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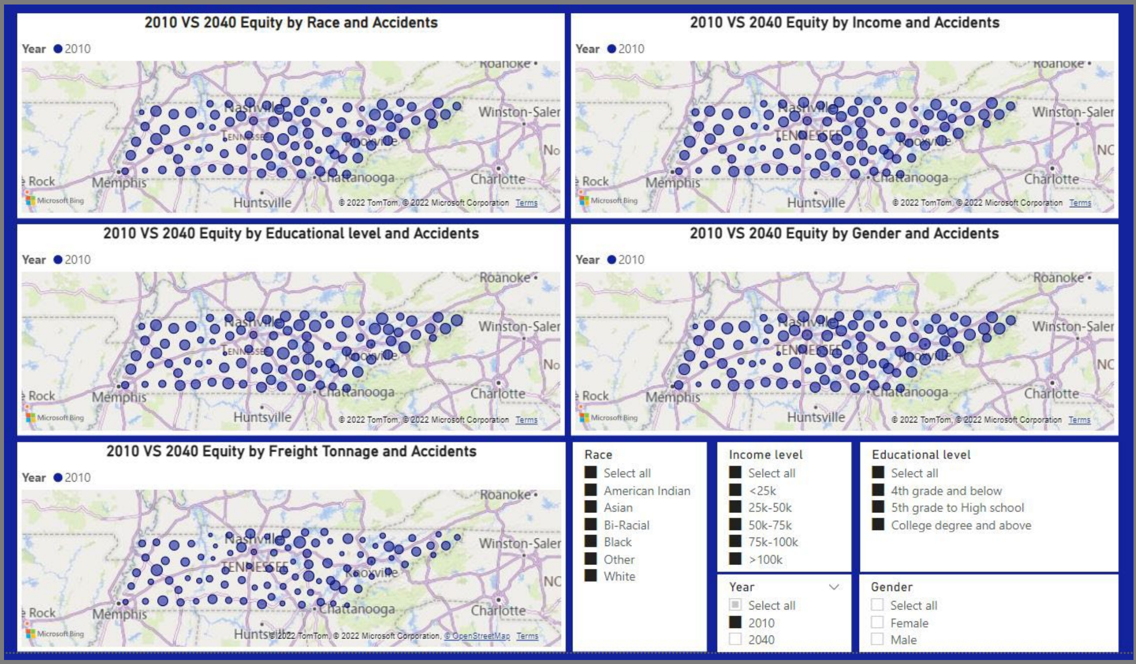

UNDERSTANDING FREIGHT IMPACTS ON TENNESSEE COMMUNITIES

Research Final Report from The University of Memphis | Mihalis Golias, Sabyasachee Mishra, Mitra Salehi Esfandarani, Neda Nazemi | August 31, 2022

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THE UNIVERSITY OF MEMPHIS

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16. Abstract

This research reviewed the negative impacts of freight activity in rural/suburban areas and developed tools to help decision makers identify the extent of these impacts in multiple contexts, including environmental, economic, safety, and security. In this study, a complete review of the public-sector initiatives (e.g., programs, project, and policies) were collected and are provided to assist decision makers in mitigating the externalities resulting from freight activity in rural/suburban communities while optimizing costs and benefits for all stakeholders. These initiatives are categorized into three major groups: environmental, social, and economic. A complete comparison between the initiatives is provided to give the decision maker a broad view to select the mitigation strategy based on their preference. Finally, possible future challenges according to current developments and future planning are provided. The research also developed a dynamic online and desktop tool to evaluate freight movement equity at the county level for various characteristics (e.g., race, education, income etc.)

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Executive Summary

Tennessee's economy is considered a ***"goods-dependent industry,"*** with most goods moved by trucks on a roadway network that consists approximately of 73 percent of rural roadways, and 77 miles designated as critical rural freight corridors (out of a total of 211 miles allowed by the federal government) [1]. A significant amount of freight is further moved by rail affecting a smaller number of counties but still a notable amount of both urban and rural populations. Inland waterways and air complete the picture with a significantly smaller number of counties being directly affected; a number that can increase due to changes in mode split if they do not operate efficiently. Even though urban areas have received most of the attention, freight movements and their impacts on rural areas cannot be overlooked, especially for a state like Tennessee. Rural areas can be the lifeline of several freight industries, and, if not adequately supported, can lead to a disproportionate increase of freight-related externalities to the local communities. This research developed a suburban/rural community-focused freight impact and mitigation guidebook for the Tennessee Department of Transportation (TDOT). The guidebook can help decision makers identify freight externalities in multiple contexts and provides a list of mitigation strategies for these externalities that minimize costs and maximize benefits for all the stakeholders. Achieving the latter objective is very important as buy-in from all the stakeholders (not only the community) is necessary for any solution to be implementable and long-lasting.

The study had multiple research objectives that are all focused toward achieving the common goal of developing guidance for transportation planners, engineers, and practitioners at local/regional agencies and TDOT. Most notably, this study aimed to identify and evaluate alternatives for freight investment to simultaneously improve freight movements and quality of life of the communities they serve. During this study, various freight movement related externalities were identified from an exhaustive literature review. The research team used various available (proprietary and public) datasets to quantify (where possible) freight movement externalities at the county and traffic analysis zone (TAZ) level. The project also developed online and desktop tools that provide data analytics capabilities to identify high freight intensity and externalities areas, areas of low equity, and the mitigation strategies that can be implemented to alleviate the effects of these externalities. The mitigation strategies and their ranking are based on effectiveness, cost, and implementation difficulty and vary by mode.

Key Findings

The key findings of the research include:

- A high number of mitigation strategies exist with varying levels of effectiveness, cost, and implementation difficulty that vary by mode and externality.
- The mitigation strategies identified, usually, address more than one externality at the same time and were qualitatively ranked to capture their potential.
- Quantitative values can only be estimated on a case-by-case basis.
- Quantitative measures of effectiveness would require a full study supported by modelling and/or simulation analysis.
- The proposed qualitative ranking can serve as a first step to select a subset of the full set of strategies to be evaluated.

- Environmental impacts mitigation and noise were the most and least researched topic respectively.
- African American and Asian population groups are the most inequitable when it comes to freight movements.
- Equity by freight movements does not show any significant difference between genders and income levels (except for emissions for the income categories).
- Low educational levels (4th grade and below) showed a low equity index for all externalities.
- Freight movement equity differences between counties in Tennessee vary significantly ranging from a maximum of approximately 0.8 to a minimum of 0.02 (with a value of one corresponding to perfect equity).

Key Recommendations

The research provides TDOT personnel, as well as local transportation agencies, with a ready and easy-to-use guidebook supported by various data analytic tools that streamline the tasks of identifying, taxonomizing, and ranking strategies (based on cost, benefits, and barriers to implementation) to improve freight transportation and minimize/mitigate the externalities they cause. The developed guidebook and tool support planning, tactical, and operational freight improvements at the state and local level that simultaneously optimize freight movements and minimize their externalities (e.g., environmental, congestion, health) to the communities they serve. Additionally, the proposed tools can help identify areas (county and TAZ level) of low equity for different population groups that can then lead to more targeted actions that promote equity (in addition to freight movement externality reduction).

The mitigation strategies identified by the research team can be internalized into the freight planning process of TDOT. The guidebook and tools developed can be included in the existing TN Statewide Multimodal Plan and be used as a reference manual for mitigation strategies. The tools from this study could also be shared with MPOs as they provide easily accessible data at disaggregate levels. All deliverables can also be shared with the various consultants and contractors that partner with TDOT as they can be used to identify solutions that would have the highest return on investment with regards to minimizing negative externalities from freight movements. Finally, TDOT can host a series of workshops for local agencies (e.g., MPOs) to showcase the guidebook and tools. The workshops could train local agency personnel on how to use the developed guidebook, tools and data produced by this research to support mitigation of negative freight externalities and identify areas of low equity.

Future research can focus on: i) linking the mitigation strategies and its impact on freight equity, ii) including noise data for the equity indices, iii) comparing freight equity measures in areas with and without a significant amount of last mile deliveries by non-motorized transport vehicles, and iv) understand the effectiveness of the mitigation strategies on local communities (especially those with high inequity). Finally, research is needed to identify and propose policies, procedures, strategies, and solutions that can improve traffic conditions (congestion, emissions, safety) in areas of low equity.

Table of Contents

List of Tables

List of Figures

Glossary of Key Terms and Acronyms

CFIMS	Community focused Freight Impacts and Mitigation Strategies
DOC	Diesel oxydation Catalyst
DPF	Diesel particule filtres
EPA	Environnemental Protection Agency
FBC	Fuel-borne catalysts
FIMST	Freight Impacts and Mitigation Strategies Tool
FTF	Flow-through filter
GHG	Greenhouse gas
LEHD	Longitudinal Employer-Household Dynamics
LPG	Liquefied petroleum gas
MOVES	MOtor Vehicle Emission Simulator
SCR	Selective catalytic reduction
TAZ	Traffic Analysis Zone
TDOT	Tennessee Department of Transportation
TITAN	Tennessee's Integrated Traffic Analysis Network
TN-STDM	TDOT Statewide Travel Demand Model
WHO	World Health Organization

Chapter 1 Introduction

As the nation continues to grow, so will the demand for freight transport. It is estimated to reach 25 billion tons/$37 trillion (from 18.1 billion tons/$19.2 trillion in 2015) by 2045 [2]. For goods valued more than $2.25 trillion, trucks are the most common mode used to move between international gateways and inland locations. The nation's economy relies on its system of highways, ports, railroads, waterways, and pipelines to move raw materials and products safely and efficiently. This exchange of goods and services underpins almost all economic activity. Unfortunately, this increase is mirrored with an increase in congestion and other externalities (e.g., emissions and accidents/crashes). Bottlenecks on highways leading to and from ports, unreliable freight systems, and deteriorating roadway conditions can strangle economic growth and, if left unchecked, place America's urban and rural areas at a global economic disadvantage.

Governmental and local public agencies, private industries, and companies are striving to become more sustainable and competitive and to operate efficiently while fostering livable environments. In addition, they are striving in limiting the impacts on disadvantaged (e.g., minority, low-income) populations. Ideally, new approaches and strategies to develop more sustainable freight systems will not compromise on efficiency and safety. Livability policies that tend to favor increased pedestrian, bicycle, or transit mode shares may have unintended consequences regarding freight efficiency or sustainability. For example, removing an industrial or distribution zone close to or around downtown areas can significantly increase delivery costs and greenhouse gas (GHG) emissions. Several candidate solutions have been proposed to minimize and mitigate the externalities caused by freight movements including FRATIS (Freight Advanced Traveler Information Systems), off-peak hour deliveries, consolidation centers, freight lockers, drones, advanced traveler information systems, dynamic routing, traffic signal optimization and preemption, innovative (e.g., dynamic and smart) truck parking, eco-driving strategies, and truck platooning, among others. The future impacts of connected vehicles, urban automation, intelligent infrastructure, and prioritized use of right-of-way on last mile deliveries and storage of goods (which is still under research) may result in new challenges and solutions for freight movement and the externalities they may cause.

Tennessee's economy is considered a *"goods-dependent industry,"* with most goods moved by trucks on a roadway network that consists approximately of 73 percent of rural roadways, and 77 miles designated as critical rural freight corridors (out of a total of 211 miles allowed by the federal government). A significant amount of freight is further moved by rail (Class I and short lines) affecting a smaller number of counties but still a significant amount of both urban and rural population. Inland waterways and air service also touch a smaller number of counties being directly affected. Even though urban areas have received most of the attention, freight movements and their impacts on rural areas cannot be overlooked (especially in a state like Tennessee where 93 percent is rural), as they can be the lifeline of several freight industries situated in these localities and, if not adequately supported, can lead to a disproportionate increase of freight-related externalities to the local communities. This research developed a suburban/rural community-focused freight impact and mitigation guidebook for the Tennessee Department of Transportation (TDOT) to help decision makers identify freight externalities in multiple contexts. It also provides a list of mitigation strategies to address these externalities while optimizing costs and benefits for all the stakeholders. Achieving the latter objective is very important to get stakeholder (not only the community) buy-in, which is necessary for any solution to be implementable and long-lasting.

