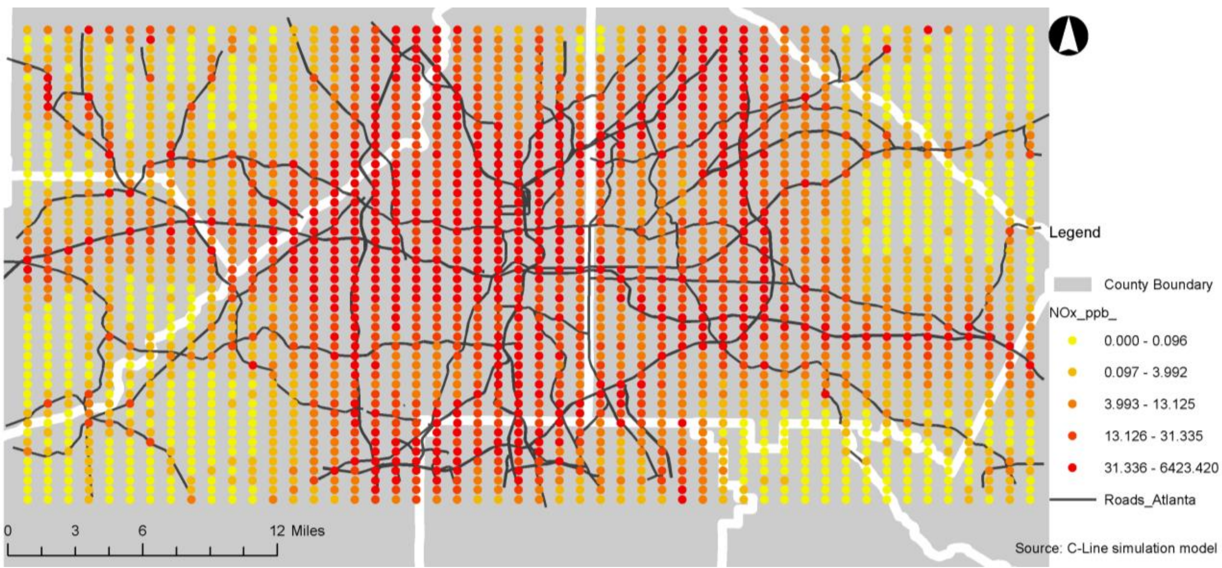
Figure 4.5 C-Line Analysis Result

RecID	xLCC	yLCC	NOx(ppb)
1	1175500	-621666	6.701550
2	1140410	-608610	4.380810
3	1171810	-604249	3.937780
4	1135580	-609270	3.081460
5	1132980	-608246	0.003406
6	1179310	-596292	13.628600
7	1166270	-617443	22.571400
8	1190070	-611318	205.495000
9	1174040	-602556	27.511200
10	1149330	-601868	3.619340
11	1181450	-620134	0.040564
12	1142260	-622145	0.204141
13	1161150	-616088	25.436600
14	1145240	-607946	9.253180
15	1165140	-609324	45.979800
16	1175980	-625048	6.930290
17	1190790	-607765	5.519220
18	1151480	-617430	24.135300
19	1175120	-618960	3.630600
20	1142360	-622822	0.004179

id	id2	from_x	from_y	to_x	to_y	sf_id	stfips	ctfips	fclass_rev	aadt	mph	gas_car_multiplier	gas_truck_multiplier	diesel_car_multiplier	diesel_truck_multiplier
157348	1	1162531.059	-617253.8254	1162942.139	-617055.9871	13874	13	121	11	172124	41	0	1	0	1
60834	2	1166556.59	-620751.354	1166004.245	-621818.5656	13874	13	63	11	106650	41	0	1	0	1
157546	3	1170543.548	-619090.8711	1170740.581	-619575.2844	13874	13	63	11	106650	41	0	1	0	1
60836	4	1174901.923	-600730.3195	1174658.644	-600107.7902	53863	13	89	11	164943	41	0	1	0	1
60834	5	1161256.618	-624754.6991	1160755.125	-625042.399	13874	13	63	11	106650	41	0	1	0	1
159491	6	1144648.947	-611697.402	1143571.572	-610442.8611	3888	13	97	2	12768	32	0	1	0	1
157413	7	1172957.258	-592591.8894	1173629.855	-593056.5563	53863	13	89	11	164943	41	0	1	0	1
60837	8	1154535.66	-620135.1645	1154170.601	-618802.5995	13874	13	121	11	172124	41	0	1	0	1
157271	9	1163261.955	-611838.3063	1163174.834	-612934.0301	13874	13	121	11	172124	41	0	1	0	1
60836	10	1173629.855	-593056.5563	1173851.97	-593330.0012	53863	13	89	11	164943	41	0	1	0	1
157320	11	1166974.567	-609783.8371	1168298.727	-609663.7428	13874	13	89	11	164943	41	0	1	0	1
60835	12	1152804.206	-600556.1873	1153558.002	-596598.432	3888	13	67	11	157941	41	0	1	0	1
60837	13	1153177.622	-613464.9261	1153314.221	-611584.378	3888	13	121	11	172124	41	0	1	0	1
157271	14	1162388.779	-604965.2565	1162475.736	-605361.9145	3888	13	121	11	172124	41	0	1	0	1
60834	15	1159713.052	-625134.5022	1158893.52	-625066.7024	13874	13	63	11	106650	41	0	1	0	1
60837	16	1158893.52	-625066.7024	1158535.736	-624990.5433	13874	13	121	11	172124	41	0	1	0	1
62455	17	1162529.86	-605802.9777	1162608.29	-606367.933	3888	13	121	11	172124	41	0	1	0	1
60405	18	1171143.255	-612558.7248	1172123.929	-612469.2524	13874	13	89	11	164943	41	0	1	0	1
60836	19	1176025.861	-613719.0031	1175303.782	-613810.9269	13874	13	89	11	164943	41	0	1	0	1
157348	20	1156392.663	-625841.197	1156574.943	-625415.5908	13874	13	121	11	172124	41	0	1	0	1

Note: the first 20 rows were shown here. Left: pollutant concentration levels, Right: road network

Figure 4.6 C-Line Outputs



Note: Dots are receptors, color coded based on different quantiles, and lines are local roads used in C-Line

Figure 4.7 C-Line Outputs of Atlanta Geocoded Using ESRI ArcGIS 10.3

Regression Analysis

This step attempts to establish the relationship between the amounts of total emissions produced from trucks on a freight corridor segment and the resultant pollutant concentration levels in nearby communities. In other words, this is a stage to estimate *a rate of dispersion* of traffic-induced pollutants from its source (e.g. on highways) to the areas in the proximity. C-Line analysis along with regression analysis produces reliable outcomes except for the fact that we are using a statistical approach combined with simplified simulation model instead of more complex simulation models such as EPA SMOKE.

Least squares regression was employed in the study using the data sets produced by C-Line for the ten sample areas throughout Georgia. As explained at the previous section, C-Line provides three types of data sets; (A) pollutants concentration levels at specific geographic locations, (B) a road network that were considered in the modeling process, and (C) traffic volume and average speed for individual road segments in the network. In this stage of the analysis, the C-Line simulation modeling outcome (A) was replicated by the statistical modeling technique of least squares, and the other two C-Line products (B and C) were used as part of independent variables to explain the variation of the dependent variable of interest (A).

The regression model and variables for the least squares are shown in Table 4.1. The basic intuition behind the equation is that the air pollution emitted from individual vehicles is dispersed in surrounding communities in a way that closer areas experience higher concentration levels, while farther areas are exposed to lower concentration levels. This is why the regression model includes a typical distance decay function of $e^{f(x)}$. The equation (4.1) shows a simplified relation which assumes that the pollutants concentration levels at a certain distance x from the nearest road segment can be explained by the total amount of emission from the road segment (*EM*), and the distance itself (*x*); i.e. *c(x)* is correlated to *EM* positively, and to *x* negatively.

The equation (4.2) represents more detailed relationship about the rate of pollutants dispersion from specific roads segment to nearby communities. It includes a number of interaction terms, or multiplicative variables, to account for "varying" rates of pollutants dispersion from a corridor segment to its nearby communities. Based on the literature, it is assumed that for the same amount of traffic-related emission, the dispersion rate of certain pollutants to a nearby community whose road density is high would be different from another community whose road density is low. For instance, urban neighborhoods surrounded by multiple high-trafficked roads may experience higher pollutant concentration levels due to their "multiple" sources of air pollution, even though some roads are beyond a threshold distance away (e.g. 400 meters) from these neighborhoods. In contrast, rural communities that are close to just one or two high-trafficked roads may be exposed to lower levels of pollutants concentration due to their "small" number of pollution sources. In brief, these interaction terms are included to control any area-specific effects on pollutants dispersion rates, which are caused by roads network density.

$$c(x) = \alpha \times EM^{\gamma} \times e^{f(x)} \tag{4.1}$$

$$f(x) = (\beta_0 + \beta_1 x + \beta_2 x^2) + (\beta_3 d_2 + \beta_4 d_3 + \beta_5 d_4 + \beta_6 d_5) + (\beta_7 x \cdot d_2 + \beta_8 x \cdot d_3 + \beta_9 x \cdot d_4 + \beta_{10} x \cdot d_5) + (\beta_{11} x^2 \cdot d_2 + \beta_{12} x^2 \cdot d_3 + \beta_{13} x^2 \cdot d_4 + \beta_{14} x^2 \cdot d_5) \tag{4.2}$$

Table 4.1: Variables Used in the Regression Model

Variable/formula	Explanation	Source
c(x)	Pollutants concentration levels at distance x from the closest corridor segment	C-Line
EM	The amount of emission from the closest corridor segment. This is calculated based on emission factors that vary by traffic volume and average speed on the specific segment.	C-Line (traffic volume & average speed) Emission factor (literature)
$e^{f(x)}$	A distance decay function whose base is exponential.	
d2, d3, d4, and d5	The four binary variables (or dummy variables) indicating 1 if the point ("receptor") in interest is in the 2nd, 3rd, 4th, or 5th group based on its "road density", and otherwise 0 (groups were 5 quantiles based on the road density measure).	FAF3.4 (FHWA)
$\alpha, \beta, and\ \gamma$	The least squares regression coefficients	

The *c(x)*, either in ppb (NO_x) or microgram/m^3 ($PM_{2.5}$), comes from the C-Line result with *(x, y)* coordinates. These coordinates are geocoded using ArcGIS, and then individual receptors are plotted on a map with their specific pollutants concentration. The distance from individual receptors and their nearest road segments were calculated using Analysis tools > Proximity > near in ArcToolbox in ArcGIS. In this case, individual receptors were from a point shapefile, and the road segments were from a polyline shapefile.

The literature finds that if the distance between nearest roads and individual communities is greater than 400 meters, then the pollutants concentration levels become the same as background levels (Karner, Eisinger, & Niemeier, 2010). In other words, communities located more than 400 meters away from a road segment have minimal impacts by traffic-induced air pollution, if any. For this reason, the regression analysis at this stage only includes those C-Line receptors that are within 500 meters (to be conservative) from any road segments in the road network. Table 4.2 shows the number of receptors in each sample area in Georgia. Initially, C-Line produced 2,500 receptors for each area; but these areas differ by their number of receptors closer than 500 or 800 meters to nearest road segments. Note that more urbanized areas tend to have higher numbers of receptors, implying denser road networks in these areas, compared to rural counties.

Table 4.2: Number of Receptors in Each Sample Area in Georgia

Sample Area	# of receptors in 800 meters from nearest road segments	# of receptors in 500 meters from nearest road segments
City of Athens	883	616
City of Atlanta	1,307	915
Coffee County	581	381
City of Dalton	851	569
Dougherty County	588	374
Jefferson County	662	432
Lowndes County	771	486
City of Savannah	636	417
Toombs County	776	503
City of Warner	803	500
Sum	7,858	5,193

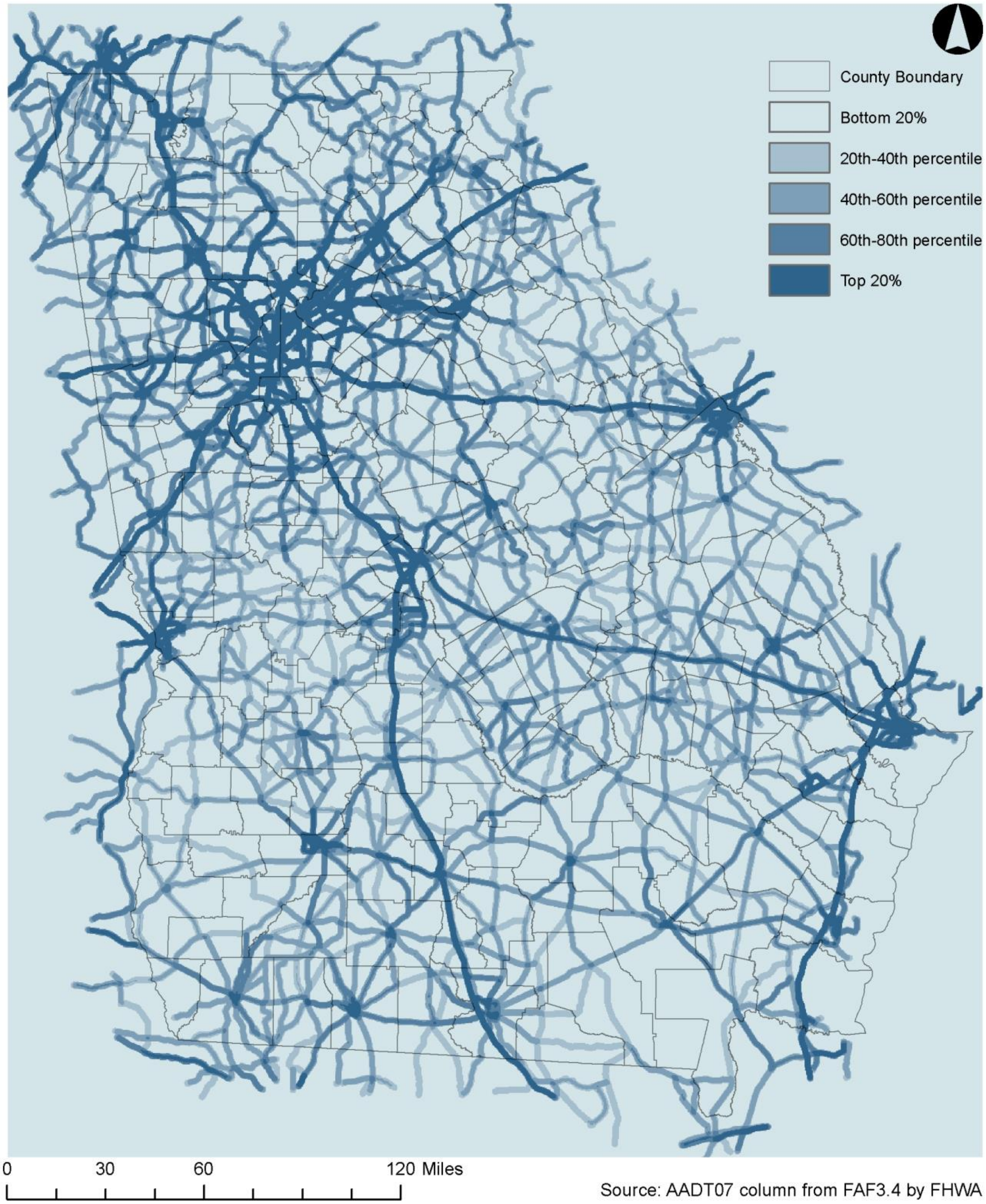
The total amount of emissions was calculated by using emission factors in the literature (Wang et al., 2010). The emission factors differ by type of vehicle (truck or not) and average speed (urban versus rural). Because this report attempts to analyze freight impacts on communities along the Georgia freight corridor, the C-Line produced results with only truck traffic, and thus, the total emissions from individual road segments were calculated only using the emission factors of trucks for different average speed. Wang et el. (2010) found that emission factors by trucks (in their words, heavy duty vehicles) are 233 microgram*kilometer^{-1}*vehicle^{-1} (rural) and 628 microgram*kilometer^{-1}*vehicle^{-1} (urban) for $PM_{2.5}$, and 9.8gram*kilometer^{-1}*vehicle^{-1} (rural) and 11.9 microgram*kilometer^{-1}*vehicle^{-1} (urban) for NO_x. Their final result including other air pollutants are shown in Table 4.3. In their research, rural highways had the average speed of 90-110km/h, or 56-68mph, and urban roads had the average speed of 40-50km/h, or 25-31mph. In our analysis, we set 70 km/h (=(90+50)/2), or 43.49597 mph, as the threshold average speed, so any road segments whose average speed is over this threshold would then be assigned emission factors for the rural case, and any road segments whose average speed is under this threshold would be assigned emission factors for the urban case presented in Wang et al. (2010). The total emission is simply the multiplication of truck volume (AADTT) and emission factors for individual road segments.

Table 4.3: Emission Factors

Parameter	Unit	EFP(total)	Std. error	EFP(LDVs)	Std. error	EFP(HDVs)	Std. error	HDVs/LDVs ratio
Highway								
NO_x	$g\ km^{-1}$	1.4	0.027	0.70	0.029	9.8	0.29	15
PN_{total}	$10^{12}\ km^{-1}$	215	5.3	81	6.9	1750	68	22
PN_{mode1}	$10^{12}\ km^{-1}$	98	3.2	54	5.8	595	56	11
PN_{mode2}	$10^{12}\ km^{-1}$	121	3.7	43	5.8	993	56	23
PN_{mode3}	$10^{12}\ km^{-1}$	76	1.9	31	2.6	575	25	19
$PN_{0.05}$	$10^{12}\ km^{-1}$	194	4.8	78	6.6	1486	64	19
$PN_{0.05-0.1}$	$10^{12}\ km^{-1}$	33	1.1	18	2.1	201	20	11
$PN_{0.1}$	$10^{12}\ km^{-1}$	6.8	0.39	3.5	0.76	44	7.4	12
PA	$cm^2\ km^{-1}$	1.5	0.037	0.51	0.045	12.4	0.44	25
PV	$cm^3\ km^{-1}$	0.029	0.001	0.01	0.001	0.25	0.011	25
$PM_{2.5}$	$mg\ km^{-1}$	29	1.0	11	2.0	233	18	21
PM_{10}	$mg\ km^{-1}$	131	4.0	44	7.0	1087	68	25
Urban								
NO_x	$g\ km^{-1}$	0.93	0.015	0.46	0.029	11.9	0.59	26
PN_{total}	$10^{12}\ km^{-1}$	187	3.1	101	6.2	2206	128	22
PN_{mode1}	$10^{12}\ km^{-1}$	31	1.4	23	3.0	208	62	9
PN_{mode2}	$10^{12}\ km^{-1}$	83	1.7	40	3.5	1088	73	28
PN_{mode3}	$10^{12}\ km^{-1}$	61	1.2	31	2.4	746	48	24
$PN_{0.05}$	$10^{12}\ km^{-1}$	101	2.4	39	4.8	1554	100	40
$PN_{0.05-0.1}$	$10^{12}\ km^{-1}$	47	1.4	34	3.1	335	64	10
$PN_{0.1}$	$10^{12}\ km^{-1}$	20.2	1.1	8.6	2.4	289.5	49.9	34
PA	$cm^2\ km^{-1}$	2.5	0.037	1.4	0.073	27.8	1.5	20
PV	$cm^3\ km^{-1}$	0.085	0.001	0.048	0.003	0.95	0.055	20
$PM_{2.5}$	$mg\ km^{-1}$	46	1.0	20	2.0	628	50	31

Note: Those used in this study are highlighted; Source: Wang et al. (2010)

The road density is calculated as the number of roads in 1 mile from a certain point (a grid centroid whose interval is a quarter mile), weighted by traffic volume of individual roads (Annual Average Daily Traffic; AADT). The roads and traffic volume information are from FAF3.4 by FHWA (traffic volume in 2007). This index is processed using the ArcGIS Spatial Analyst Tools > Density > Line Density function, and Figure 4.8 shows the result across the State of Georgia. It is assumed that traffic volume up to 1 mile may affect the way how the total amount of air pollutants emitted from the closest road segment is dispersed in the three dimensional space, and thus, is converted to a certain concentration level at individual communities. Initially, simple road density without weights were calculated and included in regression, and later, weighted road density was used instead of the simple one, because the simple road density was not differentiated enough to capture any variation in pollutants dispersion rates.



Note: Weight by AADT07 in FAF3.4, color-coded based on quantiles

Figure 4.3 Weighted Road Density

In order to estimate the least squares coefficients, the initial equation needs to be transformed according to the following:

$$\ln c(x) = \alpha' + \gamma \ln EM + f(x) \; (\alpha' = \ln \alpha)$$

Estimation of Pollutant Concentrations for 2007 and 2040

This step estimates concentration levels of NO_2 and $PM_{2.5}$ along the Georgia freight corridor in our interest, which is defined using the Freight Analysis Framework (FAF) 3.4 that is produced and maintained by the Federal Highway Administration. FAF3.4 is different from the input data set that C-Line uses in the previous sections. Currently, C-Line calculates pollutants concentration levels by "combining national database information on traffic volume (AADT) and fleet mix with emissions factors from EPA's MOVES-2010b" (CMAS, 2015b). Because this report attempts to compare freight-induced air pollution and its health impacts at two points in time, we chose to use the road network, traffic volume, and average speed in the FAF3.4, which provides estimates of these information for the year of 2007, and prediction of the same information for 2040. The road network and traffic information are different between C-Line and FAF3.4, and thus, we ran the regression model in the previous section using C-Line results and then applied the regression coefficients to the FAF3.4 data. In other words, we estimated air pollution along the Georgia Freight corridor with traffic volume and average speed from the FAF3.4, while regression coefficients, or the relationship between dependent and independent variables, were obtained by analyzing C-Line results.

Here it is imperative to mention the issue of "overestimation" in C-Line results. The C-Line was recently developed, and not yet been approved by the USEPA for regulatory purposes, although the research team at the University of North Carolina at Chapel Hill and external experts are working on algorithms and advanced modeling techniques behind C-Line to obtain approval. For mathematical reasons, the C-Line tends to over-predict pollutant concentration levels for those areas that are very close to the road network. In response, Dr. Russell and his colleagues in the Department of Civil and Environmental Engineering at Georgia Tech recently developed a scaling factor to solve this issue. Their method is to have R-Line outcomes adjusted to the average estimate from two alternative procedures (Zhai et al., 2015). The R-Line, the full version of C-Line, results are first fitted to (a) "Chemical Mass Balance (CMB) vehicle source estimates", and to (b) the recorded values at the actual monitoring stations in Georgia, and then these two fitted values ((a) & (b)) are averaged to get the final scaling result. Their scaling formula is below.

$$\Delta PM_{2.5} = 10^{[0.32*\log(RLINE\_PM2.5) - 0.05]}$$

Here it needs to be mentioned that the estimated $PM_{2.5}$ using C-Line and statistical analysis is only due to line source (traffic on roads) that does not consider other point sources such as construction sites, power plants, and manufacturing firms. So, note that even the highest estimates for annual average $PM_{2.5}$ are still far lower than the EPA ambient air quality standards of 12 microgram/m^3. However, this does not imply that these lower levels of $PM_{2.5}$ are benign. The health literature has reported that the risk of having respiratory diseases due to traffic-induced air pollutions would rise in response to the exposure levels to air pollutants, regardless of whether individuals experienced over a sort of a minimum threshold.

Unfortunately, we did not find the same kind of a rescaling factor for NO_x yet. In fact, Dr. Russell and his lab at Georgia Tech have been developing the same kind of scaling factor for NO_x; however, it was not available for use in this analysis. Given that the main goal of this study is to model relative health risks along the Georgia Freight corridor, we believe this mathematical inaccuracy would not have a disproportionate effect throughout Georgia. However, despite possible overestimates of NO_x levels in C-Line, this analysis will reliably show the *relative* chance of various health outcomes by exposure to different levels of freight-induced air pollution at different parts of Georgia, but not the *actual* chance of those outcomes. Future research may benefit from the use of an appropriate scaling factor for NO_x levels once it has been developed.

A necessary additional analysis is about emission impacts on certain subpopulations. The literature has reported that there are certain groups of people who are more vulnerable than others in the population. Seniors, pregnant women, infants, preschoolers, and K-12 students are often described as having higher health risks than others in response to air pollution. Also, as transportation planners and engineers take into account the disproportionate distributions of harmful environmental impacts to populations of different incomes, races, and social classes (Gunier, Hertz, Von Behren, & Reynolds, 2003; Rowangould, 2013), it was reasonable to take the analysis a step further by comparing different race, ethnicity, and income groups along the Georgia freight corridor in this study.

Health Risks

Relative health risks are calculated based on the estimates from the previous step and the Odds Ratios (OR) in the literature. The previous stage produces specific levels of NO_2 and $PM_{2.5}$ concentration levels for individual communities along the Georgia freight corridor. Then, these pollution levels are converted to relative risks of having certain diseases due to the exposure to freight, compared to those who are not exposed.

The literature reports Odds Ratio that are calculated by employing nonlinear regression with an odds as the dependent variable (ratio between having a certain disease and not having it); most of the models in the literature are logistic regression. As mentioned previously, odds is the ratio of developing a certain health outcome to not developing the outcome, and Odds Ratio is another ratio between one odds and another. So, converting an odds to a relevant percent of developing certain diseases is not based on a linear relationship between pollution levels, odds, and percent. In addition, a converted percent depends on the initial percent of having the disease computed assuming baseline exposure to air pollutants. Table 4.4 shows a specific process of this conversion using the findings in Abbey et al. (1999) about female lung cancer mortality by traffic-induced NO_2 emission.

Table 4.4 Conversion from Odds Ratio to Percent Change in Health Outcome

Explanation	Assumed % at basis	Odds	Chance of female lung cancer	Ratio between two %s
Odds (A_1) being exposed to approx. 20 higher ppb.	N/A	0.937 (=0.333***2.81**)	48.4%	1.93
Odds (B_1) not being exposed to approx. 20 higher ppb.	25%	0.333 (=25%/75%)	25%	
Odds (A_2) being exposed to approx. 20 higher ppb.	N/A	0.312 (=0.111***2.81**)	23.8%	2.38
Odds (B_2) not being exposed to approx. 20 higher ppb.	10%	0.111 (=10%/90%)	10.0%	
Odds (A_3) being exposed to approx. 20 higher ppb.	N/A	0.028 (=0.010***2.81**)	2.8%	2.76
Odds (B_3) not being exposed to approx. 20 higher ppb.	1%	0.010 (=0.1/99.9%)	1.0%	

In Table 4.4, there are three hypothetical baseline chances of a female having lung cancer; 25%, 10%, and 1% in the second column (represented by B_1, B_2, and B_3 in the first column). For all three cases, Odds Ratio is always the same as 2.81, and thus, the odds for being exposed to higher NO_2 levels by 20 ppb are calculated in the third column, and then, converted to percent terms in the fourth column. The fifth column indicates the ratio between percent of having lung cancer and not having lung cancer for three different cases (again, the baseline chances are 10%, 5%, and 1% respectively). Note that the smaller the baseline chances, the larger the ratio between the chance of having versus not having lung cancer. In brief, for *different baseline* probabilities of having certain diseases, the increase in the risk of having the disease *differ* greatly. For this reason, in the result section, only the odds ratios are reported in order to avoid any confusion.

SECTION V: ANALYSIS AND RESULTS

Results of C-Line Analysis

As mentioned in section IV, this study adopted a "two-stage" approach; at the 1st stage, we obtained a data set of NO_2 and $PM_{2.5}$ concentration levels at certain geographic locations in Georgia and the traffic information near these locations, and at the 2nd stage, we analyzed the relationship of those pollutants levels and characteristics of nearby freight movement. The first step was done by C-Line ambient air quality simulation model, and the second step was conducted by the least squares regression. Given that our final goal was to estimate specific air quality in those communities along the Georgia Freight Corridor over time, one might think it might have been better to use one approach, if possible, in terms of simplicity and consistency. However, due to lack of resources and unavailability of key data, we combined two approaches to get the best results for this report.

C-Line provides two types of data sets: (1) pollutants concentration levels at certain locations, and (2) information on freight movement nearby. For the first set of data, we used the annual averages of NO_2 and $PM_{2.5}$ in C-Line output option, and also exported (x,y) coordinates for individual locations of "receptors" where certain pollutants concentration levels are estimated. For the second set of data, freight volume and average speed for each and every road link were obtained. These two variables were used to determine which emission factors were needed in the regression analysis to calculate the total amount of NO_2 and $PM_{2.5}$ from individual road segments.

Figure 5.1 shows a map containing both receptors (with their NO_x estimates color-coded) and road links (with their AADT color-coded). The color code scheme is quartile, implying that all observations are classified into four same-sized groups based on either NO_x estimates (for receptor "dots") or AADT (for segmented road "lines").

Note that C-Line produces 2,500 receptor locations and their pollutant estimates for each run, and we have 10 runs for 10 places in Georgia (one run for each place). In the next stage of regression analysis, only those receptors that are located within 500 meters from their nearest road links were included in the model, based on the assumption backed by literature that beyond 400~500 meters from line sources of air pollution, the concentration levels of key pollutants including NO_2 and $PM_{2.5}$ are similar to (or even below than) background levels. Though the number of receptors within 500 meters for each place is much smaller than 2,500, the aggregate number of the 10 places is large enough to run the least squares regression. (Please refer to the next subsection to see the specific number of observations.)

In terms of road links, C-Line only includes part of actual road network in the area.[6] Though the road networks used in C-Line may be different from the Georgia Freight Corridor to some extent, as mentioned previously, this is not a serious issue, because our goal in this stage was to find the statistical relationship between NO_2 and $PM_{2.5}$ levels of the communities along the corridor and the volume and speed of freight passing by near these communities.