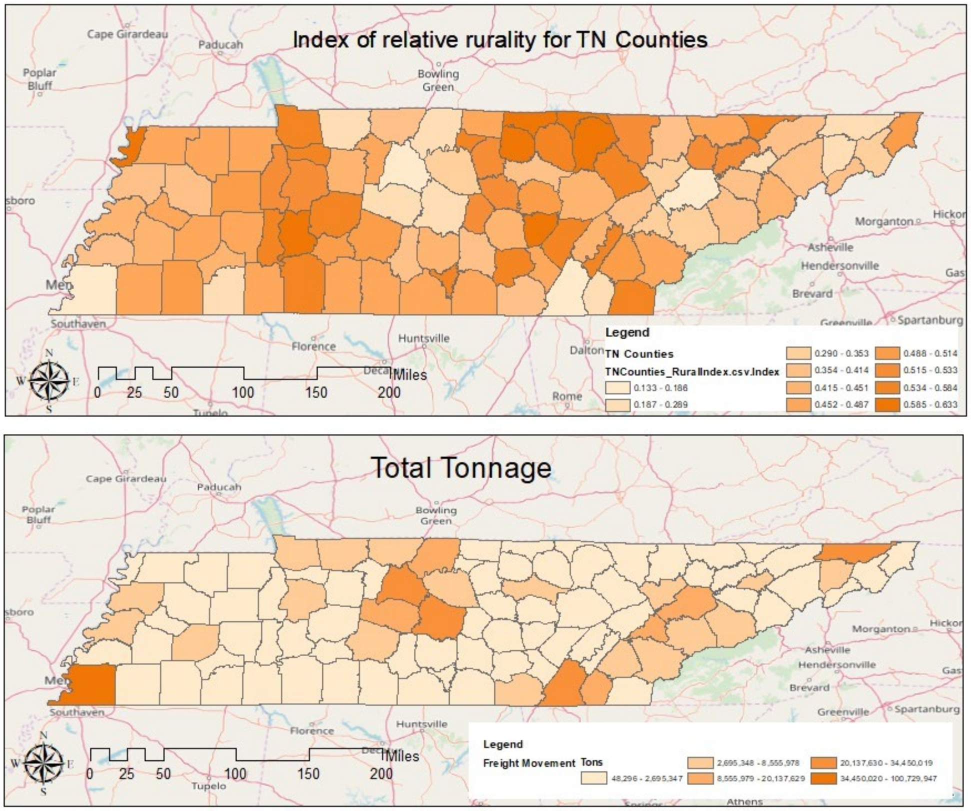


Figure 1-1 Index of relative rurality for TN Counties and Total Freight Movements (Tons) [3]

The scope of work performed as part of this project had five main components. The first component utilized the available freight movement and facility data, the Tennessee (TN) statewide travel demand model, various other freight movement data, and a toolbox (developed by the research team as part of RES2019-14), to estimate the freight impacts at the traffic analysis zone (TAZ) level in the State of Tennessee. Second, the research team performed a literature review and developed various sets of externalities, strategies, barriers, and critical factors for implementation for each strategy to mitigate externalities from freight movements. Third, an interactive tool (Power BI) that combines all the collected and estimated data and streamlines the use of these data and information for transportation planning for the entire state of Tennessee at the county and TAZ levels (a detailed description of the tool is provided in Chapter 6) was developed. Then, the team demonstrated the usage and implementation of the developed guidebook using Franklin County as the case study. Lastly, all outputs from all tasks were combined into a final report.

The remainder of the report is structured as follows. Chapter 2 provides a review of studies that have investigated freight movement impacts and mitigation strategies. Chapter 3 presents a summary of the collected and compiled available freight flow data and an analysis and estimation of their externality impacts on the rural/urban communities. Chapter 4 discusses the mitigation strategies identified as part of this research while Chapter 5 presents the equity analysis for the state of Tennessee at the county level. Chapter 6 demonstrates the Freight Impacts and Mitigation Strategies Tool (FIMST), and Chapter 7 concludes the report with a demonstration of the FIMST using Franklin County as a case study.

Chapter 2 Literature Review and Best Practices

As metropolitan areas continue to grow, freight activities spread further out to suburban and rural areas of the country. Policymakers can identify and target a variety of negative economic, environmental, accessibility, and livability impacts of these moves by freight model. The objective of this chapter is to identify and assemble the state-of-the-practice and state-of-research of effective and innovative strategies for freight transportation externalities mitigation, along with associated critical factors and barriers for implementation. This goal is accomplished by gathering and synthesizing information from the most current domestic and international published research, and by acquiring applicable information from existing practices, both customary and innovative, for application in the United States. In total, 124 studies (peer reviewed articles, conference proceedings, and reports) were reviewed from 1993 to 2022. A summary of studies that have considered air pollution, noise, light, congestion, safety, and the economy as well as a taxonomy of freight movement externalities and available strategies to counter their effects while minimizing supply chain disruptions at the suburban and rural level are presented subsections. All these strategies alongside their effectiveness, cost, and implementation difficulty by each mode are demonstrated in the FIMST tool (discussed further in Chapter 6).

2.1. Externalities

This section reviews the freight movement externalities and their impacts on rural/suburban communities. These are categorized into three major groups: i) health and environmental impact (i.e., air pollution, light exposure, and noise pollution), ii) social impact (i.e., congestion, safety, and security), and iii) economic and land use impact.

2.1.1. Health and Environment

Most of the emerging literature on freight policy is focused on health and environmental impacts ([4], [5]). Emissions and air pollution can be more intense in communities near highways, rail yards, ports, and warehousing hubs, where freight vehicles are in larger numbers to handle the goods in and out of the various facilities. A side effect of freight transportation is not restricted to just human health but also include environmental and climate effects. Fossil-fuel engines, greatly used in transportation, produce GHGs, which traps heat in Earth's atmosphere adversely impacting the global climate. In the following subsections, the most important effects of freight transportation on health and environment were reviewed.

2.1.1.1. Emissions

Since 1965, the United States (U.S.) annual freight volumes have increased from 1.2 to more than 4 million tons-miles. Roughly, one-third of commodities are handled by diesel trucks. Large trucks travel 7 percent of overall miles and account for 4 percent of total vehicles on roadways in the U.S. but emit 23 percent of particulate matter 10 (PM10), 33 percent of nitrogen oxides (NOX), 19 percent of GHGs emitted from transportation (equivalent to 5 percent of total U.S. GHGs emissions). On the other hand, railroads are responsible for 2.2 percent of pollution-related to transportation and 0.6 percent of total GHGs emissions. Therefore, freight transportation is considered one of the primary sources of air pollution ([6]-[9]). Most of the engine-emitted pollutants are the particles with a diameter less than 2.5 of volatile organic compounds (VOC), NOX, and PM, which get into the bloodstream and affect human health in terms of increasing the rate of some diseases such as asthma, cardiovascular disease, stroke, birth defects, diabetes, premature death, heart attacks, and cancer ([9]-[28]). The diesel PM is extremely toxic since they are in small size and contain approximately 40 different toxic air pollutants; 15 of them are considered cancer-causing agents [29]. In one case, Boldo et al., (2006) [30] analyzed 23 European cities in terms of air pollution and found a 10 microgram/m3 increase of PM 2.5 level increased the mortality rate, cardiopulmonary death, and risk of dying of lung cancer by 1.06, 1.09, and 1.14 times, respectively. In addition, Brunekreef et al., (1997) and Gauderman et al., (2005) ([31], [32]) analyzed the relationship between truck traffic density and lung function and found out that there is a negative association between them. Lin et al., (2002) [33] investigated this relationship and determined that children who live within 200 meters of trafficked roads were 1.93 more likely to get asthma. Increasing air pollution also affects climate change ([34], [35], [10]). Burning fossil fuel produces GHGs and eventually changes the global climate system [36]. Freight transportation in the U.S. accounts for about 6 percent of total GHGs, equal to 24.7 percent of total emissions related to transportation [9]. Carbon dioxide (CO_2) emission, as one of the most well-known GHGs, speeds up the unusual melting in polar and arctic regions and, as a result, endangers habitats and species ([37], [38]).

2.1.1.2. Noise and Light Pollution

The negative impact of freight movement growth is not limited to air pollution and includes light and noise pollution in both work and residential areas. According to the World Health Organization (WHO), community noise is defined as noise emitted from all sources except noise at the industrial workplace. Freight-related noise is an important source of noise pollution in local communities, with health effects being medically and socially significant. Noise pollution is one of the adverse outcomes of freight transportation by trucks and rail in small urban and rural areas. Numerous studies have focused on the health effect of noise pollution. Ellebjerg (2007) [39] stated that a single truck, passing at a normal under the limit speed, produces 80 to 90 decibels A (dBA), whereas 45 dBA is the limit to avoid noise-related sleep disturbance [40]. This value grows by increasing the truck's volume on the road [9]. Road and rail are considered the primary source of environmental noise since they are persistent, pervasive, and socially and medically significant [40]. WHO has recognized and recorded seven health impacts of noise pollution including hearing impairment, speech intelligibility or behavioral changes, sleep disturbance, cardiovascular disturbance and a higher rate of stroke, disturbance in mental health, impaired task performance, adverse annoyance reactions, and social behavior ([10], [40], [41], [42], [43], [44], [45], [46], [47], [48], [49], [50]). On the other hand, excessive lighting has been described as a side effect of freight operations to local communities. Most freight activities are required to support a 24/7 operation and, although not many studies have been conducted on how serious extensive light at night can be for human health, it results in numerous psychological and physiological medical implications ([51], [35], [52]). The light exposure at night has two significant physiological impacts, which suppresses melatonin production and disrupts the circadian rhythm ([10], [51], [53]). The circadian rhythm can impact hormone release, sleep-wake cycles, and other primary bodily functions ([54], [55], [56]). It also demonstrates a broad range of mood disorders such as mania, depression, and impulsivity

([35], [57]). Also, excessive light exposure makes serious negative impacts on animal and bird life. Health and environmental impacts of freight movements are summarized in Table 2-1.

TABLE 2-1 ENVIRONMENTAL AND HEALTH IMPACTS OF FREIGHT MOVEMENTS [58]

Health factor	Health outcome	Intensity	Distribution
Air Quality	Asthma and respiratory	High	Elderly; Children; Residents near the pollution hot spots
	Cardiovascular disease	High	
	Low birth weight	Medium	
	Lung cancer	High	
	Premature mortality	High	
Noise	Sleep disturbance	Medium	Residents closest to road and noise hot spots, especially elderly and infants
	Cardiovascular health	High	
	Hearing loss	High	
	Annoyance	Low	All
	Anxiety, stress, and depression	Medium	Residents closest to noise hot spots
	Impaired task performance	Medium	Residents closest to noise hot spots, especially children who attend schools close to the routes
	Interference in communication	Low	Residents closest to road especially elderly and children
Light	Metabolic disorders	High	Residents near the light hot spots
	Mood disorders	Medium	
	Sleep disorders	Medium	

2.1.2. Congestion

The growth in freight transportation demand has caused congestion in parts of the transportation system, making freight movements slower and less reliable. Although the 25 most congested segments for trucks are generally urban interstate highways, truck-related congestion has been observed at suburban and rural areas as well. Usually, corridors with a high volume of trucks are the most congested roadways, highlighting the relationship between regional congestion and truck activity [59]. In Tennessee, with high demand, the current corridor capacity cannot keep pace with the predicted freight demand growth, and the result will be more congested corridors and terminals. For example, a segment of I-40, which connects Memphis to Little Rock, is included in the top 25 congested truck segments and is projected to have at least 10,000 additional trucks per day by 2045. According to Winston and Langer (2006) [60], many factors cause high congestion, such as an increase in demand, limitation in infrastructure, and barriers to expansion, which consequently cause significant impacts on human health and residents' safety. The influx of trucks and railroad crossings in a community's network can have a serious impact on road safety and increase the risk of traffic collisions. It is statistically proven that high traffic volumes result in increased frequency of collisions between vehicles and pedestrians. Furthermore, collisions that involve trucks, which are in great numbers in areas with high freight activity, demonstrate a higher risk for serious injuries and fatalities.

2.1.3. Safety and Security

Freight movements change traffic composition and affect congestion, safety, and security ([58], [61]). Transportation safety (urban, suburban, and rural) is a big challenge due to deteriorating road quality, and varying vehicle speeds [62]. The freight transportation growth in the U.S. has intensified this challenge; with greater traffic volumes leading to a higher risk of death and injury ([63], [59], [64]). In 2017, more than 38,000 people lost their lives, and over 3 million were injured due to crashes in the U.S. ([65], [66]). Freight-involved crashes were proven to have approximately 20 percent higher fatalities and injuries than other types of crashes [67]. Collisions that involve trucks, which are in significant numbers in areas with high freight activity, demonstrate a higher risk (more than twice) for injuries and fatalities among pedestrians, bicyclists, and traffic; nearly 35 percent of fatalities related to bicyclists occur in the rural areas [62]. Rail corridors also attract trespassers, which cause destruction of property, theft, and loss of life. In addition to the safety issue, security needs to be considered. Transporting hazardous material can be dangerous as targets of possible terrorist attacks which pose a higher risk for communities, especially close to the rail corridors and/or terminals.

2.1.4. Economy and Land Use

The economy of a region highly depends on its freight activities [68] as they have various impacts on a community's economic development, such as productivity, employment, business activity, and property values. It is important to consider both positive and negative consequences from freight movements to the local communities. Historically, freight transport volumes (ton-miles) and economic activity have followed similar upward or downward trends ([69], [70]). The link between economic activity and land use and transport is described in many aggregate models such as Mckinnon and Woodburn (1996), Netherlands Economic Institute (1999), and Gleave (2003) ([71], [72], and [73]). These models use several conversion factors to transform economic activity measured in economic terms to transport activity measured in physical terms. Land development, directly and indirectly, affects freight transportation in rural areas, as land use and transportation are linked indisputably, and their coordination is essential to provide an effective and efficient system [74]. Improving roadways and arterials cause an increase in nearby land and property values, leading to land-use changes, traffic flows, and congestion ([75], [76]). On the other hand, the growth of freight transportation systems has some negative impacts on land and property values; proximity to freight transportation centers, railroads, and truck roads affect the property's values, quality of life, livability, congestion, air, and noise pollution ([75], [77], [78]).