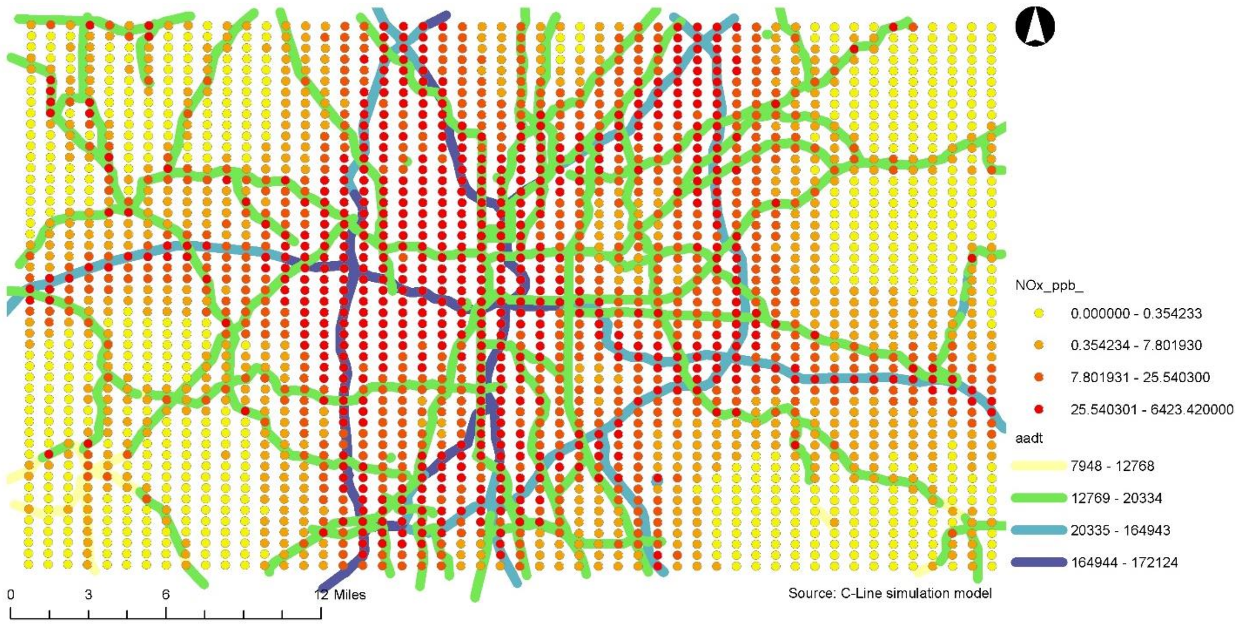


Figure 5.1 C-Line Estimate of Annual Average NO_x in Atlanta, GA (in ppb)

In fact, C-Line allows researchers to modify traffic volume and average speed for individual road links and thus, to check how air quality changes in response to this hypothetical (or planned) interventions. So, traffic counts for each links were changed to all trucks while keeping the volume and average speed the same.[7] This is because this report focuses exclusively on freight movement, not on passenger vehicles, and by doing this, C-Line uses only their "built-in" emission factors for trucks, but not for non-trucks.[8] One might argue that the NO_2 and $PM_{2.5}$ measured from this method would not be realistic, because all the passenger

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[6] "AADT values were calculated based on 2013 HPMS averages by county and apportioned to a TIGER 2010 road network by road type. *Only road types with NFC values of 1, 2, 11, and 12 (corresponding to rural interstate, rural highway, urban interstate and urban highway respectively) were included to reduce load and processing time for the web application.* Some major and secondary roadways may be missing in some areas, these are not present in the database possibly due to recent construction. In cases where the road type didn't have a matching value in the 2013 HPMS AADT, state averages by road class were used. … Since the AADT values for road types correspond to the county, it is possible to have drastic changes in AADT for adjoining segments that cross county lines." (CMAS, 2015)

[7] Currently, C-Line does *not* allow users to change the total traffic count of individual road links, so only the type of vehicles (i.e. whether all trucks, some trucks and some passenger vehicles, or all non-trucks) can be modified. (Based on email correspondence in July 2015 with Michelle G. Snyder, Environmental Modeler at Institute for the Environment/CEMPD, University of North Carolina at Chapel Hill.)

[8] C-Line uses "MOVES-2010b Emissions Factors from EPA's National Emissions Inventories (NEI) 2011 V1" (CMAS, 2015).

vehicles on the Georgia roads were replaced by trucks, which inevitably produces much higher pollutants concentration levels for communities near the corridor. This is true; however, note that the C-Line outcome is used as an intermediate input for following analyses, but not a final output, and in the regression stage, the relationship between pollutants levels and nearby freight characteristics will be the main focus, not the specific C-Line estimates at certain neighborhoods.

The Figures 5.2 through 5.4 show actual C-Line results in the spread sheet format (originally in *.csv format, and imported to ArcGIS). As mentioned previously, two sets of data were analyzed at this stage: (1) NO_x and $PM_{2.5}$ concentration levels and (x,y) coordinates of individual receptors, and (2) road networks and traffic count and average speed for individual links. For the first data set, each row (each receptor) was geocoded on a map and given the ID of, and specific distance to, its nearest road link by employing a built-in ArcGIS Geoprocessing tool (Analysis Tools>Proximity>Near). In Figure 5.2, NEAR_FID indicates the ID of a specific road link, and NEAR_DIST shows the distance between a receptor and its nearest road link in meters. Note that the number of rows is 2,500 for the Atlanta run (this is the same for all other runs), and if the nearest road link is more than 800 meters away, then ID would be "-1", and the distance to it would be "-1" in Figure 5.2, indicating these receptors would not be included in the next stage of the analysis.

NOx_Atlanta

FID	Shape	RecID	xLCC	yLCC	NOx_ppb_	NEAR_FID	NEAR_DIST
0	Point	1	1175500	-621666	6.70155	-1	-1
1	Point	2	1140410	-608610	4.38081	1397	376.920785
2	Point	3	1171810	-604249	3.93778	1767	462.787346
3	Point	4	1135580	-609270	3.08146	1062	373.66988
4	Point	5	1132980	-608246	0.003406	-1	-1
5	Point	6	1179310	-596292	13.6286	1314	162.669877
6	Point	7	1166270	-617443	22.5714	1206	96.150683
7	Point	8	1190070	-611318	205.495	62	47.148976
8	Point	9	1174040	-602556	27.5112	-1	-1
9	Point	10	1149330	-601868	3.61934	-1	-1
10	Point	11	1181450	-620134	0.040564	-1	-1
11	Point	12	1142260	-622145	0.204141	1682	634.711013
12	Point	13	1161150	-616088	25.4366	1529	118.915584
13	Point	14	1145240	-607946	9.25318	-1	-1
14	Point	15	1165140	-609324	45.9798	736	579.14271
15	Point	16	1175980	-625048	6.93029	-1	-1
16	Point	17	1190790	-607765	5.51922	1794	150.536287
17	Point	18	1151480	-617430	24.1353	1540	107.438037
18	Point	19	1175120	-618960	3.6306	-1	-1
19	Point	20	1142360	-622822	0.004179	-1	-1

0 (0 out of 2500 Selected)

NOx_Atlanta Roads_Atlanta

Note: xLCC and yLCC: receptor's location, NEAR_FID: ID of the nearest road links, NEAR_DIST: distance (meters) between the receptor to its nearest road link

Figure 5.2 Data Set after Matching Nearest Road Links to Individual Receptors

For the second data set, each road link was geocoded on a map based on four coordinates (*from_x*, *from_y*, *to_x*, and *to_y*). Then, at the next stage, AADT and MPH (average speed) columns were matched to the first data set based on road link IDs (not shown here). In Figure 5.3, it is shown that the Atlanta road network in C-Line has 1,956 road segments. Note that the last four columns are properly modified: i.e. *gas_car_multiplier* and *diesel_car_multiplier* set to zero, while *gas_truck_multiplier* and *diesel_truck_ multiplier* set to one.

Table

Roads_Atlanta

FID	Shape *	from_x	from_y	to_x	to_y	stfips	ctfips	fclass_rev	aadt	mph	gas_car_multiplier	gas_truck_multiplier	diesel_car_multiplier	diesel_truck_multiplier
0	Polyline	1162531.059	-617253.8254	1162942.139	-617055.9871	13	121	11	172124	41	0	1	0	1
1	Polyline	1166556.59	-620751.354	1166004.245	-621818.5656	13	63	11	106650	41	0	1	0	1
2	Polyline	1170543.548	-619090.8711	1170740.581	-619575.2844	13	63	11	106650	41	0	1	0	1
3	Polyline	1174901.923	-600730.3195	1174658.644	-600107.7902	13	89	11	164943	41	0	1	0	1
4	Polyline	1161256.618	-624754.6991	1160755.125	-625042.399	13	63	11	106650	41	0	1	0	1
5	Polyline	1144648.947	-611697.402	1143571.572	-610442.8611	13	97	2	12768	32	0	1	0	1
6	Polyline	1172957.258	-592591.8894	1173629.855	-593056.5563	13	89	11	164943	41	0	1	0	1
7	Polyline	1154535.66	-620135.1645	1154170.601	-618802.5995	13	121	11	172124	41	0	1	0	1
8	Polyline	1163261.955	-611838.3063	1163174.834	-612934.0301	13	121	11	172124	41	0	1	0	1
9	Polyline	1173629.855	-593056.5563	1173851.97	-593330.0012	13	89	11	164943	41	0	1	0	1
10	Polyline	1166974.567	-609783.8371	1168298.727	-609663.7428	13	89	11	164943	41	0	1	0	1
11	Polyline	1152804.206	-600556.1873	1153558.002	-596598.432	13	67	11	157941	41	0	1	0	1
12	Polyline	1153177.622	-613464.9261	1153314.221	-611584.378	13	121	11	172124	41	0	1	0	1
13	Polyline	1162388.779	-604965.2565	1162475.736	-605361.9145	13	121	11	172124	41	0	1	0	1
14	Polyline	1159713.052	-625134.5022	1158893.52	-625066.7024	13	63	11	106650	41	0	1	0	1
15	Polyline	1158893.52	-625066.7024	1158535.736	-624990.5433	13	121	11	172124	41	0	1	0	1
16	Polyline	1162529.86	-605802.9777	1162608.29	-606367.933	13	121	11	172124	41	0	1	0	1
17	Polyline	1171143.255	-612558.7248	1172123.929	-612469.2524	13	89	11	164943	41	0	1	0	1
18	Polyline	1176025.861	-613719.0031	1175303.782	-613810.9269	13	89	11	164943	41	0	1	0	1
19	Polyline	1156392.663	-625841.197	1156574.943	-625415.5908	13	121	11	172124	41	0	1	0	1

0 (0 out of 1956 Selected)

Roads_Atlanta

Figure 5.3 Road Network Tabular Data Set Imported to ArcGIS

	RecID	xLCC	yLCC	NOx_ppb_	NEAR_FID	NEAR_DIST	RASTERVALU	aadt	mph
1	2376	1174960.00000000000	-600356.00000000000	71.08550000000	3	190.33983304900	207792.68750000000	164943	41
2	249	1161170.00000000000	-625053.00000000000	37.99590000000	4	215.64323721300	64631.77734380000	106650	41
3	227	1143200.00000000000	-610985.00000000000	13.78100000000	5	635.09715282400	62508.17968750000	12768	32
4	1019	1154180.00000000000	-619126.00000000000	32.53070000000	7	76.38264238440	102728.39062500000	172124	41
5	1931	1167650.00000000000	-609662.00000000000	140.90900000000	10	60.33431644430	123340.21875000000	164943	41
6	801	1152570.00000000000	-598661.00000000000	76.66660000000	11	584.66316388700	107960.71093800000	157941	41
7	1056	1152480.00000000000	-597984.00000000000	19.68590000000	11	799.73853204900	98264.26562500000	157941	41
8	1907	1152760.00000000000	-600014.00000000000	43.88530000000	11	144.87086947500	111137.16406300000	157941	41
9	2497	1152670.00000000000	-599337.00000000000	52.10310000000	11	359.94973568200	112065.33593800000	157941	41
10	439	1153330.00000000000	-613036.00000000000	87.45290000000	12	120.90257411000	100713.92187500000	172124	41
11	855	1171650.00000000000	-611859.00000000000	36.13650000000	17	650.78865678700	83513.75000000000	164943	41
12	1960	1175560.00000000000	-613378.00000000000	54.29860000000	18	397.10435032700	153665.81250000000	164943	41
13	594	1137250.00000000000	-612489.00000000000	17.03570000000	21	555.81556141000	57709.64453130000	95243	41
14	698	1138360.00000000000	-611647.00000000000	26.33340000000	21	309.95919322900	63007.31640630000	95243	41
15	627	1174160.00000000000	-612195.00000000000	74.73800000000	28	210.91977396400	87539.35156250000	164943	41
16	291	1168640.00000000000	-599177.00000000000	98.89990000000	34	183.80351630700	152946.46875000000	164943	41
17	167	1154270.00000000000	-619802.00000000000	19.19400000000	36	128.83449109300	95880.45312500000	172124	41
18	655	1154360.00000000000	-620479.00000000000	15.98360000000	36	179.18523395200	104101.72656300000	172124	41
19	390	1135100.00000000000	-623813.00000000000	0.01646130000	37	656.54398838100	2467.01586914000	12768	32
20	2097	1135190.00000000000	-624490.00000000000	2.32407000000	37	255.58300279400	2640.97851563000	12768	32
21	1172	1152770.00000000000	-608976.00000000000	100.18900000000	39	416.79954411600	183718.93750000000	172124	41
22	51	1173810.00000000000	-592241.00000000000	93.49570000000	42	343.65933463200	240511.85937500000	164943	41

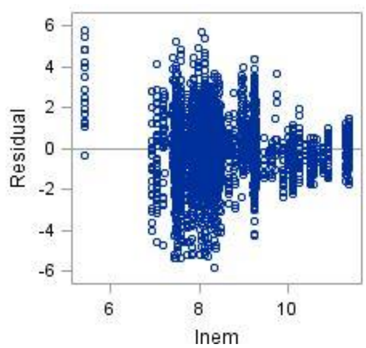
Figure 5.4 Final Data Set Ready for Regression Analysis

After processing C-Line data sets, the key variables were (1) NO_x and $PM_{2.5}$ concentration levels (in microgram/m^3 unit), (2) the distance from the location of these observations to their nearest road links (in meters), (3) the specific road links' truck volume and average speed (AADT and MPH). All of these were used as input for the next stage of analysis. Figure 5.4 shows one of the final data sets for Atlanta. Note that NO_x_ppb_ (this is converted later to NO_2 in microgram/m^3) and the last four columns (NEAR_DIST, RASTERVALU[9], AADT, and MPH) are the main input of the least squares regression.

Results of Regression Analysis

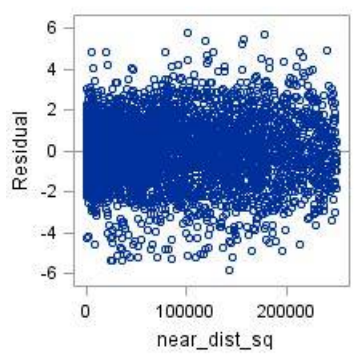
Regression of ln(NO_2)

The least squares regression results for NO_2 are shown in Table 5.1. Because C-Line produced NO_x in ppb, a conversion factor of 1.88 was used to calculate NO_x in microgram/m^3 (Department of Environmental Science, AARHUS University, 2015), and then another conversion factor of 0.8 was applied to obtain concentration levels of NO_2, from NO_x.



Note: Residuals are from the regression of ln(NO_2) on all variables

Figure 5.5 Heteroscedastic Errors by Log-Transformed Total Emission



Note: Residuals are from regression of ln(NO_2) on all variables

Figure 5.6 Homoscedastic Errors by Squared Distance

[9] As explained previously, RASTERVALU shows road density weighted by traffic volume for each grid cell across the State of Georgia. The size of a grid cell is ¼ mile by ¼ mile, and the search radius is 1 mile from the grid cell centroid. This value was calculated using a built-in ArcGIS Geoprocessing tool (Spatial Analyst Tools>Density>Line Density). This variable is included in its root term and interaction terms with other variables to control for any differences in dispersion rate of pollutants over distance from line sources, which is due to the denser/sparser road network around receptors.

Initially, the regression exhibited the issue of heteroscedasticity. Among the independent variables, the log transformed total emission from the closest road segment (i.e. ln(*EM*) in the regression model) corrects the issue of unequal variances in errors. Figure 5.5 shows that the residuals from the least squares regression differ in terms of their maximum and minimum (or a vertical range) by the values of ln(*EM*). Compare Figure 5.5 to Figure 5.6 where the same least squares residuals are plotted against the squared distance between individual communities and their nearest road segments, or x^2. Figure 5.6 shows similar relative variation in residuals for each and every value of the *near_dist_sq*.

In Figure 5.5, one of the basic assumptions behind the Ordinary Least Squares regression is violated.. Although this violation does not lead to biased coefficient estimates, heteroscedasticity makes the least squares estimation inefficient. In other words, the standard errors for individual slope coefficients are larger, and thus, the least squares regression model would have the type II error, which is to reject the statistical significance of certain variables in the model when in fact the variables are significant.

To address the problem of heteroscedasticity, we used heteroscedasticity consistent standard errors instead of standard errors for regression coefficients. This was developed by White (1980), and found to be more efficient than the least squares estimates, and of course, consistent. Table 5.1 compares the two sets of standard errors. It contains the regression result for ln(NO_2) on all other independent variables. Note that slope coefficients are the same, but for some variables, the heteroscedasticity consistent standard errors are smaller than standard errors, implying that we can avoid the type II errors.

Table 5.1: Regression Result of ln(NO_2)

Parameter Estimates													
							Heteroscedasticity Consistent						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standard Error	t Value	Pr > |t|	95% Confidence Limits		Heteroscedasticity Consistent 95% Confidence Limits	
Intercept	Intercept	1	-35.87334	1.27160	-28.21	<.0001	2.01788	-17.78	<.0001	-38.36627	-33.38040	-39.82932	-31.91735
lnem		1	7.30676	0.28063	26.04	<.0001	0.42966	17.01	<.0001	6.75659	7.85692	6.46441	8.14910
lnemsq		1	-0.31104	0.01551	-20.06	<.0001	0.02254	-13.80	<.0001	-0.34145	-0.28064	-0.35524	-0.26685
near_dist	NEAR_DIST	1	-0.01705	0.00104	-16.33	<.0001	0.00102	-16.80	<.0001	-0.01910	-0.01501	-0.01904	-0.01506
near_dist2		1	-0.02057	0.00325	-6.33	<.0001	0.00367	-5.61	<.0001	-0.02694	-0.01421	-0.02777	-0.01338
near_dist3		1	-0.01069	0.00158	-6.74	<.0001	0.00163	-6.57	<.0001	-0.01379	-0.00758	-0.01387	-0.00750
near_dist5		1	0.00947	0.00145	6.53	<.0001	0.00126	7.51	<.0001	0.00662	0.01231	0.00699	0.01194
near_dist_sq		1	0.00001043	0.00000207	5.05	<.0001	0.00000213	4.90	<.0001	0.00000638	0.00001448	0.00000625	0.00001460
near_dist_sq2		1	0.00003530	0.00000640	5.51	<.0001	0.00000752	4.69	<.0001	0.00002275	0.00004786	0.00002055	0.00005005
near_dist_sq3		1	0.00001583	0.00000314	5.04	<.0001	0.00000340	4.66	<.0001	0.00000967	0.00002199	0.00000916	0.00002249
near_dist_sq5		1	-0.00000520	0.00000286	-1.82	0.0690	0.00000264	-1.97	0.0492	-0.00001081	4.056134E-7	-0.00001039	-1.75587E-8
den2		1	1.36820	0.34797	3.93	<.0001	0.30566	4.48	<.0001	0.68602	2.05038	0.76897	1.96743
den3		1	0.67997	0.17474	3.89	0.0001	0.15581	4.36	<.0001	0.33740	1.02254	0.37451	0.98544
den4		1	-0.08067	0.07705	-1.05	0.2952	0.08191	-0.98	0.3248	-0.23172	0.07038	-0.24126	0.07992
den5		1	-1.00485	0.16467	-6.10	<.0001	0.13543	-7.42	<.0001	-1.32768	-0.68201	-1.27034	-0.73935

The number of observations (or receptors) in the ln(NO_2) model is 4,761 that is even lower than 5,193 that are within 500 meters from the nearest road links. To control for any outliers, or to exclude any extreme values from the model, only those observations are used whose NO_2 are within 1% percentile and 99% percentile. Table 5.2 indicates specific values for 0.1, 1, 5, 95, 99, and 99.9 percentiles for NO_2 concentration levels. Moreover, those observations that are within 5 meters and 495 meters (=500 meters - 5 meters) are included in the analysis.

Number of Observations Used	4761

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	14	33499	2392.81596	1112.10	<.0001
Error	4746	10212	2.15162		
Corrected Total	4760	43711			

Root MSE	1.46684	R-Square	0.7664
Dependent Mean	0.57444	Adj R-Sq	0.7657
Coeff Var	255.34945		

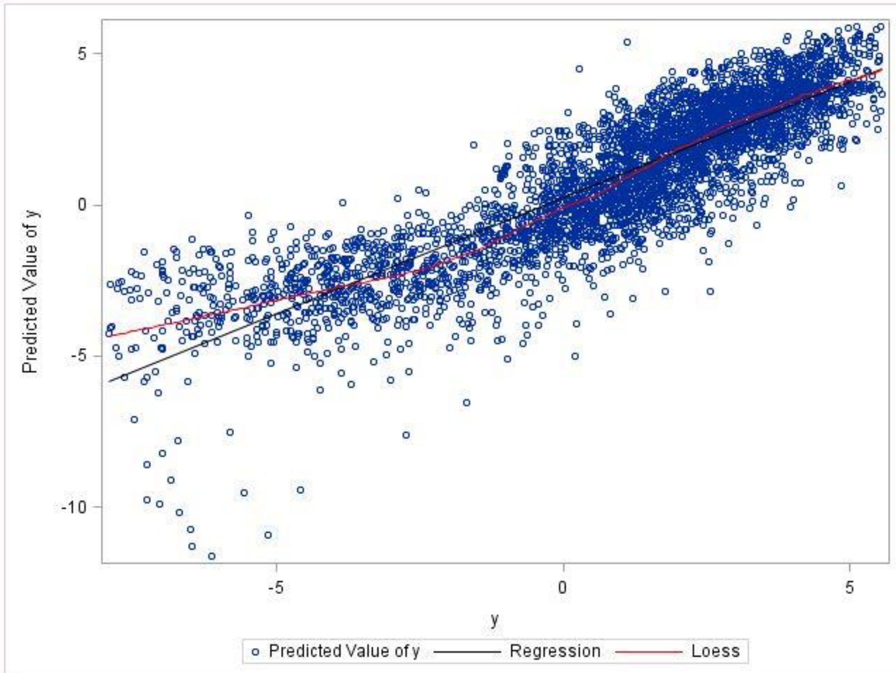
Figure 5.7 Regression of ln(NO2) Measures for Fitness

Figure 5.7 shows the R square of the ln(NO_2) model is 0.7664. The correlation of ln(NO_2) and estimated ln(NO_2) is 0.8754 (not reported in Figure 5.7). Although not ideal, we can claim that the least squares regression model with heteroscedasticity consistent standard errors is reliable for the goal of this study, and can be used to analyze the health impacts of traffic-induced air pollution, and their geographic distribution in the State of Georgia.

Table 5.2: Specific NO_2 Concentration Levels for Different Percentiles

Percentile	0.10%	1%	5%	95%	99%	99.90%
NO_2(microgram/m^3)	0.000052	0.000352	0.001757	82.255400	263.320000	892.896000

The scatter plot between the estimated ln(NO_2) from the regression and the ln(NO_2) modeled in C-Line is in shown in Figure 5.8. Though there is a nonlinearity between these two values to some extent, it is not a serious problem for the purposes of this study.



Note: y axis-predicted ln(NO_2), x axis-ln(NO_2) from C-Line

Figure 5.8 Scatter Plot for NO_2

In Figure 5.8, the black line in the plot shows the regression line, and the red line indicates the Loess line. The Loess line implies that there seems to be a nonlinear relationship between predicted ln(NO_2) and actual ln(NO_2)[10]; and the degree of this nonlinearity varies by the values of actual ln(NO_2). The larger the actual ln(NO_2) values, the smaller are the nonlinearity. Note that the maximum annual average NO_2 level that the US EPA allows is 53 microgram/m^3, which is 3.98 in log form. This indicates that, if we are concerned about those areas exceeding the US EPA ambient air quality standards, then in this range where actual ln(NO_2) is over 3.98, the regression model works quite well. This is because in this range, there is no serious nonlinearity between predicted ln(NO_2) and actual ln(No_2). Note that there is another range in the left side, where the nonlinearity may be a serious problem, e.g. where ln(NO_2) is smaller than zero. However, given that ln(NO_2) ≤ 0 means $NO_2 \leq 1$ microgram/m^3, and our reference category in the analysis of "relative" health impacts by freight is this range of below 1 microgram/m^3, any nonlinearity in this range to a little extent would not be a significant problem, although this is not an ideal situation. We need to keep in mind that this regression analysis is based on modeling results from C-Line, and some key variables are not included due to limited resources and data availability (e.g. meteorological conditions). Given these

[10] An "actual" ln(NO_2) in this context means the ln(NO_2) obtained from C-Line. Because there is a small number of "real world" observations in the State of Georgia, this study attempts to replicate the C-Line result of ln(NO_2) using the least squares regression techniques, as though the C-Line result represents an "actual" level of air pollution induced by traffic. Based on our search (EPA Air Data website and email correspondence in August 2015 with DeAnna Oser, the Ambient Program Manager in GA EPD), the numbers of actual monitoring observations are fewer than 10 for annual average NO_2, and only 17 for annual average $PM_{2.5}$ in 2007. With these small numbers, a typical least squares regression cannot be run.

limitations, we have obtained reliably high quality results to proceed to the next step.

Regression of ln($PM_{2.5}$)

The same procedure as above was employed to produce the least squares slope coefficients obtained from regression of ln($PM_{2.5}$) on all other independent variables. The results are in Figure 5.9 through 5.11. Table 5.3 contains the same kind of information for $PM_{2.5}$ as Table 5.2 does for NO_2 in order to exclude any outliers. The regression results for the least square and the least square with White robust standard errors are included in Table 5.4. Figure 5.9 includes the goodness of fit of the regression model to the data set, Figure 5.10 indicates that the correlation coefficients between predicted and actual $PM_{2.5}$ concentration levels is fairly high, around 0.9, and Figure 5.11 shows both linear regression line and LOESS line implying the same as the previous NO_2 case.

Table 5.3: Specific $PM_{2.5}$ Concentration Levels for Different Percentiles

Percentile	0.10%	1%	5%	95%	99%	99.90%
$PM_{2.5}$(microgram/m^3)	0.000006	0.000019	0.000090	5.049190	16.974300	46.281100

Number of Observations Used	4780

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	13	35218	2709.06105	1188.42	<.0001
Error	4766	10864	2.27954		
Corrected Total	4779	46082			

Root MSE	1.50982	R-Square	0.7642
Dependent Mean	-2.30942	Adj R-Sq	0.7636
Coeff Var	-65.37642		

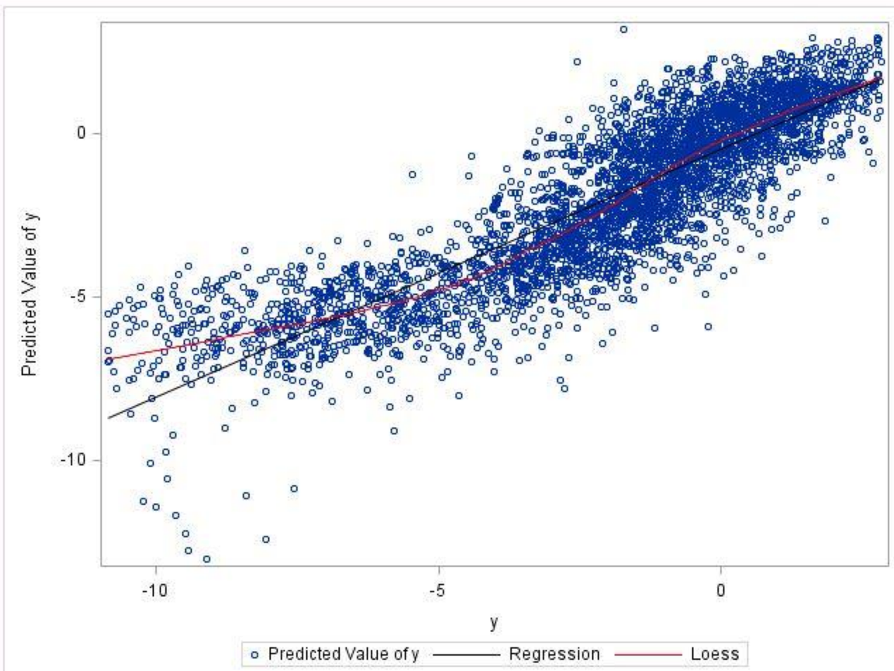
Figure 5.9 Regression of ln($PM_{2.5}$) Measures for Fitness

Variable	N	Mean	Std Dev	Sum	Minimum	Maximum	Label
y	4780	-2.30942	3.10526	-11039	-10.84579	2.82876	
yhat	4780	-2.30942	2.71464	-11039	-13.03377	3.17789	Predicted Value of y

Pearson Correlation Coefficients, N = 4780 Prob > |r| under H0: Rho=0		
	y	yhat
y	1.00000	0.87421
		<.0001
yhat	0.87421	1.00000
Predicted Value of y	<.0001	

Note: y is Actual ln(PM2.5) and yhat is predicted ln(PM2.5)

Figure 5.10 Correlation Coefficients for $PM_{2.5}$



Note: y axis-predicted ln($PM_{2.5}$), x axis-ln($PM_{2.5}$) from C-Line

Figure 5.11 Scatter Plot for $PM_{2.5}$

Table 5.4: Regression Result of ln(PM2.5)

Parameter Estimates													
							Heteroscedasticity Consistent						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Standard Error	t Value	Pr > |t|	95% Confidence Limits		Heteroscedasticity Consistent 95% Confidence Limits	
Intercept	Intercept	1	-49.37142	1.90577	-25.91	<.0001	2.11582	-23.33	<.0001	-53.10761	-45.63523	-53.51941	-45.22343
lnem		1	6.79544	0.30552	22.24	<.0001	0.32750	20.75	<.0001	6.19648	7.39441	6.15340	7.43749
lnemsq		1	-0.21618	0.01221	-17.70	<.0001	0.01256	-17.21	<.0001	-0.24012	-0.19224	-0.24080	-0.19155
near_dist	NEAR_DIST	1	-0.01647	0.00076014	-21.67	<.0001	0.00069010	-23.87	<.0001	-0.01796	-0.01498	-0.01783	-0.01512
near_dist2		1	-0.01784	0.00335	-5.33	<.0001	0.00366	-4.87	<.0001	-0.02441	-0.01128	-0.02502	-0.01066
near_dist3		1	-0.01322	0.00143	-9.24	<.0001	0.00148	-8.92	<.0001	-0.01602	-0.01042	-0.01613	-0.01031
near_dist5		1	0.00689	0.00037206	18.52	<.0001	0.00035823	19.23	<.0001	0.00616	0.00762	0.00619	0.00759
near_dist_sq		1	0.00000937	0.00000145	6.45	<.0001	0.00000133	7.02	<.0001	0.00000652	0.00001222	0.00000676	0.00001199
near_dist_sq2		1	0.00002874	0.00000657	4.38	<.0001	0.00000740	3.88	0.0001	0.00001587	0.00004161	0.00001423	0.00004326
near_dist_sq3		1	0.00002124	0.00000280	7.58	<.0001	0.00000309	6.87	<.0001	0.00001574	0.00002673	0.00001518	0.00002730
den2		1	1.32141	0.35849	3.69	0.0002	0.30990	4.26	<.0001	0.61860	2.02422	0.71387	1.92895
den3		1	0.89765	0.16830	5.33	<.0001	0.14902	6.02	<.0001	0.56771	1.22759	0.60550	1.18980
den4		1	-0.14483	0.07918	-1.83	0.0674	0.08291	-1.75	0.0807	-0.30006	0.01040	-0.30737	0.01771
den5		1	-1.01113	0.12218	-8.28	<.0001	0.10974	-9.21	<.0001	-1.25067	-0.77159	-1.22627	-0.79600

In Figure 5.11, the nonlinearity between predicted ln($PM_{2.5}$) and actual (or C-Line) ln($PM_{2.5}$) seems more severe, compared to the previous NO_2 case. However, once actual ln($PM_{2.5}$) is over 0 (or $PM_{2.5}$ is greater than 1 microgram/m^3), then this nonlinearity almost disappears. Moreover, note that this study uses the scaling factor developed by nationally renowned air quality modeling expert Dr. Russell at Georgia Tech (his scaling factor was introduced in the previous section). Therefore, again this slight nonlinearity would not be a serious problem in this study.