Freight transportation provides two major benefits to the economy: service for the population and service to the local industry. Everyday household goods are being delivered, keeping families functioning, and raw and other materials are distributed to the local industries. Local economies are strongly supported by truck freight, which drives manufacturing, distribution, and trade [79]. But the higher the cost of moving goods, the higher the price of the products and the cost of doing business, decreasing the ability to attract and retain jobs and investments in the region. Increased traffic on truck roadway routes is a potential threat to residential property values, which can trigger economic hardships to a local economy. Class I railroads also have a heavy footprint on a region's economy. The impact is both direct and indirect, ranging from the economic benefits from the movement of goods to employment. According to the Organization for Economic Co-operation and Development, the U.S. is ranked second worldwide in freight rail with over 2.4 million ton-km, with the dominant commodity (30 percent of total tonnage) being coal.

The growth of freight volumes in the United States has caused an increase in development and improvement of local economies ([68], [80]); especially road and rail transport (with the occasional addition of inland waterways) have opened new opportunities for the communities by providing new access to the global marketplace. Reducing transportation costs, increasing employment opportunities, and tax revenue are the positive economic impacts [74]. As an example, in 2017, total direct employment resulting from Class I railroads exceeded 147,000 jobs with total wages reaching $12.8 billion. Based on an analysis by the Regional Economic Studies Institute in 2017, about 1.1 million jobs and $71.3 billion in wages, as well as $25.9 billion in total tax revenue, were supported by Class I railroads in the U.S. Also, approximately 134,000 jobs in other service industries such as industrial machinery, commercial, equipment maintenance, and repair were noted [81].

Chapter 3 Data Collection, Analysis, & Impact Estimation

In this chapter, the work to collect, organize, summarize, and present available information on commodity movements is documented. Additionally, the location of facilities accommodating these various commodities in Tennessee are noted. The final deliverable from this work is an online tool with freight movements at the county and TAZ level. Using this tool, the user can identify key commodities that could potentially be accommodated by the various strategies and mitigation strategies identified in Chapter 2 of this report. Under this task, the research team also estimated (where possible) the externalities caused by current freight movements at the county and TAZ level for the state of Tennessee. Under this task, the research team utilized the methodology and tools developed as part of RES2019-14 to obtain the freight flows at the county and TAZ levels [82] and RES2020-18 to obtain socioeconomic data for the base (2010 and 2012) and future year (2040).

3.1. Data Inventory

To organize and present information of commodity movements and the estimated externalities in the state of Tennessee, the research team combined the following available datasets:

Freight Flows

- IHS Global Insight's TRANSEARCH commodity freight database
- Infogroup InfoUSA business and consumer contact database
- Bureau of Economic Analysis Input-Output Accounts

Socioeconomic Data

- Employment data, by Longitudinal Employer-Household Dynamics (LEHD)
- Race, income, age and gender, and education, by U.S. Census Bureau

Externalities

- Emissions (Environmental Protection Agency's (EPA's) MOtor Vehicle Emission Simulator (MOVES))
- Crash (Tennessee's Integrated Traffic Analysis Network (TITAN))
- Congestion (TDOT Statewide Travel Demand Model (TN-STDM))

Congestion data (i.e., delay) at the county and TAZ levels were obtained from the TN-STDM developed by the Resource Systems Group. Delay was defined as the difference of congestion to free flow travel time. Accident data (rail and truck) was obtained through the TITAN database for the year 2010. Next, the methodology used to estimate the emissions externalities from truck movements is described.

3.2. Emissions Estimation

This subsection presents the methodology used to estimate the emissions from freight movements in the state of Tennessee (namely emissions from truck movements) at the county and TAZ level. To estimate emissions (VOC, PM, NOx, and CO), the MOVES model from the Federal Highway Administration was used. Equation (1) was used to estimate CO_2 emissions [83].

$$Z = f \,.\, NCV \,.\, I \,.\, CEF \quad (1)$$

Where:

Z = Total CO_2 emitted (gram),
f = Average fuel consumption of the vehicle (gram/mile)
NCV = Net calories of the fuel (MJ/gram)
I = Traffic intensity of travelled truck flow (miles)
CEF = Coal equivalent Carbon producing CO_2 emitted per mega-Joules (gram/MJ)

Table 3-1 shows the values of the fuel consumption, NCV, and CEF values factors used in this research.

TABLE 3-1 VEHICLE AVERAGE FUEL CONSUMPTION ([84]**,** [85]**)**

Truck Type	Fuel Consumption (gram/mile)
Single-Unit Diesel Truck	441.2
Single-Unit Gasoline Truck	384.1
Combination Diesel Truck	545.8

TABLE 3-2 NET CALORIES OF FUEL AND COAL EQUIVALENT CARBON PRODUCING CO2 EMITTED PER MEGA-JOULES ([86]**,** [87]**)**

	Diesel	Gasoline
NCV (MJ/g of Fuel)	0.046	0.044
CEF (g of CO_2/MJ)	70.27	66.96

The CEF factor was obtained from the amount of carbon and hydrogen content of the fuel and the total heat produced from the combustion of both carbon and hydrogen. In this methodology, it was considered that the equivalent carbon in coal was produced the same amount of heat as the fuel [84]. However, this amount may be changed based on the other contents of the fuel. For example, water and other contents may lower the heat production and increase CO per joules produced. In this case, the total burnt carbon was 99 percent [88]. The density of diesel and gasoline were also considered 850 and 740 kg/m^3, respectively [89].

To calculate other air pollutants for rural areas, the emissions factor shown in Table 3-3 was obtained from the MOVES model and multiplied by the total miles travelled.

TABLE 3-3 EMISSION RELEASED FROM DIFFERENT TRUCK TYPES (GRAM/TRAVELED MILE) [90]

Truck Type	VOC	CO	NOx	PM-10 (Exhaust only)
Single-Unit Gasoline Truck	0.35	18.07	6.09	0.07
Single-Unit Diesel Truck	0.3	1.41	11.95	0.13
Combination Diesel Truck	0.27	1.44	12.39	0.13

Figure 3-1 provides the total estimated pollution released from the three different truck types including single unit diesel, single unit gasoline, and combination diesel in Tennessee for 2010 and 2040. Note, these numbers do not account for the current trend of cleaner truck engines and truck electrification (the EPA announced that starting in 2027, heavy-duty vehicles will need to meet new standards for criteria pollutants and GHG emissions standards).

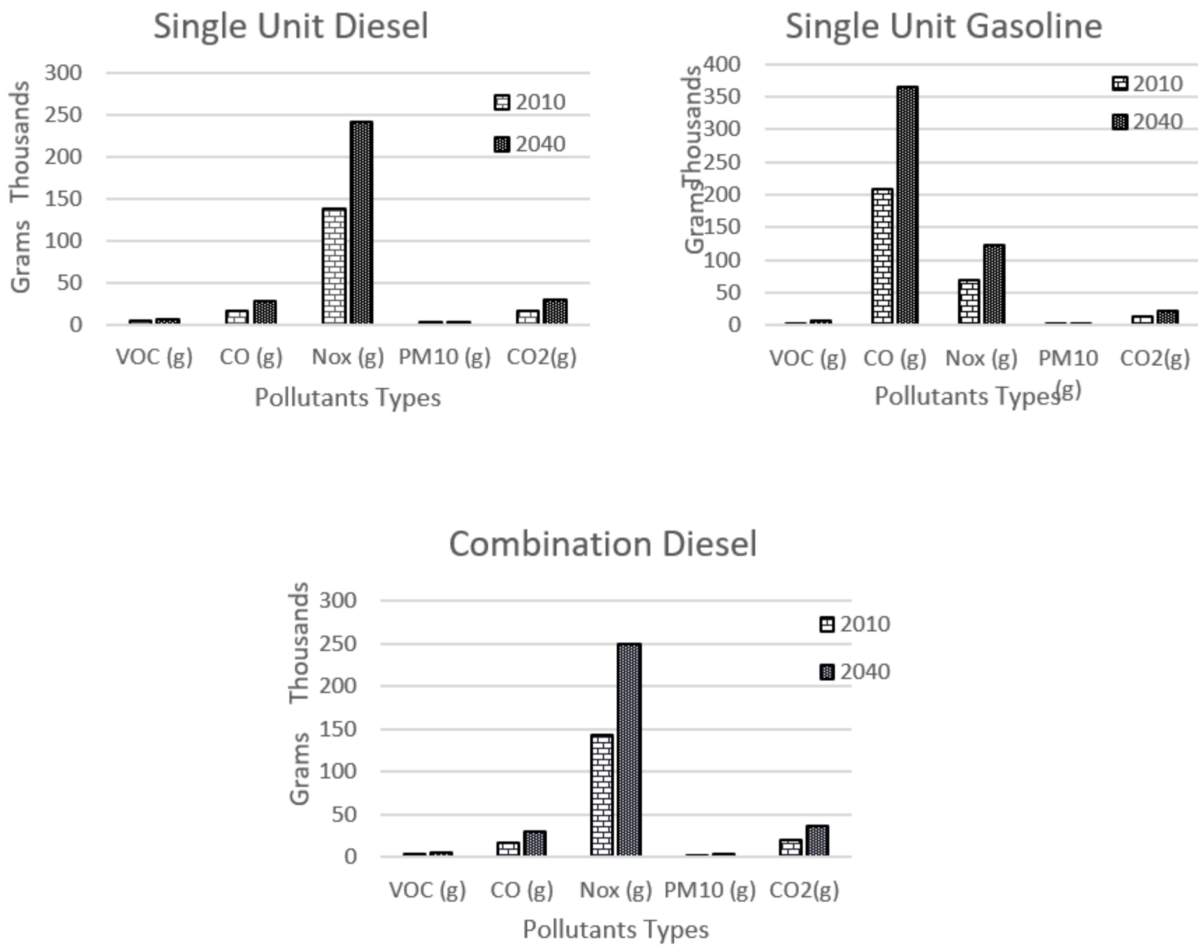


Figure 3-1 Average emission released from single unit diesel, single unit gasoline, and combination truck type in TN

Chapter 4 Mitigation strategies

A list of mitigation strategies by type of mode were identified based on the literature review presented in Chapter 2. In the following subsections, presented are detailed descriptions of various sets of mitigation strategies based on the externalities as identified by the literature.

4.1. Environmental Strategy

This subsection presents and discusses the various strategies as identified by the literature review, that can counter environmental externalities (i.e., emissions, noise, and light pollution).

4.1.1. Emissions

Various mitigation strategies and plans were identified from the literature to reduce emissions from freight transport. One of the most effective strategies (as expected) was modal split to move commodities with more environmentally friendly modes (i.e., rail and barge). In addition to the well-known modal split share change [91], there are two different strategies to mitigate air pollution: technology and operational. The first strategy contains four sub-strategies: i) after-treatment control, ii) repowering, iii) alternative fuels, and iv) energy efficiency. The after-treatment controls consist of emission control devices which are combined into retrofit and new engines. Diesel particulate filters (DPF), diesel oxidation catalyst (DOC), DPF with NOx catalyst, flow-through filter, and selective catalytic reduction are the available retrofits for freight diesel engines. All of the mentioned after-treatment control methods can be used to remove the PM from the diesel exhaust by nearly 90 percent ([9], [34]). The repowering strategy also refers to converting the power, replacing an old engine with a cleaner engine, or even a new engine. Replacing old engines with the newer and cleaner model for trucks and locomotives reduces the smog-forming PM and NOX emission by 80 percent ([9], [61]). This performance motivates some government agencies to provide these strategies with an incentive, such as tax-free plans or grant programs, to encourage freight companies to implement this technology. In addition, the alternative fuels strategy presents cleaner-burning options for equipment and freight vehicles such as natural gas, biofuels, and fuel cells. Each of the options is appropriate for the specific mode. For example, liquefied natural gas is more effective for rail applications due to greater density and less refueling frequency. Moreover, energy efficiency as another technology approach reduces PM emissions by implementing more efficient tires, hybrid-electric vehicles, weight reduction, improved vehicle aerodynamics, and reducing the friction of wheel-to-rail. In one case, the energy efficiency can be increased by redesigning the vehicles and eliminating unnecessary idling; for example, trucks can be constructed with aerodynamic fronts and adjusted with panels to decrease the drag. Building the truck with lighter materials can also haul the same volume of commodities with less pollution. This type of strategy has great advantages in reducing fuel costs compared to other strategies [34].

On the other hand, policymakers can employ operational strategies to reduce the negative impacts of freight movements. These strategies usually take three forms: local regulations and ordinance, congestion mitigation efforts, and operational changes. The first form, which is applicable for all modes, contains the anti-idling programs which decrease emissions by cutting down the idling time. Providing strict idling limits reduce trucks' emissions when loading, waiting, unloading, or parked. There are several methods for implementing the anti-idling program, such as installing the idling limit devices, providing the truck stop electrification, setting auxiliary power units, and enacting some regulations regarding prohibiting excessive idling. It should be noted that that some localities (cities and communities) may have stricter regulations regarding anti-idling programs. The second form, congestion mitigation, concentrates on the efforts that target the pollution emitted from congestion since these emissions are much more than what is emitted during travel. Several methods mitigate the congestion and consequently the pollution, such as grade separation for rail and road, improvements in rail infrastructure, and signal coordination for high traffic routes. The third form, operational changes, focuses on changing the operational practices to reduce emissions by using new technology, regulations, or even partnership with the private sector. Different methods are introduced to implement this type of strategy, such as speed reduction plans, driver training, weigh station bypass, reduced empty mileage, expansion or construction of rail/ truck intermodal facilities, and truck fleet operational techniques ([9], [34]). Also, improving the handling practices can reduce the idling time by eliminating loading, reducing, or eliminating paperwork, and reduced unloading and loading times. Other examples are implementing the automated gate technology, adjustments in scheduling the empty truck's movements, and providing terminal appointment systems ([9], [92], [93], [94]).