Estimation of NO_2 and $PM_{2.5}$ along the Georgia Freight Corridor

This step calculated pollutants concentration levels for NO_2 and $PM_{2.5}$ for individual communities that are located within 400 meters from the Georgia Freight Corridor. The study area for this part of the analysis was delineated using census block groups and the 400-meter corridor buffer, resulting in 3,708 segmented block groups ("communities"). When referring to the total population of the study area, we mean the population of these segmented block groups near the freight corridors. Two target years were considered here, 2007 and 2040, and relevant information such as truck volume and average speed for individual road links were obtained from the FAF3.4 dataset. Given that only truck traffic was considered in this process, the analysis in this step can be understood as the "marginal" contribution of Georgia freight movement to ambient air quality of those who live next to the freight corridor.

The same emission factors were used for both years of 2007 and 2040. Note that this approach implies that any improvements in vehicle technologies are not taken into account. In other words, it assumes no changes in fleet mix, only assuming that volumes change for individual freight corridor links. In the FAF3.4, truck volumes are approximately doubled for most of the Georgia Freight Corridor links.

Table 5.5: Estimated Pollutants Concentration Levels by Freight

Category	All communities	Urban communities	Small urban communities	Rural communities
# of communities along the Georgia Freight Corridor	3,708	2,462	815	431
NO2 in 2007 (microgram/m3)				
mean	2.80	4.00	0.38	0.54
median	0.11	0.19	0.02	0.01
standard deviation	8.18	9.77	1.38	1.83
0th percentile (min)	0.00	0.00	0.00	0.00
25th percentile	0.01	0.06	0.00	0.00
50th percentile (median)	0.11	0.19	0.02	0.01
75th percentile	0.79	2.16	0.13	0.08
95th percentile	17.59	23.56	2.21	3.83
99th percentile	40.82	46.85	5.95	7.08
100th percentile (max)	100.73	100.73	20.12	18.00
NO2 in 2040 (microgram/m3)				
mean	7.97	11.08	1.63	2.24
median	0.60	0.94	0.13	0.04
standard deviation	20.05	23.60	5.80	7.08
0th percentile (min)	0.00	0.00	0.00	0.00
25th percentile	0.09	0.33	0.01	0.00
50th percentile (median)	0.60	0.94	0.13	0.04
75th percentile	3.58	8.29	0.67	0.46
95th percentile	46.90	60.29	8.88	12.06
99th percentile	101.42	109.47	24.80	37.15
100th percentile (max)	228.95	228.95	84.85	66.03
PM2.5 in 2007 (microgram/m3)				
mean	0.14	0.19	0.04	0.04
median	0.04	0.08	0.01	0.01
standard deviation	0.27	0.32	0.07	0.08
0th percentile (min)	0.00	0.00	0.00	0.00
25th percentile	0.01	0.02	0.00	0.00
50th percentile (median)	0.04	0.08	0.01	0.01
75th percentile	0.13	0.20	0.04	0.04
95th percentile	0.60	0.79	0.18	0.21
99th percentile	1.52	1.61	0.34	0.33
100th percentile (max)	3.26	3.26	0.71	0.63
PM2.5 in 2040 (microgram/m3)				
mean	0.40	0.53	0.13	0.14
median	0.13	0.20	0.04	0.03
standard deviation	0.68	0.77	0.30	0.35
0th percentile (min)	0.00	0.00	0.00	0.00
25th percentile	0.04	0.07	0.01	0.00
50th percentile (median)	0.13	0.20	0.04	0.03
75th percentile	0.38	0.67	0.13	0.12
95th percentile	1.83	2.08	0.51	0.66
99th percentile	3.34	3.51	1.33	2.00
100th percentile (max)	5.77	5.77	3.63	3.13

This approach would show a reference estimation, against which any policy interventions or technological advancements would be calculated and checked to see their individual or aggregate effects on ambient air quality.

In this section, analyses by location type (e.g. urban, small urban, and rural) and by subpopulation (e.g. seniors, youth, minority, and low income households) were included. Due to lack of resources and data, the proportion of each subpopulation to the total is assumed to be constant from 2007 to 2040. However, demographic changes mean that these proportions will likely change. For example, the proportion of the subpopulation aged 65 and older will likely increase.

Table 5.5 shows estimated NO_2 and $PM_{2.5}$ concentration levels for each geographic category (urban, small urban, and rural) and for 2007 and 2040. In Table 5.5, mean, median, standard deviation, 0^{th}, 25^{th}, 50^{th}, 75^{th}, 95^{th}, 99^{th}, and 100^{th} percentile values are specified for all three location types and for both years. It is clear that without changes in the fleet mix (e.g. retirement of old trucks) and/or technological improvements (e.g. less polluting vehicles), air quality along the Georgia Freight corridor will worsen in 2040. In terms of the mean concentration, both NO_2 and $PM_{2.5}$ levels will be three times higher in 2040 compared to 2007. However, the 2040 estimation in this table is not realistic, given that no changes in either/both fleet mix and vehicle technology is unlikely, and stricter environmental regulation could be passed in the near future. Thus, the prediction in the Table 5.5 needs to be interpreted as a reference to help quantify specific amounts of improvements in ambient air quality by any measures that will be taken by both public and private sectors. Further analysis is required to identify regulations and incentives that would be most efficient in reducing negative public health impacts in Georgia.

As expected, urban communities near freight corridors were more highly exposed to the two pollutants, NO_2 and $PM_{2.5}$, than small urban and rural counterparts in all 10 measurements. The results also reveal that rural communities have higher pollutant concentration values for 95^{th} and 99^{th} percentiles than small urban communities for all four estimates (NO_2 and $PM_{2.5}$ for 2007 and 2040), though their concentration levels are below the EPA ambient air quality standards. This implies that there are some rural communities in Georgia which are exposed to a large amount of freight traffic and thus are negatively affected to a greater degree than denser small urban areas.

As a next step, subpopulation analysis was conducted. This step answers the question of who lives in those communities that experience *relatively* more or less pollution from nearby freight movement. If certain subgroups among the total population are always (or in most cases) exposed to more severe levels of traffic-induced air pollution, then transportation planners and engineers need to prepare appropriate actions to prevent this disparity in the future. In Table 5.6 and Table 5.7, the columns show different percentages of certain subgroups among the population, and the rows indicate different levels of air pollution.

For NO_2, the current EPA ambient air quality standard for annual mean is 53 ppb, or 99.64 microgram/m^3.

It is good to see that there is almost no communities whose NO_2 concentration levels are over this threshold in 2007. However, in the 2040 scenario, there would be 38 communities (in urban areas) among 3,708 along the Georgia Freight Corridor, if we do not have any changes in fleet mix, technological advancements, and/or stricter environmental regulation.

Table 5.6: Vulnerable Subpopulations by NO_2 Exposure Levels

NO_2 levels (2007)	# of communities	% youth	% senior	% minority	% African American	% Hispanic	% poor
Lower than 19.64	3,547	**22.0%**	**10.2%**	47.0%	36.1%	11.4%	21.7%
19.64~39.64	119	20.8%	7.8%	**56.3%**	**39.7%**	**20.0%**	**23.8%**
39.64~59.64	31	19.0%	7.0%	**67.1%**	**46.8%**	**15.0%**	**26.2%**
59.64~79.64	8	12.0%	8.1%	**48.8%**	36.0%	8.6%	21.5%
79.64~99.64	2	9.7%	7.3%	**50.8%**	**41.9%**	12.0%	**26.9%**
Greater than 99.64	1	0.8%	2.7%	41.8%	23.0%	6.6%	**30.2%**
Average (for 3,708)	3,708	21.8%	10.0%	48.1%	36.6%	12.1%	21.9%
NO_2 levels (2040)	**# of communities**	**% youth**	**% senior**	**% minority**	**% African American**	**% Hispanic**	**% poor**
Lower than 19.64	3,238	21.8%	**10.5%**	44.9%	33.8%	11.6%	21.7%
19.64~39.64	233	**24.9%**	8.0%	**63.0%**	**53.6%**	9.7%	21.4%
39.64~59.64	109	20.4%	8.5%	**57.0%**	**45.5%**	**13.6%**	21.4%
59.64~79.64	67	20.8%	6.6%	**56.1%**	35.4%	**23.5%**	**24.6%**
79.64~99.64	23	**24.3%**	8.3%	**59.8%**	**41.6%**	**18.4%**	**24.4%**
Greater than 99.64	38	15.5%	7.9%	**62.4%**	**51.2%**	9.4%	**26.5%**
Average (for 3,708)	3,708	21.8%	10.0%	48.1%	36.6%	12.1%	21.9%

Note: Numbers in red font represent higher than the average of all 3,708 communities

Table 5.7 Vulnerable Subpopulations by $PM_{2.5}$ Exposure Levels

$PM_{2.5}$ levels (2007)	# of communities	% youth	% senior	% minority	% African American	% Hispanic	% poor
Lower than 1.0	3,616	**21.9%**	**10.1%**	47.5%	36.4%	12.0%	**22.0%**
1.0~1.5	53	19.5%	8.7%	**61.1%**	**46.7%**	10.9%	21.6%
1.5~2.0	27	**21.8%**	6.3%	**51.5%**	**25.2%**	**22.6%**	**19.3%**
2.0~2.5	11	17.9%	6.8%	**49.6%**	34.1%	9.2%	**26.7%**
2.5~3.0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Greater than 3.0	1	14.5%	**17.8%**	**82.3%**	**79.5%**	6.6%	**26.3%**
Average (for 3,708)	3,708	21.8%	10.0%	48.1%	36.6%	12.1%	21.9%
$PM_{2.5}$ levels (2040)	**# of communities**	**% youth**	**% senior**	**% minority**	**% African American**	**% Hispanic**	**% poor**
Lower than 1.0	3,216	**21.8%**	**10.5%**	45.0%	33.9%	11.6%	21.7%
1.0~1.5	218	**23.4%**	8.5%	**59.9%**	**49.9%**	9.7%	21.0%
1.5~2.0	123	**22.0%**	8.5%	**59.6%**	**46.1%**	**16.5%**	**22.3%**
2.0~2.5	68	20.9%	6.1%	**56.8%**	36.4%	**23.3%**	**25.7%**
2.5~3.0	27	**23.3%**	8.5%	**49.3%**	**38.0%**	10.1%	20.4%
Greater than 3.0	56	17.4%	8.6%	**61.2%**	**51.3%**	8.5%	**24.7%**
Average (for 3,708)	3,708	21.8%	10.0%	48.1%	36.6%	12.1%	21.9%

Note: Numbers in red font represent higher than the average of all 3,708 communities

In Table 5.6 and Table 5.7, each row indicates specific percentages of certain subpopulations who live along the freight corridor in Georgia. The NO_2 concentration levels are grouped in ranges of 20 microgram/m^3 that increase from the first row to each subsequent row; likewise, $PM_{2.5}$ concentration levels are grouped in ranges of 0.5 microgram/m^3. Exposure to NO_2 and $PM_{2.5}$ increases moving down the rows of the table.

The subgroups in Table 5.6 and Table 5.7 were either reported to be more vulnerable to harmful air pollution than the average people in the population, or to have been treated inequitably in terms of exposure to environmental hazards (Gunier et al., 2003; Rowangould, 2013). Red-colored percentages indicate that of the population experiencing a particular pollutant concentration level, the *proportion* of the affected subpopulation is *higher* than the proportion of that subpopulation out of the total population living near freight corridors. For example, whereas individuals below the poverty line make up 21.9% of the population across the study area of 3,708 communities near freight corridors, they make up 30.2% of everyone affected by the highest concentration of NO_x and 26.3% of everyone affected by the highest concentration of PM2.5 – poor people are disproportionately affected by higher levels of pollution. Thus, red-marked percentages are located towards the lower rows of Tables 5.6 and 5.7 imply that these vulnerable or minority subpopulations experience more pollution from nearby heavy-trafficked freight corridors than populations near freight corridors that are white, that are more wealthy, or that are not young or elderly.

It is clear that, in 2007, minority (non-white), African Americans, those with Hispanic origins, and those under poverty levels were exposed to high levels of NO_2 and $PM_{2.5}$ by freight movement in Georgia, and this trend does not change much in 2040. Among these subgroups, African Americans and non-white minorities more broadly show much higher percentages than the averages, implying that these two groups need to be targeted first when transportation planners and engineers prepare appropriate measures to alleviate any disproportionate exposer to subgroups in the population. Unfortunately, the impact of freight emissions on minorities and African Americans will become disproportionately high by 2040 as shown in Table 5.6 and Table 5.7. Though 2007 data shows that these groups comprise a lower proportion of those affected by the highest NO_2 levels (41.8% affected were minorities and 23% were African Americans, specifically, though these groups comprise 48.1% and 36.6%, respectively, of the total population near freight corridors), they will make up a disproportionately larger portion of those that will experience the highest NO_2 levels in 2040. Holding constant the demographic distribution of the total study area population, in the 2040 scenario, the number of areas with high NO_2 levels will increase, and those affected will be composed of 62.4% minorities, with 51.2% African Americans, even though these groups would still be assumed to make up only 48.1% and 36.6% of the total population. Thus, how much these gaps can be reduced by specific actions can be another very important research project in the future.