4.1.2. Noise and Light

Truck and rail are the major contributors to noise and light pollution from freight movements. To mitigate noise impacts from truck movements, several mitigation strategies have been identified, such as placing the storage areas next to the road to act as a barrier of noise, using muffler systems to reduce the noise from internal combustion engine [95], and using existing buildings or other structures. There are also several strategies that reduce the negative impacts of rail noise and vibration, including installing welded rail [96], building berms, limiting hours of operation, creating “quiet zones,” implementing quiet dollies, and roll cages ([61], [97]). For example, the movement of roll cages is the single biggest source of noise, particularly with empty ones. High performance thick rubber matting can reduce the impact of delivery noise. Another example of reducing noise from equipment and trucks would be noise nuisance by the activation of the roll-off safety devices when unloading roll containers. A simple and cost-effective solution of noise damping can be retrofitted to most tail lifts and allow deliveries during night and early hours of the morning. Such practices, in combination with good driver behavior, have the potential to minimize the noisiest aspects of deliveries. To address the local concerns about train horn noise, Federal safety regulation provides some rules to create quiet zones while requiring additional safety strategies. Also, implementing trenching allows the rural road network to remain at existing grade, removes the consequent noise signals, eliminates pedestrian and train conflicts, increases the train speed through a corridor, and provides additional connectivity. However, it has a high construction cost, and it is difficult to be implemented on pre-existing rail lines. Another useful method for reducing noise pollution is the walling approach. This approach provides a concrete barrier between the rail yard and adjacent uses, decreases noise pollution, and increases safety and security with low construction cost. In addition, using the brake shoe is recommended to reduce the track retarder noise especially at hump yards ([98], [99]). Also, zoning is a great strategy that can be used for the nonresidential area around the rail yards. This strategy causes noise reduction as well as industrial and commercial expansion ([53]). It should be noted that some of the strategies can be used for both truck and rail, such as modifying or limiting the operational hours for trucks and rail facilities, designing, and setting noise barriers at the noise source to reduce the sound experienced by people who live in proximity of roadways and rail yards. Examples of noise barriers would be trees and other vegetation which are an efficient and cost effective solution, especially in rural areas with great vegetation cover [100]. Using the soundproofing features in a residential area close to rail and truck facilities is another strategy that could be used to absorb the excessive noise [61]. To reduce the light exposure directly, using a specialized fixture is effective. The facility should implement some fixtures to reduce its light spills over the surrounding community.

4.2. Congestion

Modal switch is one of the most effective strategies to reduce congestion, as it reduces truck volumes and their interaction with pedestrians and passenger vehicles ([59], [101]) which can also have a benefit to the reduction of emissions and increase safety. About 12.4 million additional trucks are needed to handle 223.5 million tons of freight transported by rail in 2012 throughout Tennessee [74]. Therefore, converting the mode can be a great remedy for decreasing congestion. Adding truck-friendly or truck-only lanes can relieve congestion by reducing the existing conflicts between passenger cars and heavy trucks, as well as stabilizing the traffic flow, improving safety, and increasing the convenience and comfort for car passengers. High costs and implementation difficulty are two prohibiting factors and there is less interest in implementing truck-friendly or truck only lanes. Changing hours of operation for rail, relocating the rail yards, replacing rail lines from at-grade to below or above-grade, and replacing rail crossings from at-grade to grade-separated can also help relieve congestion, delays and eliminate freight rail transportation disruptions effectively, but they are costly and implementation is difficult ([61], [59], [102], [79]).

4.3. Safety/Security

The safety and security of roads as well as railroads is critical. By implementing congestion mitigation strategies, automatically, bicyclist and pedestrian safety in rural areas is increased. However, to increase security, additional strategies are needed, such as creating pedestrian paths or walls, as well as installing upgraded rail barriers ([53], [58], [61]). Implementing these strategies improve the safety and security issues simultaneously. Placing more dynamic and static warning signs, including speed limits and potential hazards for large and heavy-duty trucks, is recommended as economical efficient approaches. Also, improving the lighting across the state is an economical strategy to increase the visibility of animal passing ([59]). Converting the truck's transportation mode to rail is another effective way to decrease fatalities and injuries. In other words, truck fatalities and injuries were estimated around 6 and 17 times more than rail, respectively [68]. Since most hazardous material and crude oil are transported by rail, terrorists targeted rail more than trucks to harm the citizens and disrupt transportation. Therefore, the U.S. Department of Homeland Security increased the rail system's security by deploying and training the manpower for high-risk locations, developing and evaluating the new security technology, and providing funding to local partners and the State [74].

4.4. Economic and Land Use Strategy

Relocating rail yards and leveraging the freight transportation system are excellent ways to contribute to economic development in rural areas. For example, adjusting the freight transportation system allows the evolution of other property uses [61]. Creating and developing new policies and regulations in local communities decrease the negative environmental impacts resulting from freight transportation. Such policies can move sensitive residents away from the pollution source, discourage establishing new development in proximity of truck and rail routes, and protect them from nearby emissions [100]. To avoid degradation of property values, developing warehouse and distribution centers, giving permission to overlay industrial zoning with other zoning districts, and hiring locally for ongoing freight transportation construction projects, modifying rail hour operations, and providing tax relief policies to encourage redevelopments in brownfields are the practical approaches ([61], [75] ,[103]).

Chapter 5 Equity Analysis

Transportation connects each part of American lives. Getting goods and people to where they need to be both directly and indirectly are helping to improve quality of life by creating more jobs and making connections easier. However, misguided policies can intensify racial, ethnic, and disability disparities and divide neighborhoods, which is against the government's role of empowering American success. One of the major responsibilities of the federal government is to enhance equity, racial justice, and environmental justice to ensure that everyone has equal human rights. This concept leads us to define the term "Equity," which is a consistent, unbiased, and fair treatment of all groups of communities, such as minorities and people of color. Due to the most recent executive order related to equity (E.O.13985), governments are required to follow a comprehensive approach to enhance racial justice and equity, as well as provide the equal opportunity to reinforce the under-served communities who are suffering from inequality. Over the recent years, transportation equity research has emerged to precisely reflect the distributive outcomes of transport policies ([104], [105], [106]). Transportation equity analysis investigates the impartiality of impact distribution from transportation planning. In other words, it investigates which population groups reap the most benefits and which suffer the burdens. In this chapter, the research team provides the methodology used to develop various freight movement equity indices for the state of Tennessee at the county level.

5.1. Equity Estimation Methodology

Equity (or inequity) can be measured by the geographic concentration of a certain phenomenon with respect to the population. A common use of inequity measure is the distribution of a certain socioeconomic attribute among the population. For example, a significant amount of research has focused on determining the cumulative proportion of a population of a geographic area based on their income level to estimate income-based equity measures [107]. To the knowledge of the authors, this is the first time that an extensive equity analysis has been performed using freight movement externalities. To estimate freight movement equity indices for this project, the data collected and estimated in Task 2 including socioeconomic data (collected from the U.S. Census Bureau and LEHD), as well as freight movements data obtained from a previously developed tool (RES2019-14) at TAZ level were used. Since the socioeconomic data was available for year 2010, the research team applied the model developed by Samani et al., (2022) [108] to forecast the data for race, gender/age, educational level, and income at the TAZ level for 2040. After compiling the datasets and disaggregating the data at the appropriate geographic level (TAZ), the most used socioeconomic inequity index was implemented to estimate the equity for income, race, and education. This measure was introduced by Corrado Gini in 1912 [109]. The Gini Index could be obtained from the Lorenz curve[1] [110] by calculating the ratio of the area between the Lorenz curve and perfect equality line[2] divided by the area under the perfect equality line [111]. In other words, the Gini index estimates the difference

[1] Real socioeconomic attribute (i.e., income) distribution

[2] A straight line, where 0 percent, 50 percent and 100 percent of socioeconomic attribute (income) are held by 0 percent, 50 percent, and 100 percent of the population, respectively.

between the Lorenz curve and the perfect equity [112]. The Gini index takes values between 0 and 1. A Gini index value of 0 shows a perfect inequity while a Gini index value of 1 shows perfect equity. The same approach can be used to evaluate the distribution of freight movements equity. In this case, it becomes the cumulative proportion of total population/socioeconomic attributes (i.e., income, gender, educational levels, and race) and the cumulative proportion of freight-related externalities (i.e., emission, accidents, and congestion) that affects the population. The resulting Gini index demonstrates the distribution of freight movements externalities to be compared across different TAZs. In Figure 5-1, a graph of a sample Lorenz curve and perfect equity line are shown. The perfect equity line is a 45-degree angle line which shows an equal distribution of cumulative externalities among the population/ socioeconomic attributes. The difference in the areas below the Lorenz curve and perfect equity line is used to estimate the value of inequity [107].

$$G_s = 1 - 2\sum_{k=1}^{n}(X_k - X_{k-1})(Y_k - Y_{k-1}) \tag{2}$$

Where G_s is the Gini index for county s, X_k and Y_k are the cumulative proportion of externality and cumulative proportion of socioeconomic attribute k (k=1 ,..,n).

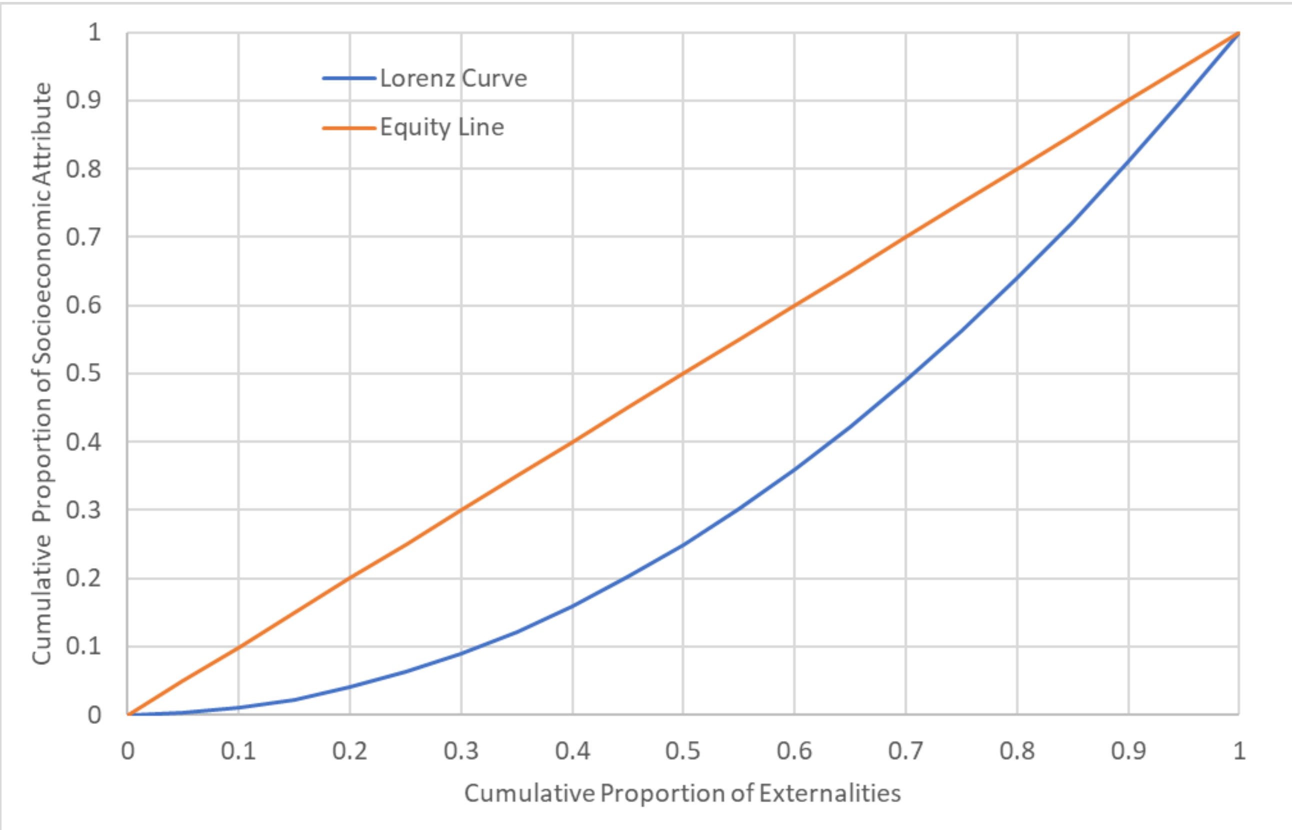


Figure 5-1 Illustrative example of Gini Index for socioeconomic data and externalities

Chapter 6 Freight Impacts & Mitigation Strategies Tool

This chapter provides a description of the interactive **Freight Impacts and Mitigation Strategies Tool (FIMST)** developed as part of this project. The tool (desktop and online version) can be accessed at: https://sites.google.com/view/res2021-07/home. The tool allows the user to select a specific area (e.g., TAZ or county) and query for the possible freight issues (e.g., economic, social, environmental, congestion, etc.) that may affect that area. The tool gives the option to rank the available strategies (for that specific area and freight-related issues) that can alleviate the externalities and maximize freight movement performance. Strategies and their ranking are based on transportation mode, externalities, cost, and barriers to implementation. The tool also provides the user with socioeconomic data (race, educational level, age/gender, and income) and equity indices for the specified area.

6.1. Freight Movements Tool

This subsection briefly describes the part of the tool developed that summarizes freight movements at the county and TAZ level in the state of Tennessee. The freight movement analytics tool allows the user to identify areas of high growth in terms of either tonnage or value by commodity type, mode, origin, and destination at two different disaggregation levels (i.e., county and TAZ) for a base year (2012) and a future year (2040). The tools capability to analyzes freight movements in the state of Tennessee to demonstrate its capabilities and usage is briefly discussed. For example, Figure 6-1 shows the inbound freight commodity movements in Tennessee by county for 2012. The user can rank the commodity movements by tonnage or value for specific counties, modes, and commodity types. For example, using the tool, the top ten inbound commodities by tonnage in 2012 (for the entire State and irrespective of mode) was gravel and crushed stone, drayage, coal, non-metallic mineral products, agricultural products, cereal grains, waste and scrap, other prepared, gasoline, and natural sand (Figure 6-1). Based on the data, truck and rail are the two major modes, responsible for most of the inbound freight movements in 2012 and Shelby County was the county with the highest inbound movements. In the next chapter, a case study for one county in Tennessee is presented, where more detail of implementation of this tool is provided.

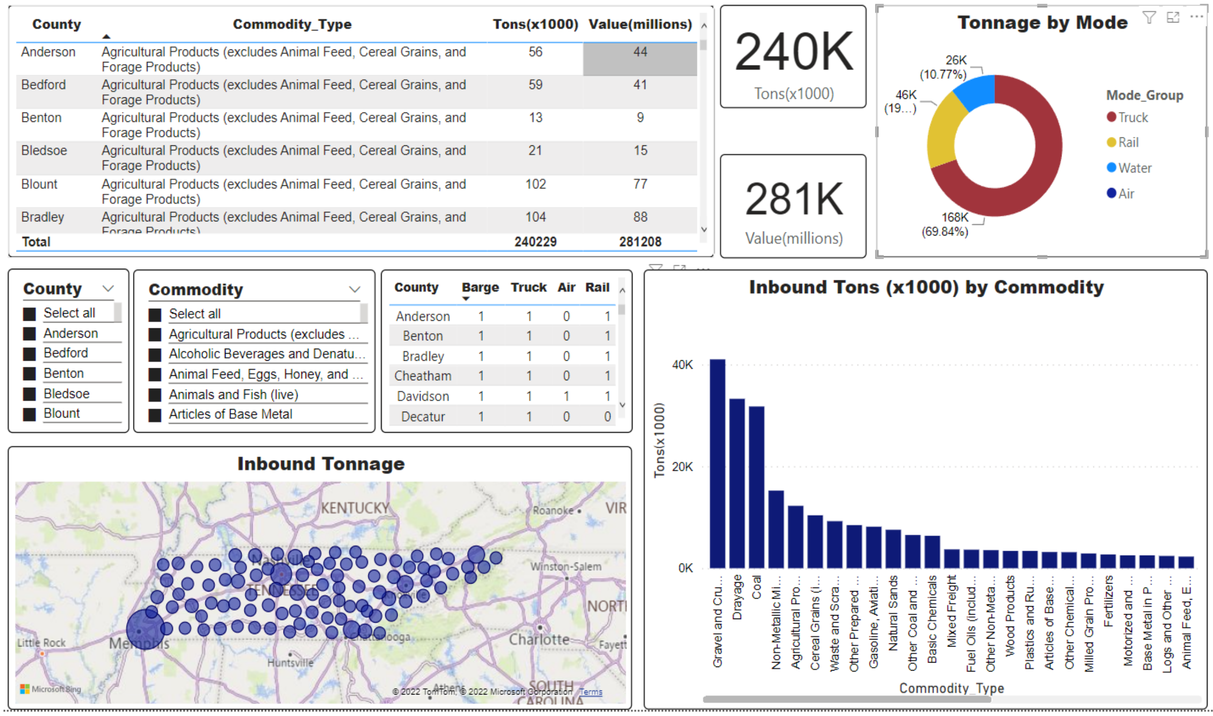
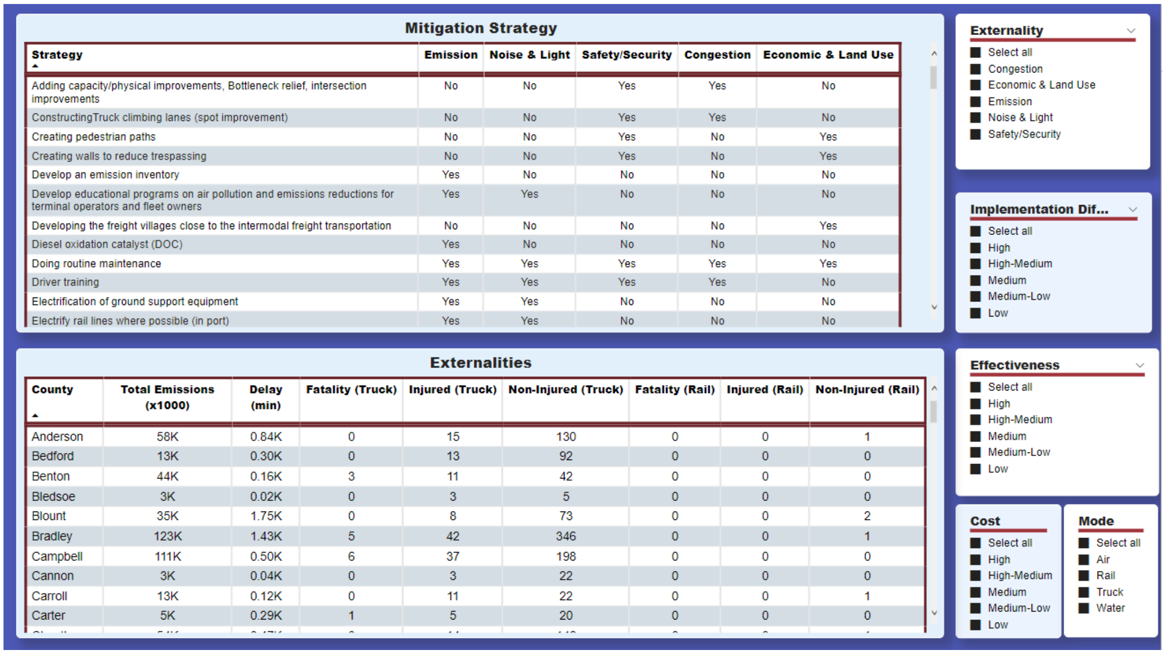


Figure 6-1 Inbound Freight Movements for Year 2012

6.2. Mitigation Strategies Tool

Figure 6-2 shows a screenshot of the Mitigation Strategies Tool. The tool lists the various mitigation strategies that reduce the negative impact from freight movements by different modes. The tool provides the option to select the type of externality (i.e., emissions, noise & light, safety/security, congestion, and economic land use) and return the various mitigation strategies. The tool also allows to query the different strategies based on their implementation difficulty, cost, effectiveness, and mode. Finally, the tool provides the values for the different externality types by county.



Mitigation Strategy

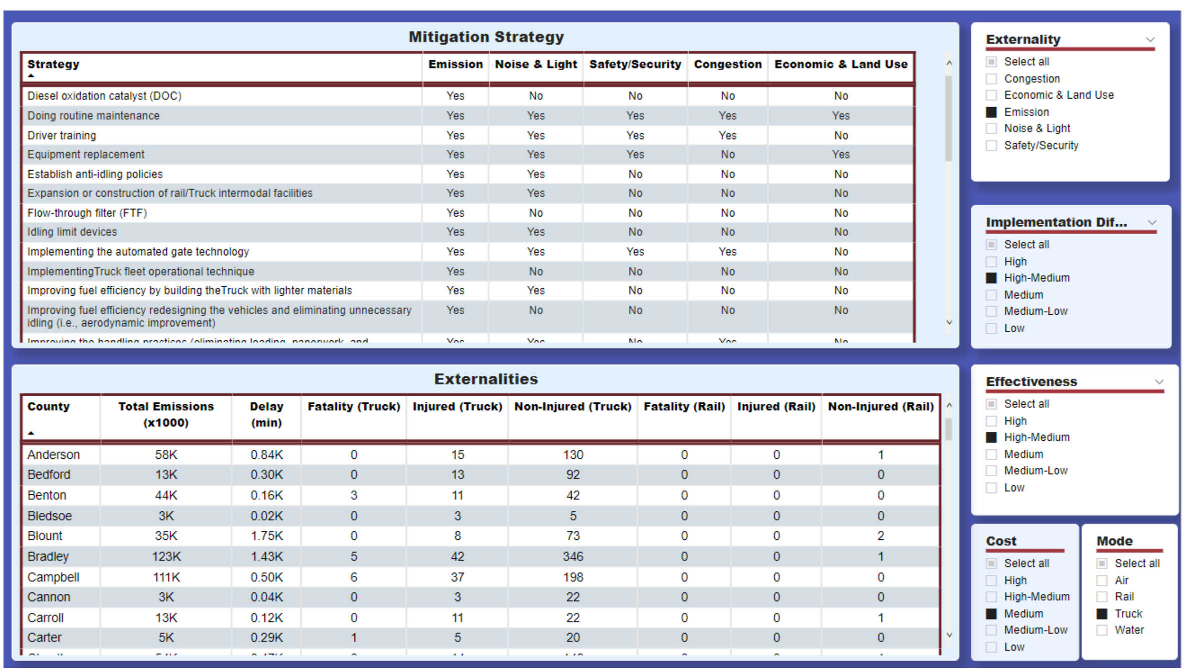
Strategy	Emission	Noise & Light	Safety/Security	Congestion	Economic & Land Use
Adding capacity/physical improvements, Bottleneck relief, intersection improvements	No	No	Yes	Yes	No
ConstructingTruck climbing lanes (spot improvement)	No	No	Yes	Yes	No
Creating pedestrian paths	No	No	Yes	No	Yes
Creating walls to reduce trespassing	No	No	Yes	No	Yes
Develop an emission inventory	Yes	No	No	No	No
Develop educational programs on air pollution and emissions reductions for terminal operators and fleet owners	Yes	Yes	No	No	No
Developing the freight villages close to the intermodal freight transportation	No	No	No	No	Yes
Diesel oxidation catalyst (DOC)	Yes	No	No	No	No
Doing routine maintenance	Yes	Yes	Yes	Yes	Yes
Driver training	Yes	Yes	Yes	Yes	No
Electrification of ground support equipment	Yes	Yes	No	No	No
Electrify rail lines where possible (in port)	Yes	Yes	No	No	No

Externalities

County	Total Emissions (x1000)	Delay (min)	Fatality (Truck)	Injured (Truck)	Non-Injured (Truck)	Fatality (Rail)	Injured (Rail)	Non-Injured (Rail)
Anderson	58K	0.84K	0	15	130	0	0	1
Bedford	13K	0.30K	0	13	92	0	0	0
Benton	44K	0.16K	3	11	42	0	0	0
Bledsoe	3K	0.02K	0	3	5	0	0	0
Blount	35K	1.75K	0	8	73	0	0	2
Bradley	123K	1.43K	5	42	346	0	0	1
Campbell	111K	0.50K	6	37	198	0	0	0
Cannon	3K	0.04K	0	3	22	0	0	0
Carroll	13K	0.12K	0	11	22	0	0	1
Carter	5K	0.29K	1	5	20	0	0	0

Figure 6-2 Demonstration of Mitigation Strategies in FIMST

Figure 6-3 shows an example of the FIMST where the user selected the strategies with high-medium effectiveness, medium cost, and high-medium difficulty that can be implemented to mitigate emissions from freight movements by truck only. As is shown in Figure 6-3, there are several strategies such as using DOC, replacing the equipment, establishing anti-idling policies, installing idling limit devices, and others for the reduction of emissions that are associated with freight movement.