Based on results of this study, children under 15 or seniors over 65 were not disproportionately exposed to high levels of air pollution, compared to the minority subpopulations and those living below poverty in

2007. However, still there may be an issue of over-exposure of youth to air pollutants, especially for $PM_{2.5}$ in 2040. In 2007, the percentages of children up to 15 years old were smaller than the average (again, the column average meaning the average of youth under 15 for all 3,708 communities along the Georgia Freight Corridor) especially for the areas with higher $PM_{2.5}$ concentration levels (e.g. greater than 2 microgram/m^3). However, in 2040, it is predicted that the same subpopulation would consist of 23.3% of those who live with 2.5 to 3.0 microgram/m^3 in $PM_{2.5}$, which is higher than the average by about 1.5% point. In contrast, seniors seem to live farther from heavy-trafficked freight corridors in both 2007 and 2040. The only exception is a single community that had 17.8% of seniors in 2007 (higher than its average by approximately 8%), who were exposed to more than 3.0 microgram/m^3 of $PM_{2.5}$. However, this single observation (only one in 3,708) cannot be generalized.

Figure 5.12 through 5.15 are visualization of Table 5.6 and Table 5.7. Figure 5.12 and Figure 5.13 show the proportion of each subpopulation exposed to different levels of NO_2 estimated for 2007 and 2040 respectively. Figure 5.14 and Figure 5.15 visualize the same information by different levels of $PM_{2.5}$ modeled for 2007 and 2040 respectively. In addition, Figure 5.16 through 5.19 represent geographic distributions of the key pollutants in this report, NO_2 and $PM_{2.5}$, for 2007 and 2040. Figure 5.16 and Figure 5.18 contain NO_2 and $PM_{2.5}$ concentration levels of those communities along Georgia Freight Corridor in 2007, and Figure 5.17 and Figure 5.19 display the same information in 2040. Figure 5.17 and 5.19 clearly show that without advanced vehicle technology, fleet mix change, and public intervention, the air quality of those neighborhoods located next to highly trafficked roads will worsen significantly.