Mitigation Strategy

Strategy	Emission	Noise & Light	Safety/Security	Congestion	Economic & Land Use
Diesel oxidation catalyst (DOC)	Yes	No	No	No	No
Doing routine maintenance	Yes	Yes	Yes	Yes	Yes
Driver training	Yes	Yes	Yes	Yes	No
Equipment replacement	Yes	Yes	Yes	No	Yes
Establish anti-idling policies	Yes	Yes	No	No	No
Expansion or construction of rail/Truck intermodal facilities	Yes	Yes	No	No	No
Flow-through filter (FTF)	Yes	No	No	No	No
Idling limit devices	Yes	Yes	No	No	No
Implementing the automated gate technology	Yes	Yes	Yes	Yes	No
ImplementingTruck fleet operational technique	Yes	No	No	No	No
Improving fuel efficiency by building theTruck with lighter materials	Yes	Yes	No	No	No
Improving fuel efficiency redesigning the vehicles and eliminating unnecessary idling (i.e., aerodynamic improvement)	Yes	No	No	No	No

Externalities

County	Total Emissions (x1000)	Delay (min)	Fatality (Truck)	Injured (Truck)	Non-Injured (Truck)	Fatality (Rail)	Injured (Rail)	Non-Injured (Rail)
Anderson	58K	0.84K	0	15	130	0	0	1
Bedford	13K	0.30K	0	13	92	0	0	0
Benton	44K	0.16K	3	11	42	0	0	0
Bledsoe	3K	0.02K	0	3	5	0	0	0
Blount	35K	1.75K	0	8	73	0	0	2
Bradley	123K	1.43K	5	42	346	0	0	1
Campbell	111K	0.50K	6	37	198	0	0	0
Cannon	3K	0.04K	0	3	22	0	0	0
Carroll	13K	0.12K	0	11	22	0	0	1
Carter	5K	0.29K	1	5	20	0	0	0

Figure 6-3 Example of Mitigation Strategies that Reduce Emissions Resulting from Truck Movements

6.3. Socioeconomic Analysis

The same type and volume of freight movements can have different impacts (congestion, accidents, and emissions) to different groups based on their social and economic status (e.g., race, gender, income, employment, education, etc.). This research developed a tool to query the various socioeconomic data in the state of Tennessee (by county and TAZ) by externality type and mode to allow identification of areas with high concentration of different socioeconomic subgroups. Figure 6-4, shows an example of the tool where the user can select different counties and TAZs by truck type and see the distribution of races (Asian, Black, Bi-racial, Other, and White), emissions (CO, CO_2, NOX, PM_{10}, VOC), and average delay for the base and future year. Moreover, the tool provides the user with the option of selecting an area based on its rurality index. For example, as shown in Figure 6-5, by selecting the rurality index between 0.53 to 0.57 (maximum value), the map and tables filter to the most rural counties with average delay of 1 minute which is negligible compared to urban areas with average delay of 16.35 minutes. The tool allows similar analysis to be performed based on the distribution of income, education, age, and gender.

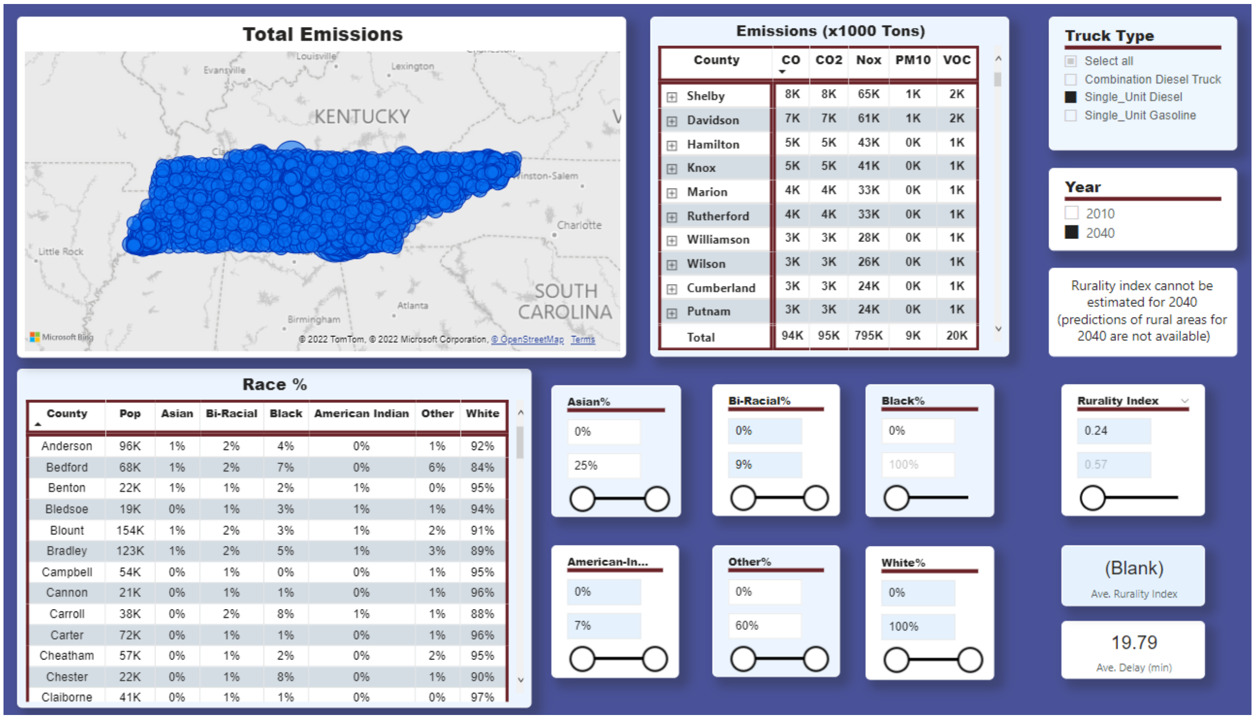


Figure 6-4 Race and Emissions Statistics for TN at the TAZ Level

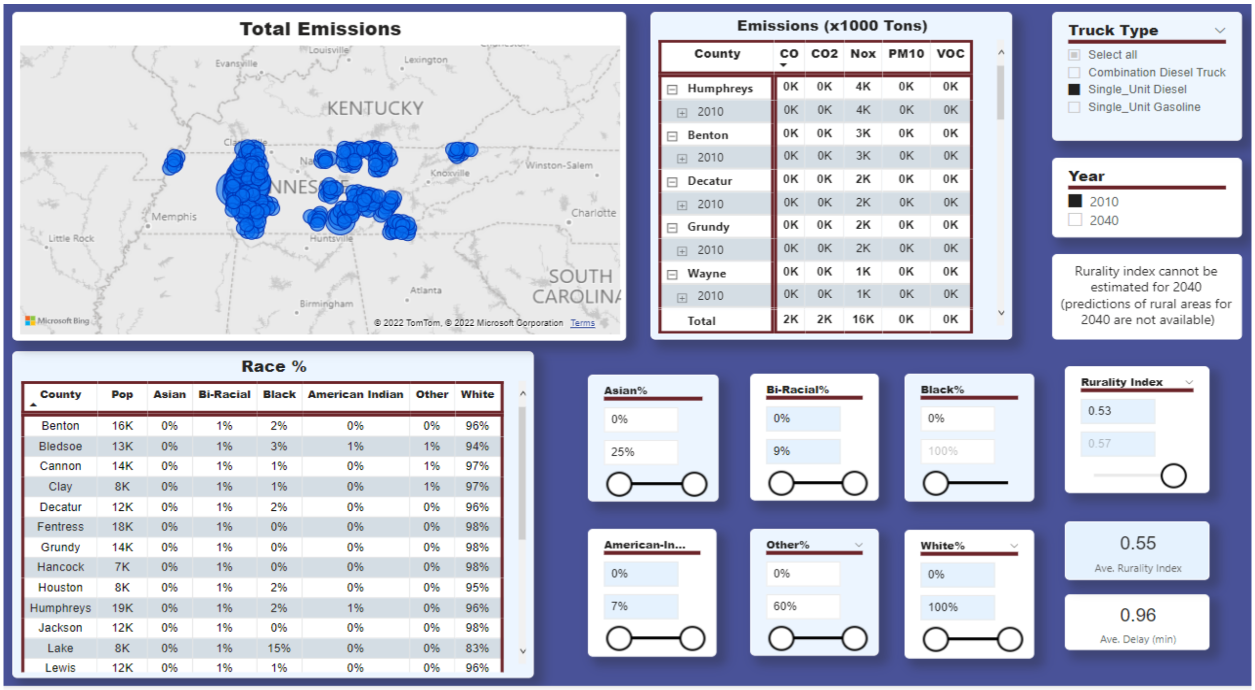


Figure 6-5 Race and Emissions Statistics for Counties with Rurality Index between 0.53 and 0.57 in TN at the TAZ Level

6.4. Equity Indices

As discussed in Chapter 5, various equity indices were estimated for the state of Tennessee at the county level (using TAZ level data as input). These indices were combined into a tool to perform equity comparison in terms of race, gender, education, income, and freight movements. In addition to equity analysis, this tool can be used to identify and prioritize areas for freight improvements to minimize externalities and improve equity. Figure 6-6 illustrates part of the tool where the equity index value for the six different races and three different externality types are shown. An equity index value of 1 corresponds to perfect equity while a value of 0 to perfect inequity.

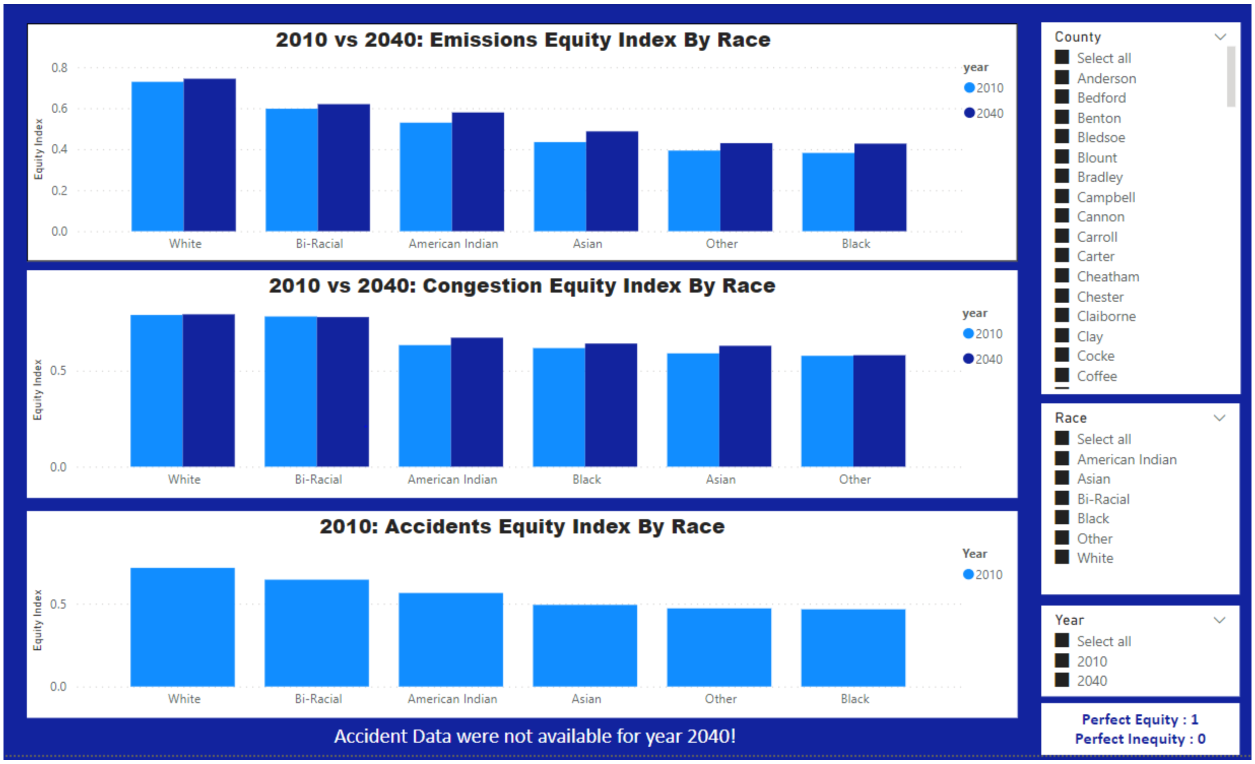


Figure 6-6 Visualization of Equity Index for Externalities and Race Groups

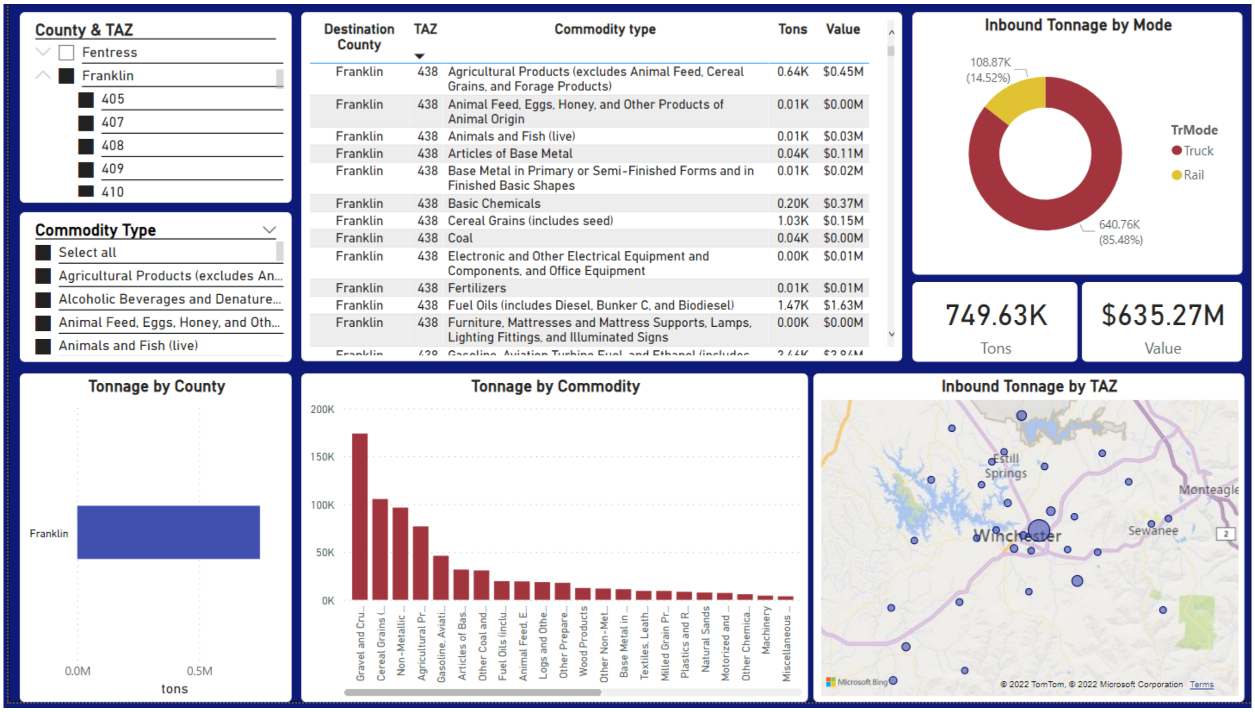
Chapter 7 Case Studies

The methodology was implemented for the entire state of Tennessee. In this chapter, we use Franklin County as an example to illustrate the use of the various metrics developed as part of this project. This county was selected due to the combined high rurality index and high freight flow movements (as compared to other rural counties in Tennessee). This chapter also present the equity index for the top and bottom 10 counties in Tennessee, as well as for the four major counties in Tennessee. All the information provided herein can be obtained from the online and desktop tools developed as part of this project.

7.1. Freight Movements

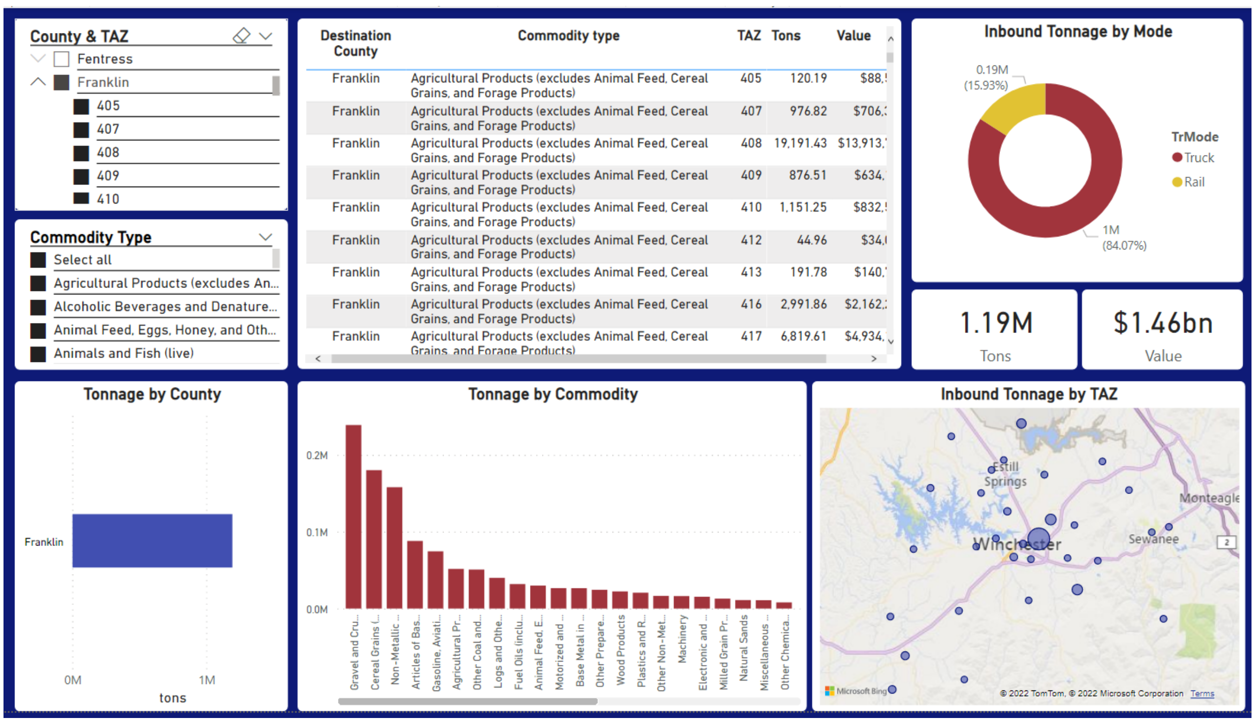
This subsection describes the part of the tool summarizing freight movements at the county and TAZ level in the state of Tennessee. The rationale for developing these subsets of tools was to easily identify areas of current (2012) and future (2040) high freight activity (by mode and commodity) and identify possible areas of high freight movement externalities. The tool provides the user the ability to see the growth of tonnage or value of different commodities by modes and locality. Figure 7-1 through Figure 7-4 show screenshots of the tool with the inbound and outbound freight movements for Franklin County at the TAZ level for 2012 and 2040, respectively. In a similar fashion, Figure 7-5 and Figure 7-6 show the comparison of freight movements from/to Franklin County between 2012 and 2040 at the TAZ level.

The user can rank the commodity movements by tonnage or value for specific counties/TAZ, modes, and commodity types. As shown in Figure 7-1, the key commodities transported to Franklin County in 2012 were gravel and crushed stone, cereal grains, non-metallic mineral products, agricultural products, gasoline, articles of base metal, other coal and petroleum products, fuel oils, animal feed, and logs and other wood. Figure 7-2 shows the same ranking for 2040. In a similar way, the outbound freight movements for Franklin County for 2012 and 2040 are visualized in Figure 7-3 and Figure 7-4. As can be seen in Figure 7-1 through Figure 7-4, truck moves most of the tonnage both inbound and outbound in 2012 and 2040. Figure 7-5 and Figure 7-6 show the comparison of inbound and outbound movements by mode, county, and commodity type.



Destination County	TAZ	Commodity type	Tons	Value
Franklin	438	Agricultural Products (excludes Animal Feed, Cereal Grains, and Forage Products)	0.64K	$0.45M
Franklin	438	Animal Feed, Eggs, Honey, and Other Products of Animal Origin	0.01K	$0.00M
Franklin	438	Animals and Fish (live)	0.01K	$0.03M
Franklin	438	Articles of Base Metal	0.04K	$0.11M
Franklin	438	Base Metal in Primary or Semi-Finished Forms and in Finished Basic Shapes	0.01K	$0.02M
Franklin	438	Basic Chemicals	0.20K	$0.37M
Franklin	438	Cereal Grains (includes seed)	1.03K	$0.15M
Franklin	438	Coal	0.04K	$0.00M
Franklin	438	Electronic and Other Electrical Equipment and Components, and Office Equipment	0.00K	$0.01M
Franklin	438	Fertilizers	0.01K	$0.01M
Franklin	438	Fuel Oils (includes Diesel, Bunker C, and Biodiesel)	1.47K	$1.63M
Franklin	438	Furniture, Mattresses and Mattress Supports, Lamps, Lighting Fittings, and Illuminated Signs	0.00K	$0.00M

Figure 7-1 Inbound Freight Movements for Franklin County in 2012



Destination County	Commodity type	TAZ	Tons	Value
Franklin	Agricultural Products (excludes Animal Feed, Cereal Grains, and Forage Products)	405	120.19	$88,!
Franklin	Agricultural Products (excludes Animal Feed, Cereal Grains, and Forage Products)	407	976.82	$706,:
Franklin	Agricultural Products (excludes Animal Feed, Cereal Grains, and Forage Products)	408	19,191.43	$13,913,'
Franklin	Agricultural Products (excludes Animal Feed, Cereal Grains, and Forage Products)	409	876.51	$634,
Franklin	Agricultural Products (excludes Animal Feed, Cereal Grains, and Forage Products)	410	1,151.25	$832,!
Franklin	Agricultural Products (excludes Animal Feed, Cereal Grains, and Forage Products)	412	44.96	$34,(
Franklin	Agricultural Products (excludes Animal Feed, Cereal Grains, and Forage Products)	413	191.78	$140,'
Franklin	Agricultural Products (excludes Animal Feed, Cereal Grains, and Forage Products)	416	2,991.86	$2,162,:
Franklin	Agricultural Products (excludes Animal Feed, Cereal Grains, and Forage Products)	417	6,819.61	$4,934,