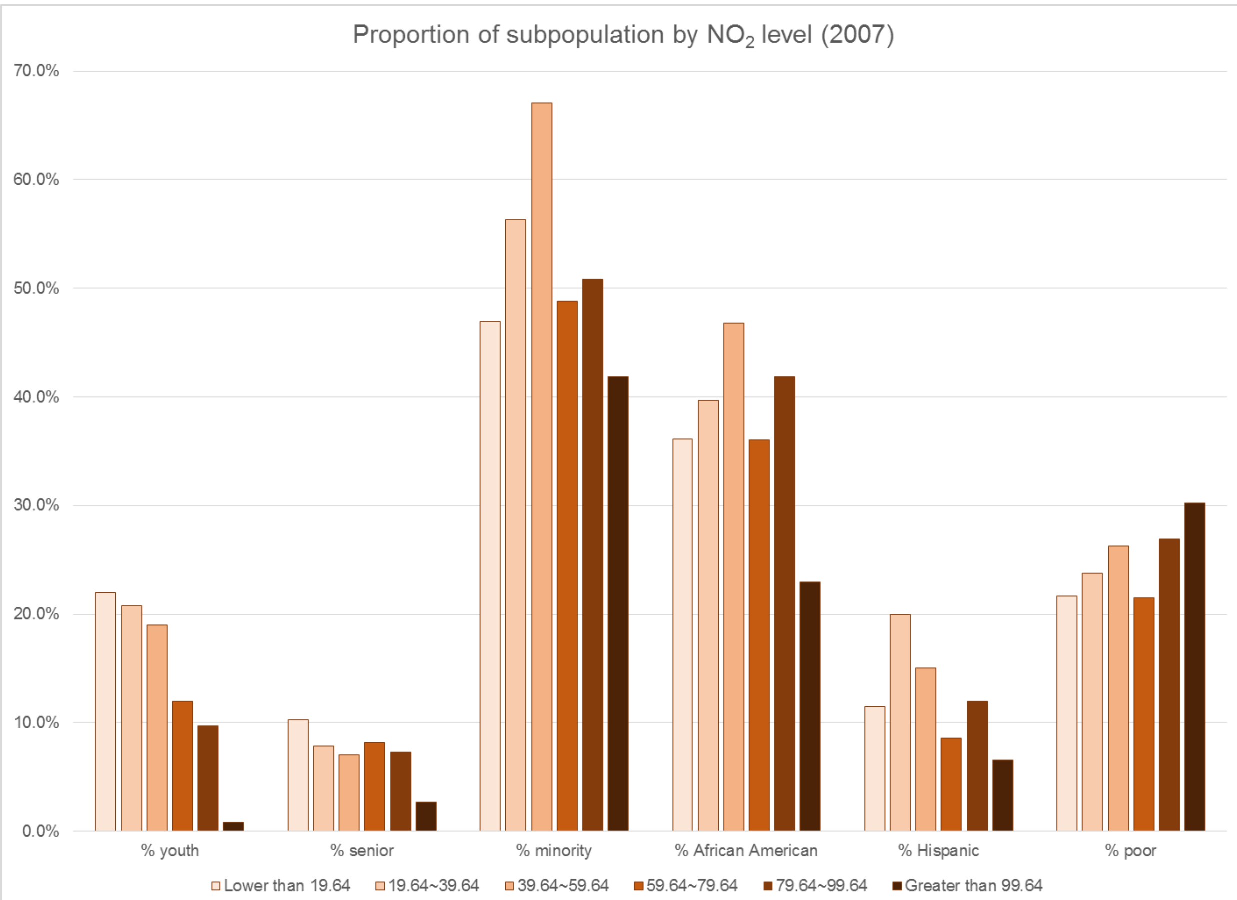


Figure 5.12: Fraction of Population Affected by NO_2 in 2007

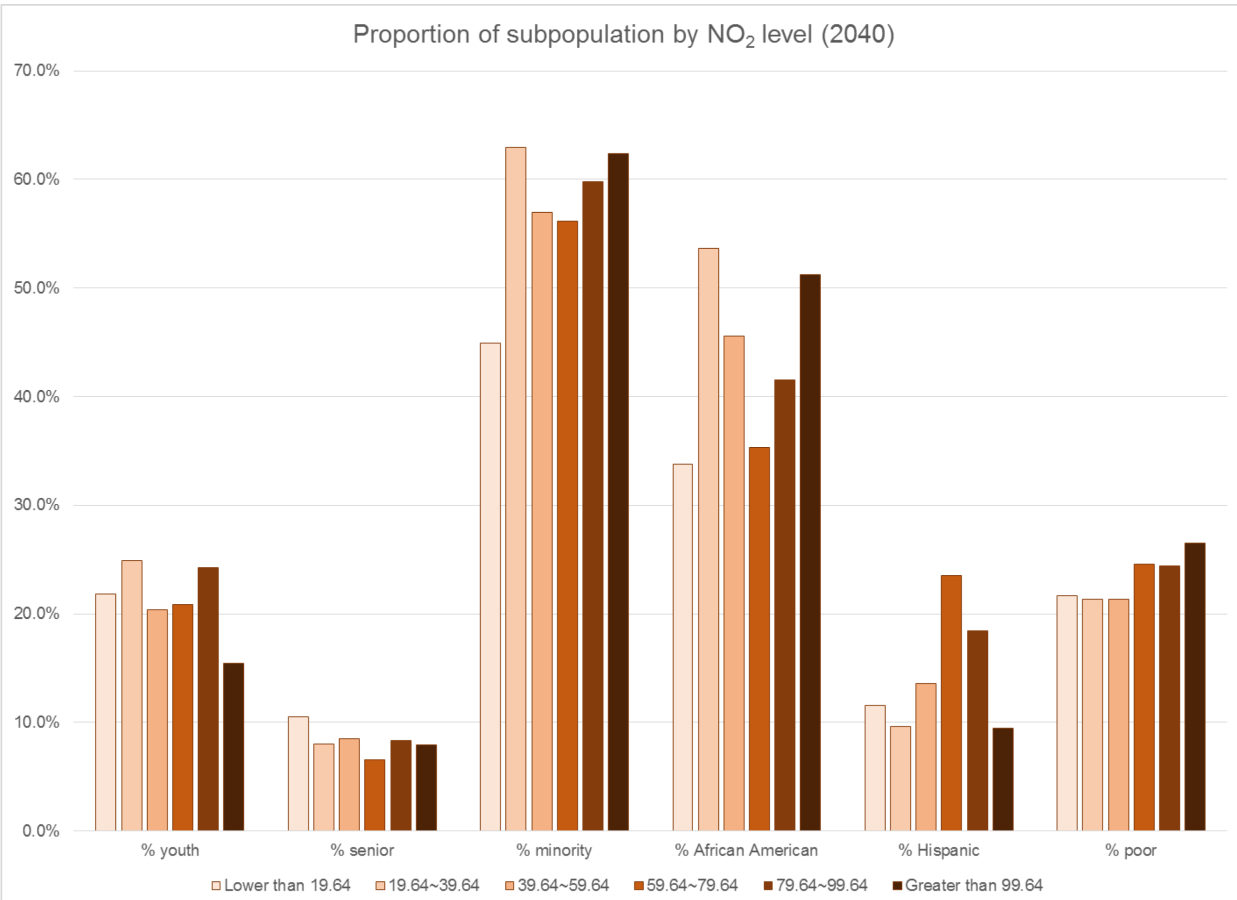


Figure 5.13: Fraction of Population Affected by NO_2 in 2040

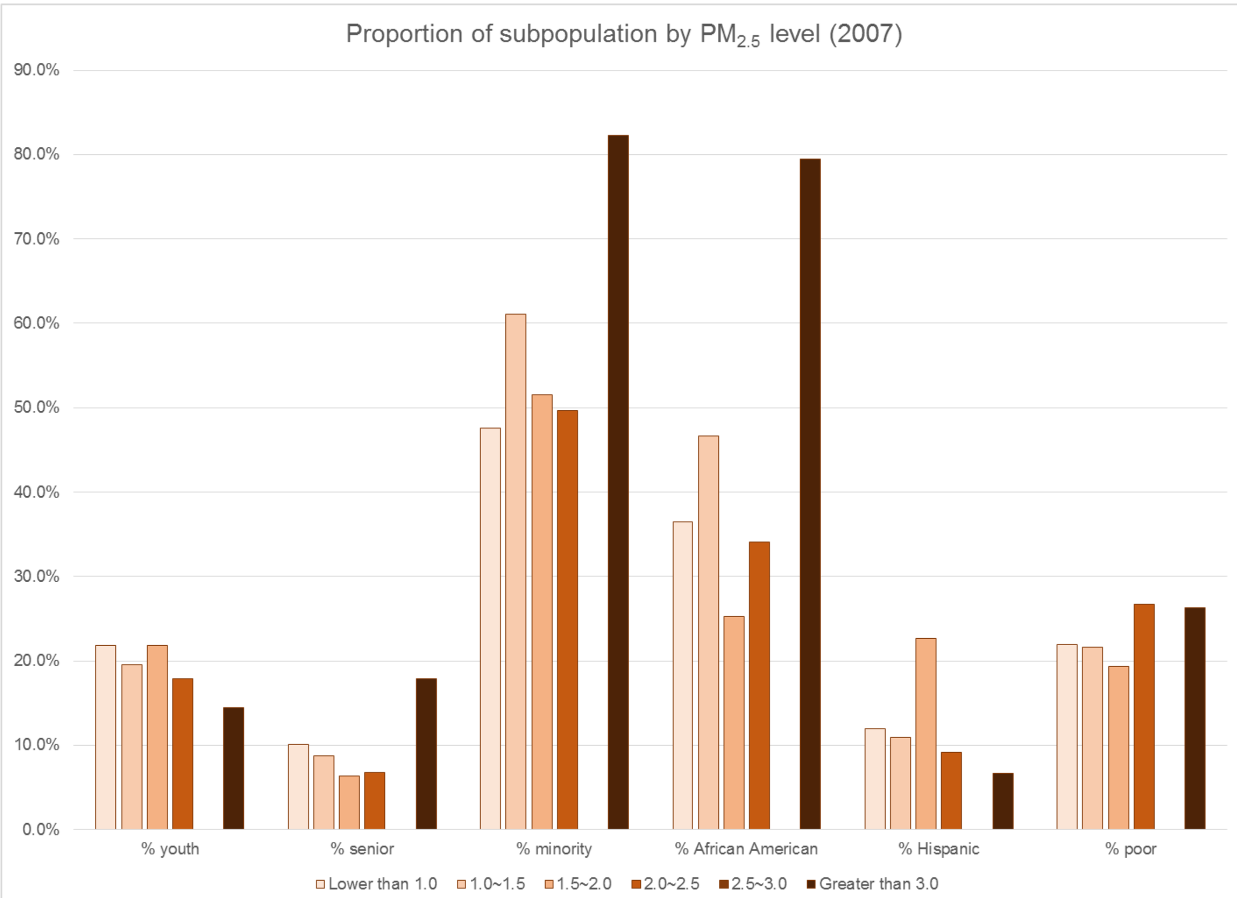


Figure 5.14: Fraction of Population Affected by $PM_{2.5}$ in 2007

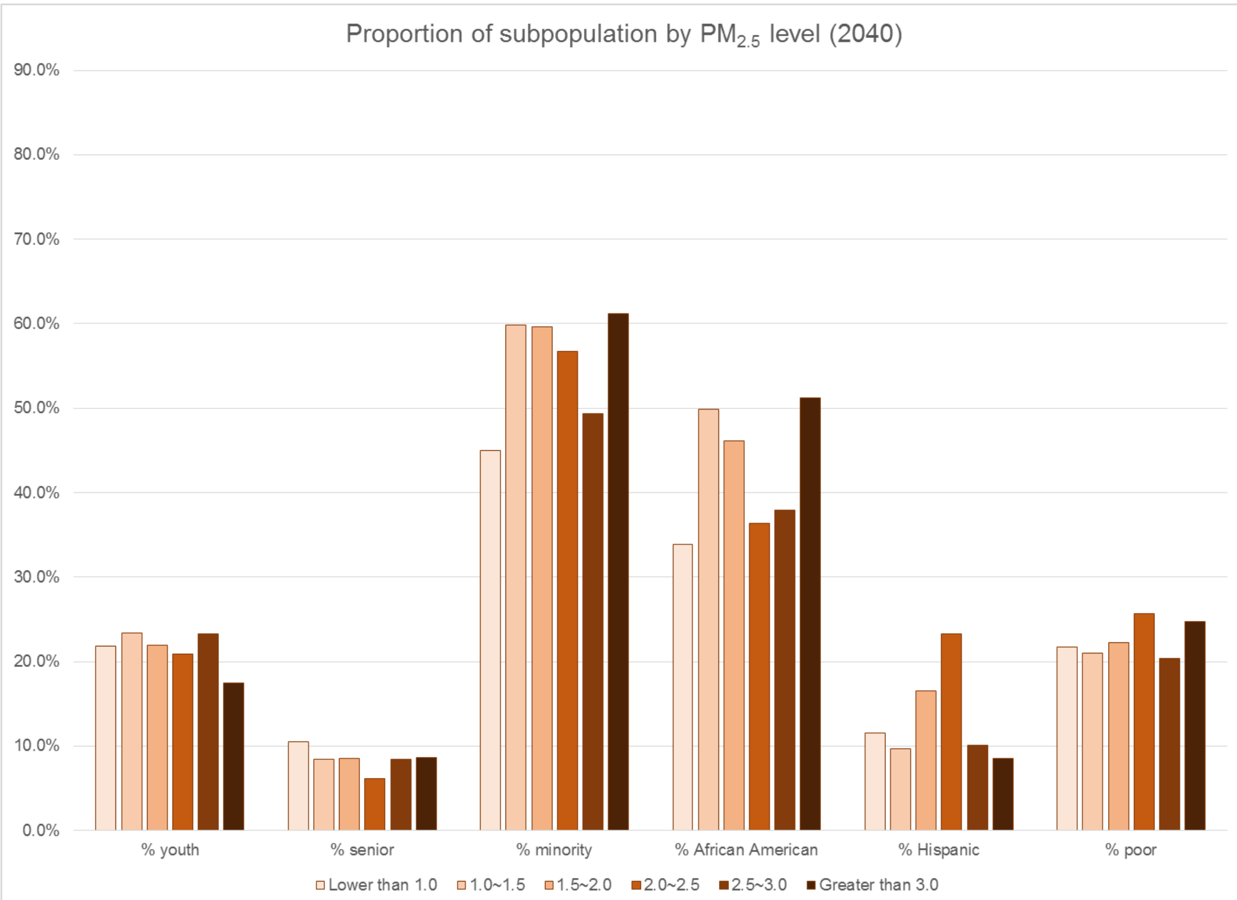


Figure 5.15: Fraction of Population Affected by $PM_{2.5}$ in 2040

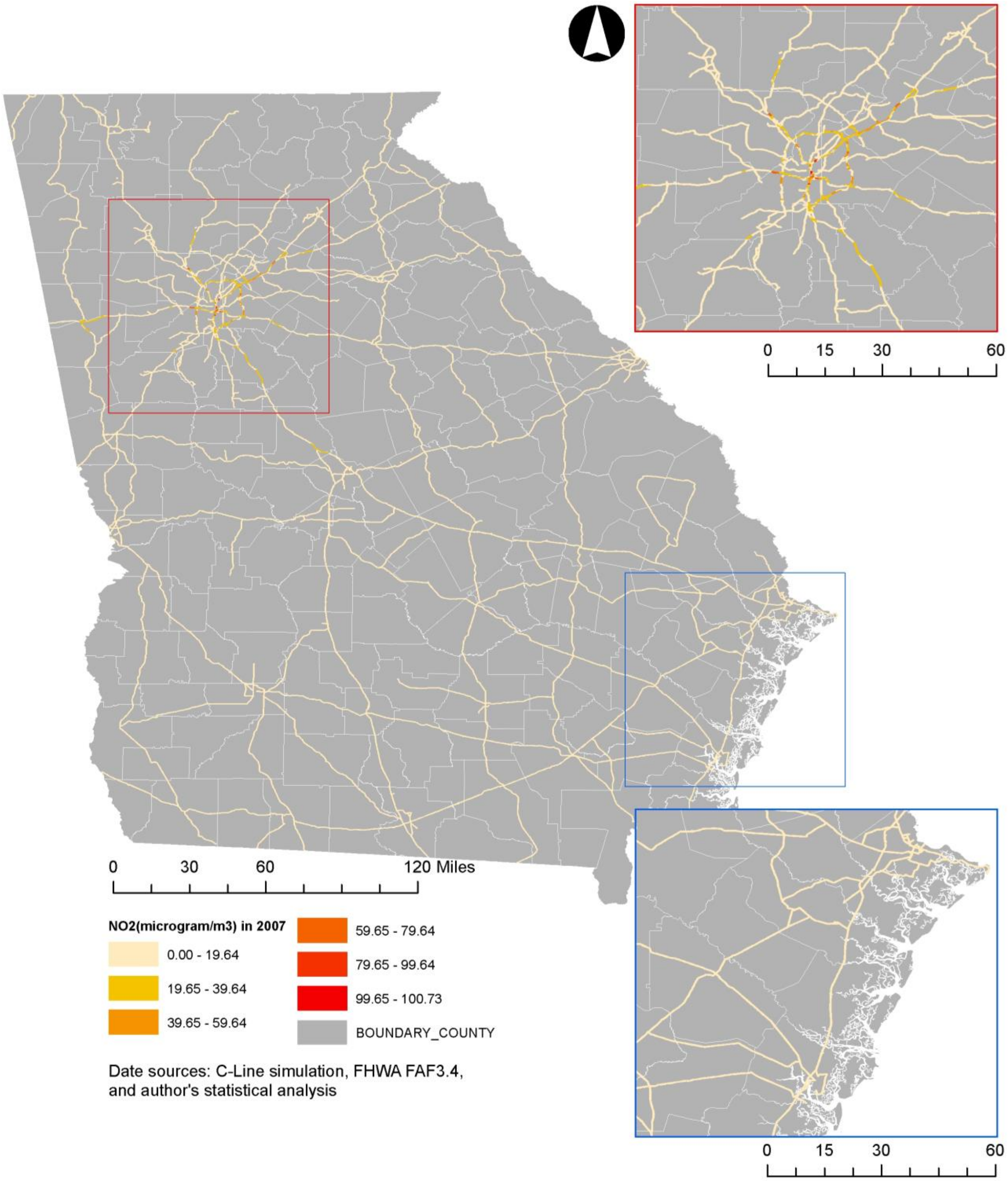


Figure 5.16 NO_2 Estimation for 2007

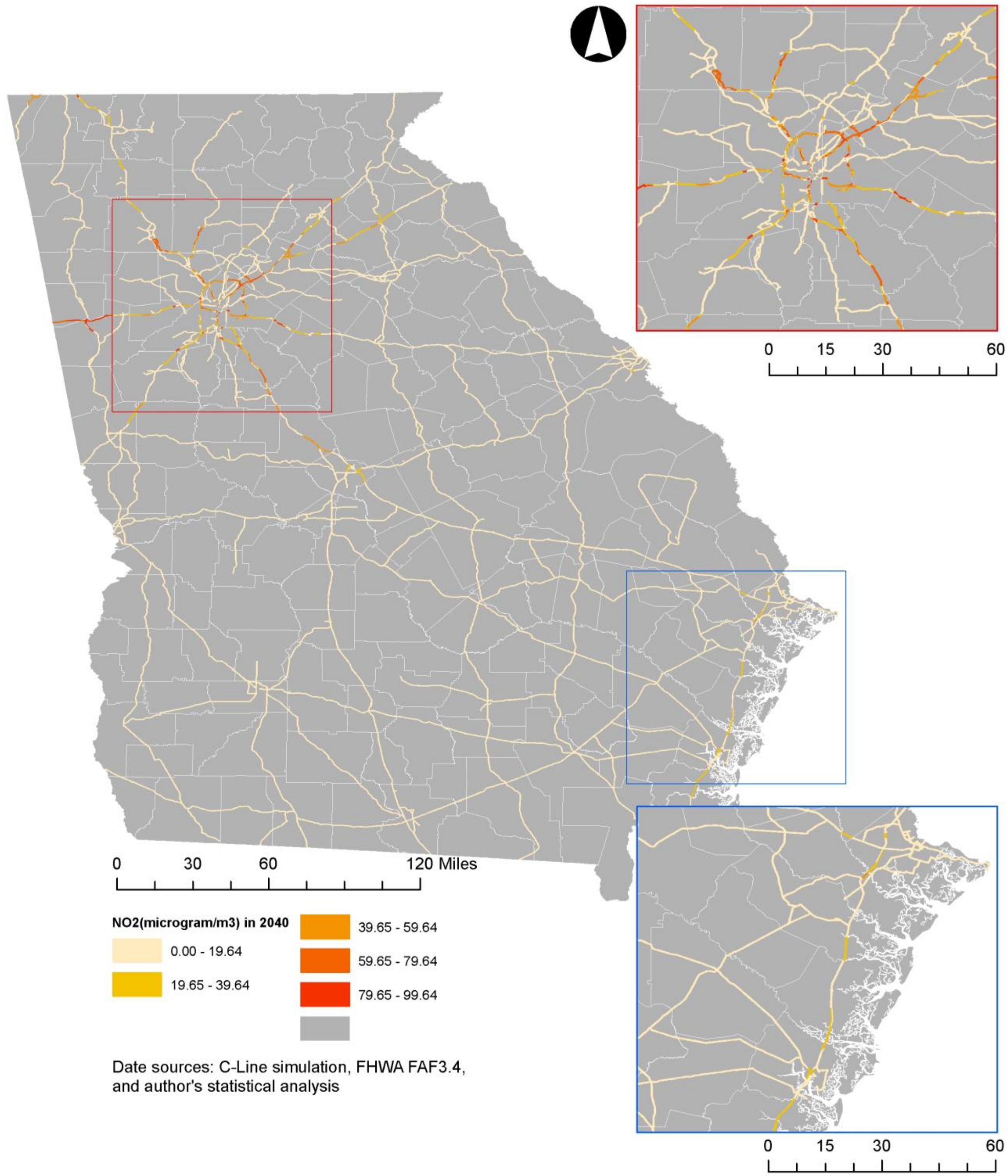


Figure 5.17 NO_2 Estimation for 2040

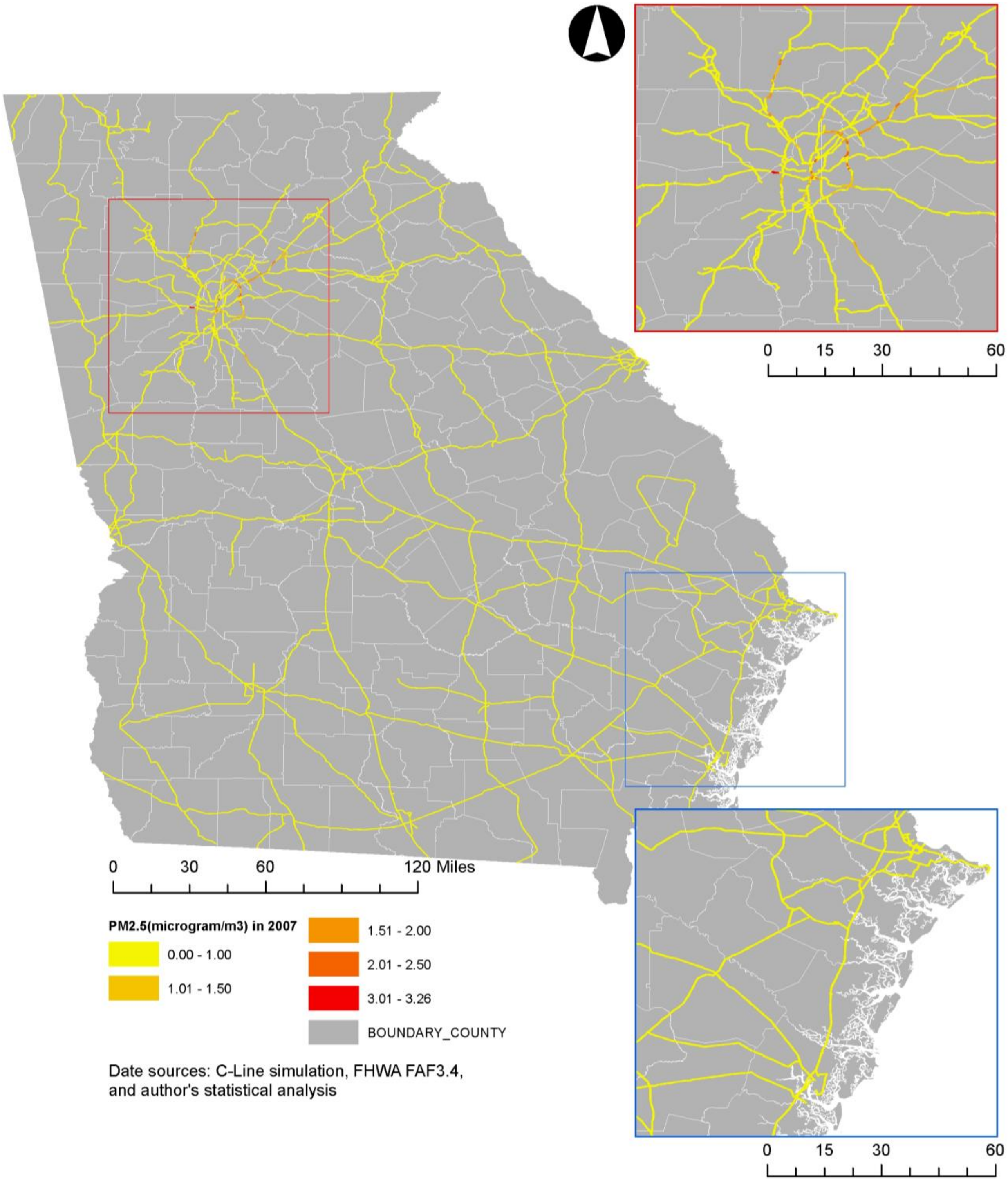


Figure 5.18 $PM_{2.5}$ Estimation for 2007

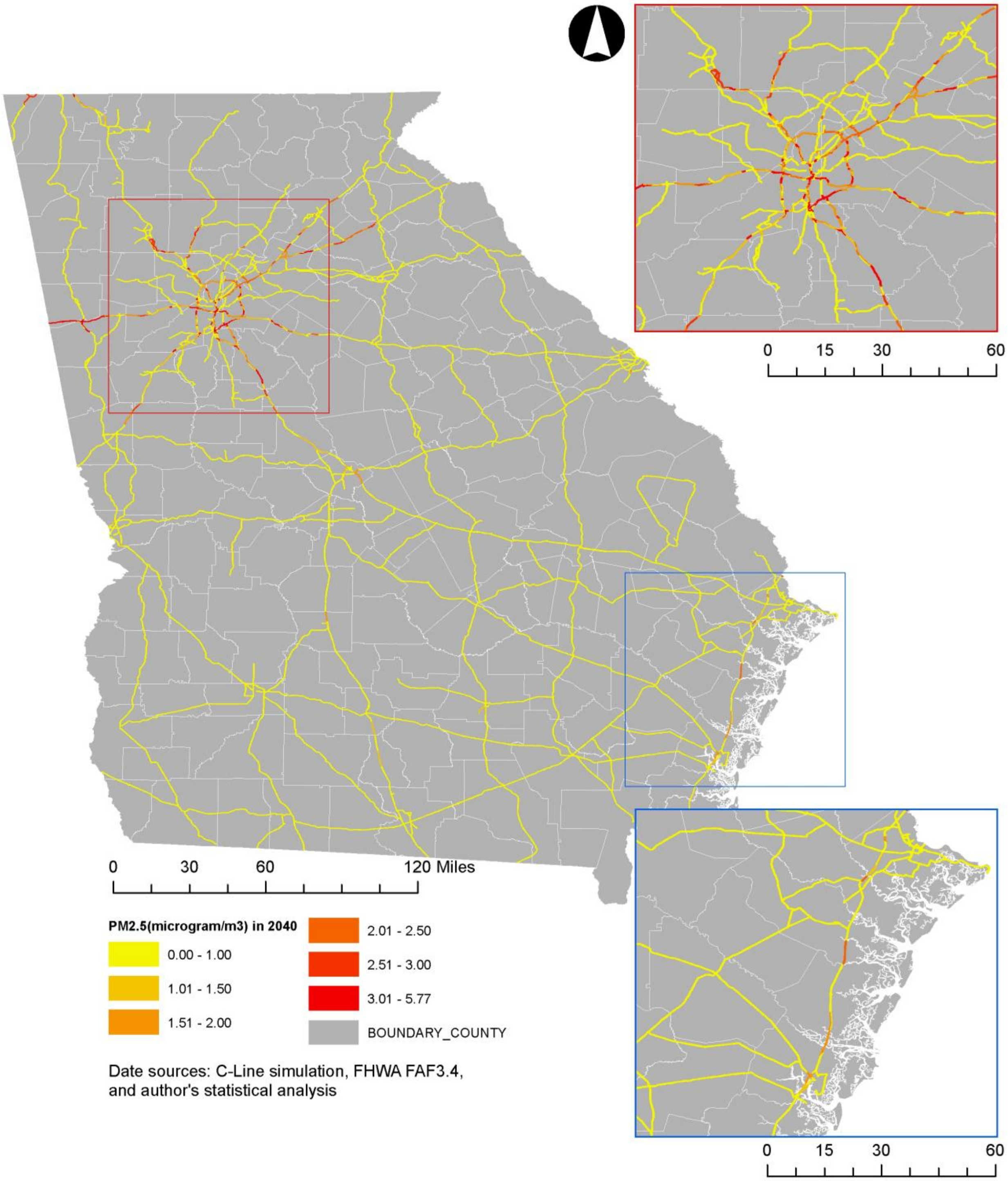


Figure 5.19 $PM_{2.5}$ Estimation for 2040

Health Risk Analysis

Table 5.8 and Table 5.9 show relative health risks for a set of serious diseases that have been reported to be associated with traffic-related air pollution. Table 5.8 and Table 5.9 are produced based on odds ratios of the critical diseases that were introduced in the previous literature review section. Two important dimensions are added; the level of NO_2 and $PM_{2.5}$ concentration levels at individual communities along the Georgia Freight Corridor, and two years, 2007 and 2040. In Table 5.8 and 5.9, each column shows different levels of NO_2 and $PM_{2.5}$ levels; i.e. the far left column (the reference level) represents the lowest exposure to the pollutants and the far right column indicates the highest exposure. In the first five rows, the number of residents and communities, and the percentage of the population experiencing specific concentration levels in 2007 and 2040 are calculated. Note that there is no row specifying the number of residents in each pollution level in 2040, because we do not have accurate population predictions at geographic unit as small as the Census block group. Therefore, to see any changes in population distribution across different levels of NO_2 and $PM_{2.5}$ between 2007 and 2040, we need to see any differences in their percentages. As explained previously, if there are no changes in fleet mix, vehicle technology, and environmental regulations, then more communities and higher percentages of people would be exposed to higher levels of NO_2 and $PM_{2.5}$ that are emitted by freight in Georgia.

The next rows in Table 5.8 and Table 5.9 contain relative health risks for those who experience specific air pollution levels, compared to the reference category, the lowest NO_2 and $PM_{2.5}$ levels. Note that most values in those rows are calculated based on the odds ratios in the literature, and non-linear formulas are employed to produce final estimates, so these values should be understood in comparison to the far left columns (the reference showing the baseline). For instance, if we set the risk of first COPD incidence as “1” for the reference air pollution level, then those who live at the highest NO_2 level would have 3.769 times higher risk compared to those who live at the lowest NO_2 levels. Note that, in 2007, those who live in the highest exposure category were lower than 0.3% of the population along the corridor; however, in 2040, the people in this category is expected to increase up to 3% of those who live close to freight movement. Thus, as pollutant concentration levels increase, health risks become more severe. In 2040, more people will be exposed to both high levels of freight-induced air pollution and resultant health risks, if economic and policy solutions do not aim to prevent the degradation of air quality.

Table 5.8 Health Risk by NO_2 in 2007 and 2040

NO_2 levels (microgram/m^3)				**0 ~ 19.64**	**19.64~ 39.64**	**39.64~ 59.64**	**59.64~ 79.64**	**79.64~ 99.64**	**99.64 ~**
2007									
# of residents				1,247,819	96,217	33,543	5,372	2,266	2,658
# of communities				3547	119	31	8	2	1
% of residents for those near the corridor				89.9%	6.9%	2.4%	0.4%	0.2%	0.2%
2040									
# of communities				3238	233	109	67	23	38
% of residents for those near the corridor				78.7%	7.6%	4.9%	4.4%	1.3%	3.0%
Relative Health Risks	RR/ OR+	Per NO_2	subpopulation						
Chronic obstructive pulmonary disease (COPD) first incidence	1.08	5.8	all	1.000	1.304	1.700	2.217	2.891	3.769
% increase in daily hospital admissions for acute respiratory infections *	+1.09 %	22.3	all		+3.9%	+7.7%	+11.5%	+15.3%	+19.1%
first coronary events (cases fatal within 28 days or out-of-hospital deaths)	1.03	10	all	1.000	1.061	1.126	1.194	1.267	1.344
Lung cancer mortality	2.81	37.1864	female	1.000	1.743	3.038	5.296	9.232	16.093
Respiratory-related mortality	1.37	30	female	1.000	1.234	1.522	1.877	2.315	2.856
Diabetes diagnosis	1.04	1.88	female	1.000	1.518	2.304	3.496	5.307	8.054
physician-confirmed asthma	1.09	6.768	female children-3rd to 5th grade	1.000	1.290	1.664	2.147	2.769	3.573
new-onset asthma	2.17	44.368	kindergarten and first-grade children	1.000	1.418	2.011	2.851	4.043	5.732

*Note: * increase in percentage point compared to the reference category (the lowest exposure), + Relative Risk (RR) if Cox Proportional Hazard model is used, OR (Odds Ratio) if logistic regression is used.*

Table 5.9 Health risk by $PM_{2.5}$ in 2007 and 2040

$PM_{2.5}$ levels (microgram/m^3)				Lower than 1.0	1.0~1.5	1.5~2.0	2.0~2.5	2.5~3.0	Greater than 3.0
2007									
# of residents				1,304,344	47,289	24,969	10,859	0	415
# of communities				3616	53	27	11	0	1
% of residents for those near the corridor				94.0%	3.4%	1.8%	0.8%	0.0%	0.0%
2040									
# of communities				3216	218	123	68	27	56
% of residents for those near the corridor				77.3%	7.3%	6.0%	4.3%	1.5%	3.6%
Relative Health Risks	RR/ OR+	Per $PM_{2.5}$	subpopulation						
all-cause mortality	1.06	10	all	1.000	1.003	1.006	1.009	1.012	1.015
cardiopulmonary mortality	1.09	10	all	1.000	1.004	1.009	1.013	1.017	1.022
lung-cancer mortality	1.14	10	all	1.000	1.007	1.013	1.020	1.027	1.033
% increases in respiratory hospital admissions*	+3.1 %	3.8	under 1-yr old		+0.4%	+0.8%	+1.2%	+1.6%	+2.0%
% increases in respiratory hospital admissions*	+2.9 %	3.8	between 1-4 yr		+0.4%	+0.8%	+1.1%	+1.5%	+1.9%
physician diagnosis of otitis and respiratory infections	1.13	3.2	under 2-yr old	1.000	1.019	1.039	1.059	1.079	1.100
doctor-diagnosed asthma ever	1.32	3.3	under 4-yr old	1.000	1.043	1.088	1.135	1.183	1.234
childhood incident asthma	1.30	17.4	kindergarteners and 1st graders	1.000	1.008	1.015	1.023	1.031	1.038
prevalent asthma	1.26	3.2	under 8-yr-old	1.000	1.037	1.075	1.114	1.155	1.198
incident asthma	1.28	3.2	under 8-yr-old	1.000	1.039	1.080	1.123	1.167	1.213
asthma symptoms	1.15	3.2	under 8-yr-old	1.000	1.022	1.045	1.068	1.091	1.115

*Note: * increase in percentage compared to the reference category (the lowest exposure), + Relative Risk (RR) if Cox Proportional Hazard model is used, OR (Odds Ratio) if logistic regression is used.*

SECTION VI: CONCLUSION

Review of Research Question and Methodology

The primary purpose of this study was to analyze the health impacts of traffic-induced pollutants on small urban and rural communities along the Georgia Freight Corridor. This goal has been achieved by completing a set of tasks sequentially. In the first step, specific air pollution levels of these communities along the Georgia Freight Corridor were estimated, and then in the second step, health risks associated with pollutants concentration levels were evaluated for all the residents in these communities and particular subgroups; e.g. children, seniors, racial/ethnic minorities, and individuals living in poverty.

First Step (Estimation of Air Pollution Levels): In the first step, the study adopts a "two-stage" approach for estimating the air pollution concentration levels along the Georgia Freight Corridor. The first stage consisted of using the C-Line ambient air quality simulation model to obtain a NO_x and PM concentration levels for certain geographic locations in Georgia and the traffic information near these locations. The purpose of employing the C-Line simulation was to generate data set to be used as inputs for the regression analysis in the next stage. Therefore only a small number of representative areas in Georgia, and not the complete area along the freight corridor was selected for air quality simulation using C-Line. Since C-Line does not provide the NO_2 level directly, the analysis uses a conversion factor to obtain NO_2 level from the NO_x concentration level.

In the second stage, least squares regression was employed to obtain the statistical relationship between pollutants levels and characteristics of nearby freight movement. Then, this relationship was used to estimate actual pollutant concentration levels along Georgia Freight Corridor for the year 2007 and the year 2040. This allowed us to analyze whether any temporal changes can be expected in disaggregate air pollution levels by year 2040 at individual communities.

Although the final goal was to estimate specific measures of air quality along the Georgia Freight Corridor over time, the study chose the two-stage method over more complicated one-step methods after an evaluation of the trade-off between simplicity and consistency. In fact, the adopted two-stage methodology helped to overcome the barriers arising due to lack of resources and key data such as disaggregate population and demographic forecasts, and provided flexibility to obtain the best results for this report under these constraints.

Second Step (Evaluation of Health Risks): In the second step, the relative health risks posed by freight emissions were evaluated based on the estimates from the previous step and the Odds Ratios (OR) and Relative Risk (RR) in the literature. The previous stage produced specific levels of NO_2 and $PM_{2.5}$ concentration levels for individual census block groups along the Georgia freight corridor. Then, these pollution levels were converted to relative risks of having certain diseases due to the exposure to freight emissions, compared to those who are not exposed.

Findings of the Study

The study analyzed ten statistical measures for concentration levels for two important pollutants (NO_2 and $PM_{2.5}$) namely, the mean, median, standard deviation, 0th, 25th, 50th, 75th, 95th, 99th, and 100th percentile values. These ten measures were estimated and analyzed for urban, small urban, and rural location types, and for both years 2007 and 2040. The important outcomes and the findings from the analysis conducted in this study are listed below. These findings may guide planners and policy makers in strategic planning and decision making to overcome the health disparities of small urban and rural communities in future.

- Urban communities were more highly exposed to the two pollutants, NO_2 and $PM_{2.5}$, than small urban and rural counterparts in all 10 statistical measurements
- Rural communities often have higher values for 95th and 99th percentiles than small urban communities in all four estimations (NO_2 and $PM_{2.5}$ for 2007 and 2040), implying that there are some rural communities in Georgia that are exposed to a large amount of freight emissions, and are thus more negatively affected than small urban areas. Fortunately, their average annual estimated concentration levels are still below the EPA ambient air quality standards. (Note: these estimates is based on freight traffic only.)
- There are almost no census block groups whose NO_2 concentration level estimates are over the current EPA ambient air quality standard (annual mean 53 ppb, or 99.64 microgram/m^3) threshold in 2007. However, in the 2040 scenario, there would be 38 communities (in urban area) among 3,708 along the Georgia Freight Corridor that could experience freight emissions higher than national ambient air quality standards allow, assuming no changes in fleet mix, technological advancements, and/or stricter environmental regulation.
- The numerical estimates from this study indicate that in 2007, minority (non-white), African American, Hispanic, and below-poverty subpopulations were disproportionately exposed to high levels of NO_2 and $PM_{2.5}$ by freight movement in Georgia, and this pattern does not change much in 2040.
- The study results suggests that among the subgroups considered in this study, minorities and African Americans, specifically, are exposed to higher levels of NO_2 and $PM_{2.5}$ than the total population, implying that these two groups need to be targeted first when transportation planners and engineers prepare appropriate measures to alleviate any disproportionate exposure to vulnerable subpopulations.

- The discrepancy between the proportion of minorities and African Americans exposed to higher pollutant levels compared to the rest of the population seems to increase from 2007 to 2040 for both NO_2 and $PM_{2.5}$ generated by freight movement in Georgia.
- The results further indicate that children under 15 or seniors over 65 were not disproportionately exposed to bad air pollution, compared to the minority groups in 2007. However, there may be an issue of over-exposure of youth to air pollutants, especially for $PM_{2.5}$ in 2040.

Limitations of Study and Future Research Directions

The concentrations levels in this study are based on traffic volumes and speed data only. It does not take into consideration other sources of NO_x and PM sources such as construction, manufacturing and power plants. As such the estimated emission concentration levels may be less than the observed/measured levels in the study area.

The study also makes the assumption that emission factors are valid for future years, which may lead to overestimates as with improving technology the newer vehicles may be less polluting. In addition the vehicle mix may change in future. The autonomous vehicle technology is at the verge of deployment. This technology may drastically change both traffic characteristics (volume and density) as well as emission rates. Hence there are multiple uncertainties in future that can dictate the pollutant concentrations.

Although study analysis makes several simplifying assumptions for the estimation process, for example that demographic distributions remain the same, the results nonetheless provide many useful insights for policy makers and planners; the geographic distribution of areas experiencing high levels of freight emissions is likely to remain consistent even if the emission levels and demographic patterns change if the uncertainties stated above are factored in. These limitations and uncertainties of the present study provide opportunity for a more advanced and fine-grained study for future.

Recommendations

Based on the computational analysis, results, and findings of this study, the study makes the following recommendations:

Finer-scale geographic distribution of traffic-induced air pollution needs to be analyzed and updated.

This report reveals that there are a number of small urban and rural communities along the Georgia Freight Corridor whose levels of exposure to criteria air pollutants are higher than the EPA ambient air quality standards. This may contradict a naïve assumption that air pollution will only be a critical issue for those urban and suburban areas.For this reason, timely analysis and update of spatial distribution of traffic-induced air pollutions are of great importance in terms of public health for *all* residents in State of Georgia.

Though "county-level" analysis has been conducted and updated on an annual base by the Air Protection Branch in the Environmental Protection Division of Georgia Department of Natural Resources[11], finer-scale such as individual communities has not been dealt with properly. In addition, there are certain subpopulations who have been reported to be disproportionately more vulnerable and/or exposed to environmental harms than other groups. So, even though the size of small urban and rural communities may seem small compared to large metropolitan areas, residents of small urban and rural areas, particularly minority and low-income residents, may experience greater health risks.

Traffic-induced air pollution in small urban and rural communities needs to be taken into account for freight planning.

It is an obvious next step to take air pollution for small urban and rural communities into account when planning freight-related projects. For example, highly-trafficked freight corridors may need to be reviewed in terms of their air pollution impacts on surrounding small urban and rural communities. If necessary, analysis results can be used to support alternative policies and programs designed to reduce public health impacts on those communities. This may include regulating freight traffic in certain areas and instead, rerouting them to alternative areas where there will be smaller public health impacts on nearby communities.

The impact of freight emissions should be included in the decision-making process of locating facilities and land uses for vulnerable subpopulations.

As the literature has clearly pointed out, those who are more vulnerable to traffic-induced air pollutants than the general public need to be protected. For example, schools should be located far from the Georgia Freight Corridor. Any facilities supporting seniors, minorities, and those who live under poverty need to be located far enough from freight corridors to prevent disproportionate exposure to pollutants. Moreover, when evaluating current facilities and land use and/or reviewing plans for the future changes, these communities need to be informed of air pollution impacts and health risks.

[11] For example, the Air Protection Branch made the recent five annual reports available on the website (http://www.georgiaair.org/amp/report.php).

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