Figure 7-2 Inbound Freight Movements for Franklin County in 2040

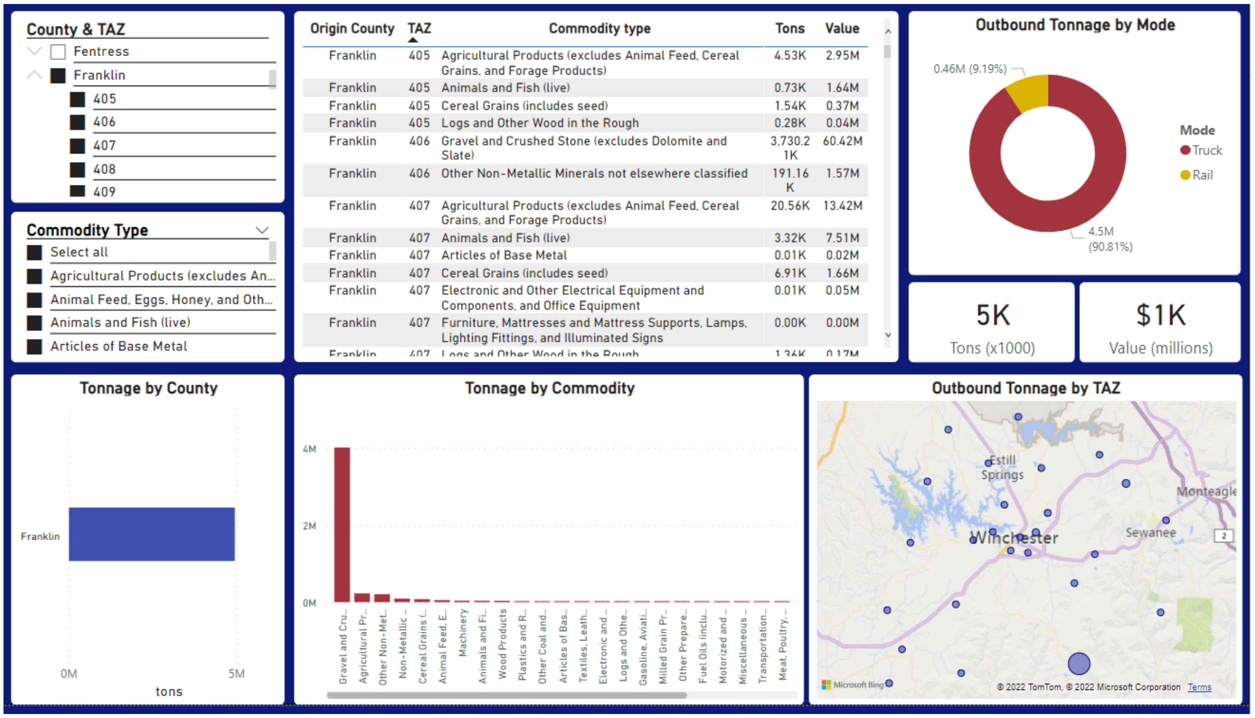


Figure 7-3 Outbound Freight Movements for Franklin County in 2012

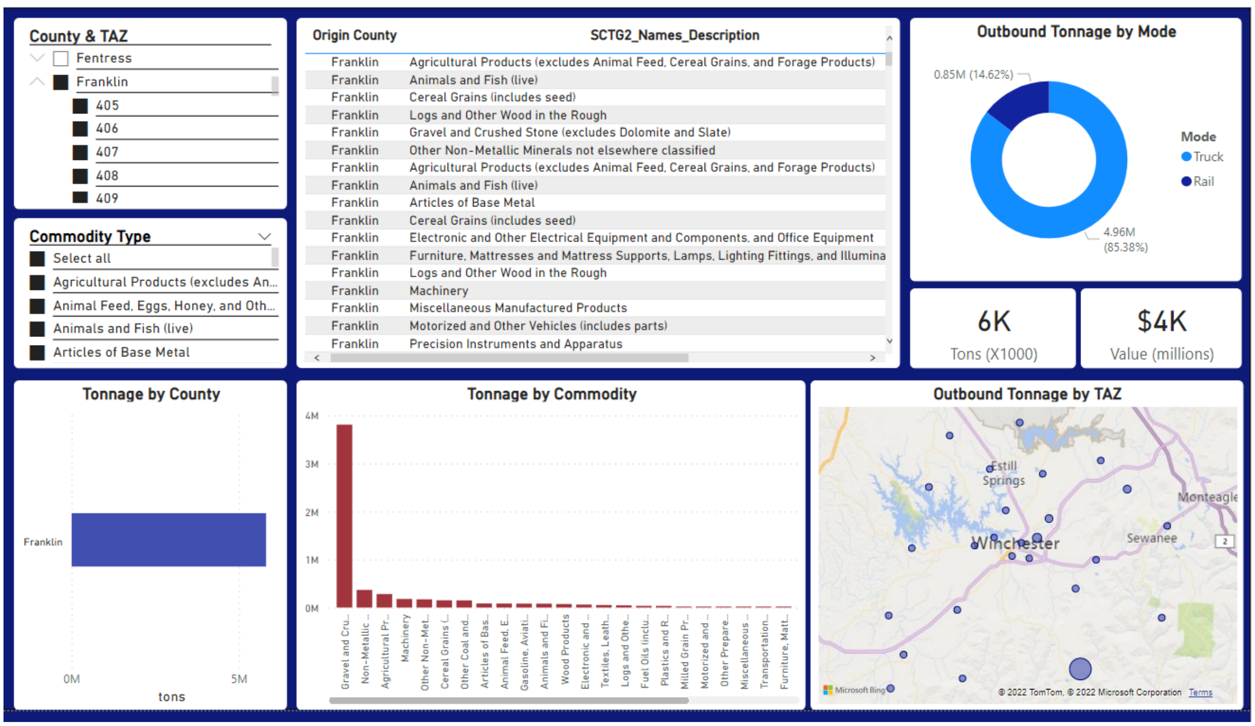


Figure 7-4 Outbound Freight Movements for Franklin County in 2040

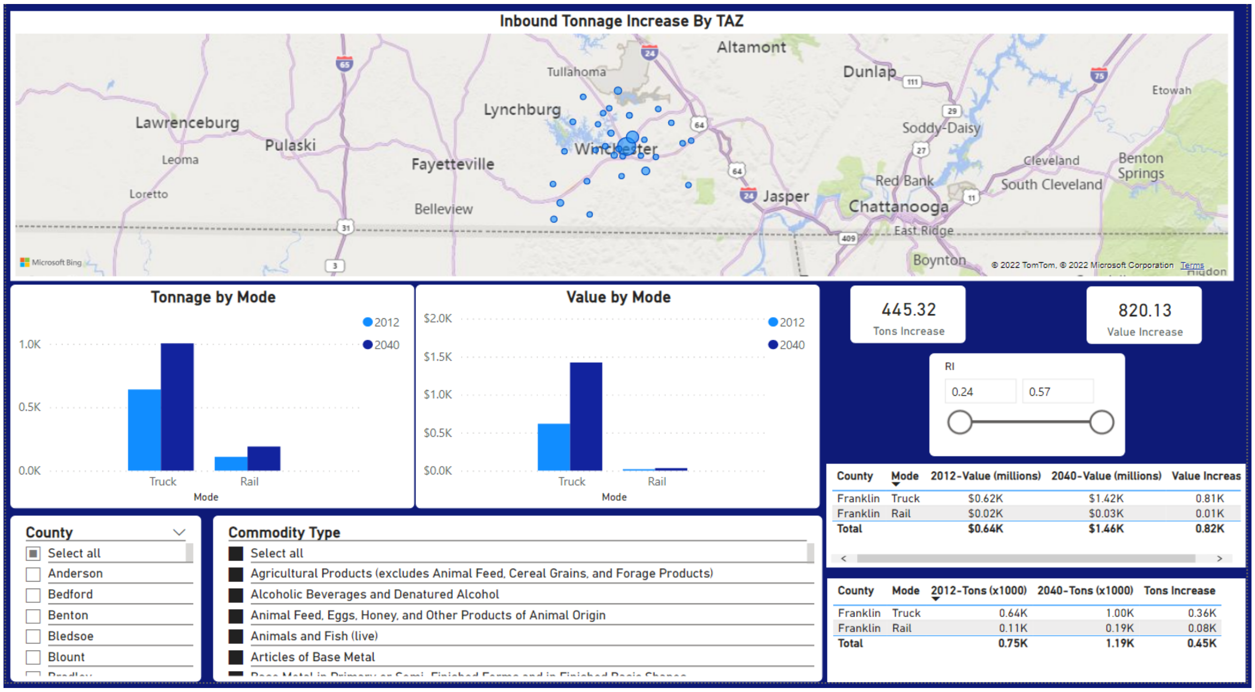


Figure 7-5 Inbound Movement Comparison for Franklin County

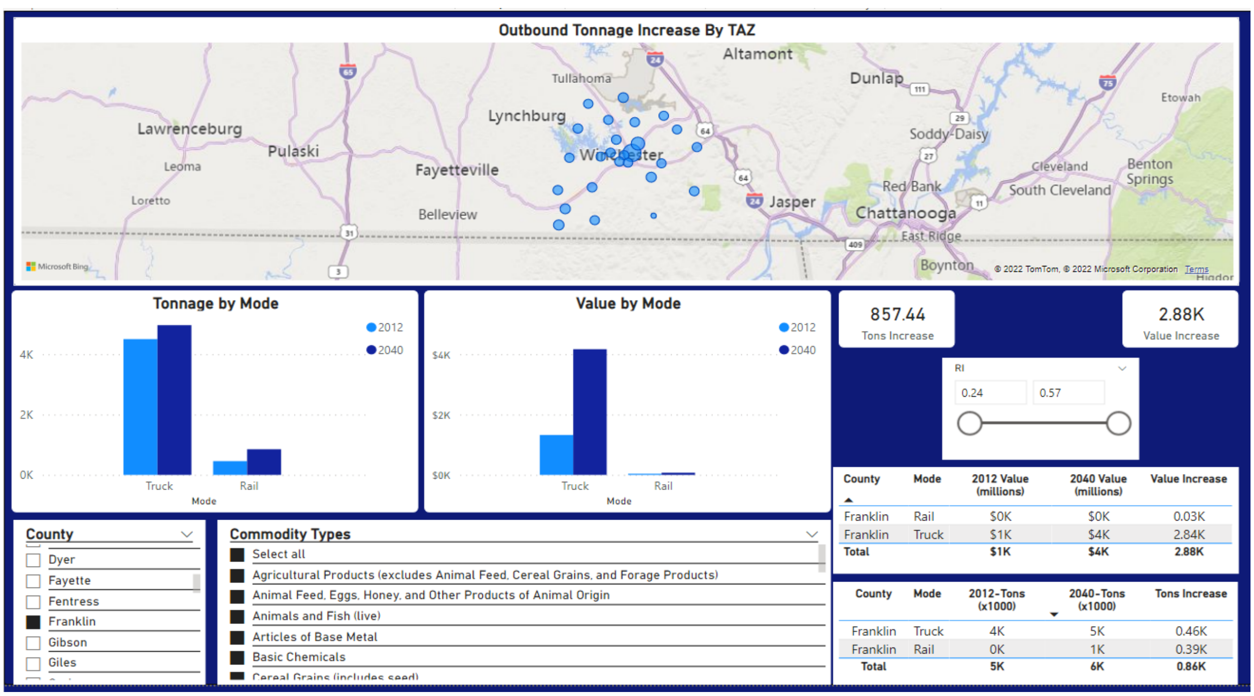


Figure 7-6 Outbound Movement Comparison for Franklin County

7.2. Socioeconomic Analysis

In this subsection, the research team demonstrates how the developed tool can be used to query the various socioeconomic data (using Franklin County as the example) and identify TAZs with a high concentration of different socioeconomic subgroups. Figure 7-7 through Figure 7-13 show screenshot examples of the tool where the user has selected (for Franklin County) a specific truck type and obtained the distribution of race (Asian, Black, Bi-racial, Other, and White), emissions (CO, CO2, NOX, PM10, VOC), and average delay for the base and future year. Figure 7-7 shows the distribution of race in Franklin County in 2010 (1 percent Asian, 2 percent bi-racial, 5 percent black, 1 percent other, and 91 percent white). This population experienced an average of 2.22 minutes delay and almost 112k tons of CO, 113k tons of CO_2, 947k tons of NOX, 10k tons of PM10, and 24k tons of VOC in 2010 just from the single unit diesel truck type. Figure 7-8 shows the projected data for year 2040.

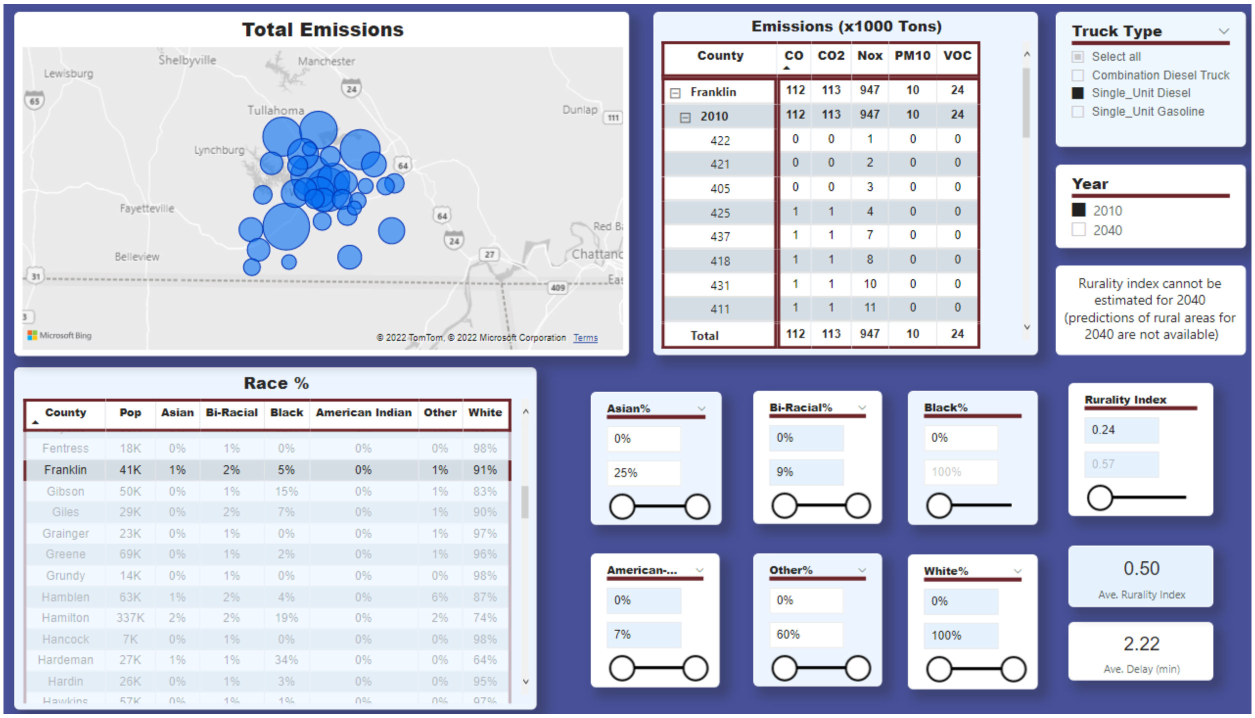


Figure 7-7 Race and Emission Statistics for Franklin County in 2010

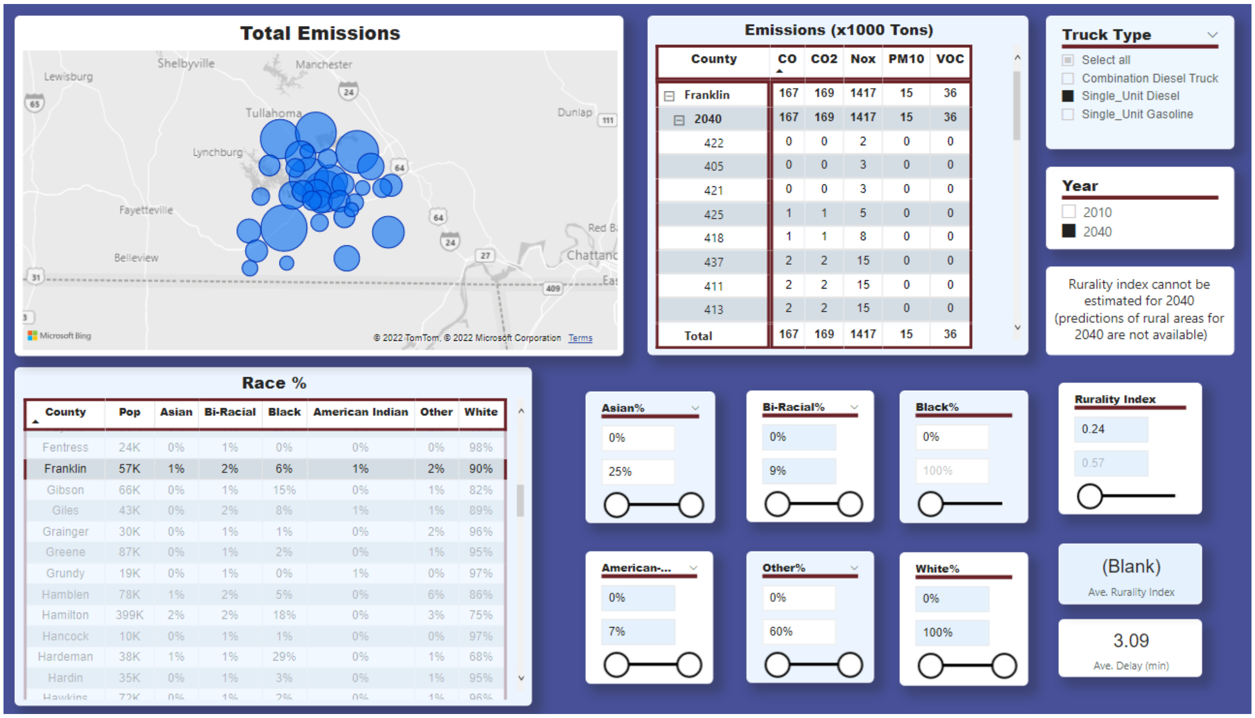


Figure 7-8 Race and Emission Statistics for Franklin County in 2040

Figure 7-9 illustrates the distribution of income groups for Franklin County in 2010. The distribution of income groups shows the highest percentage of total population (7 percent) belongs to the “50k to 75k” income category. On the other hand, data shows around 8 percent of total population in Franklin County under the poverty line (income less than 20k) in 2010. In 2040, the same category of 50k to 75k income is projected to increase to 9 percent while the population with below poverty line income is expected to decrease from 8 percent to 4 percent (Figure 7-10).

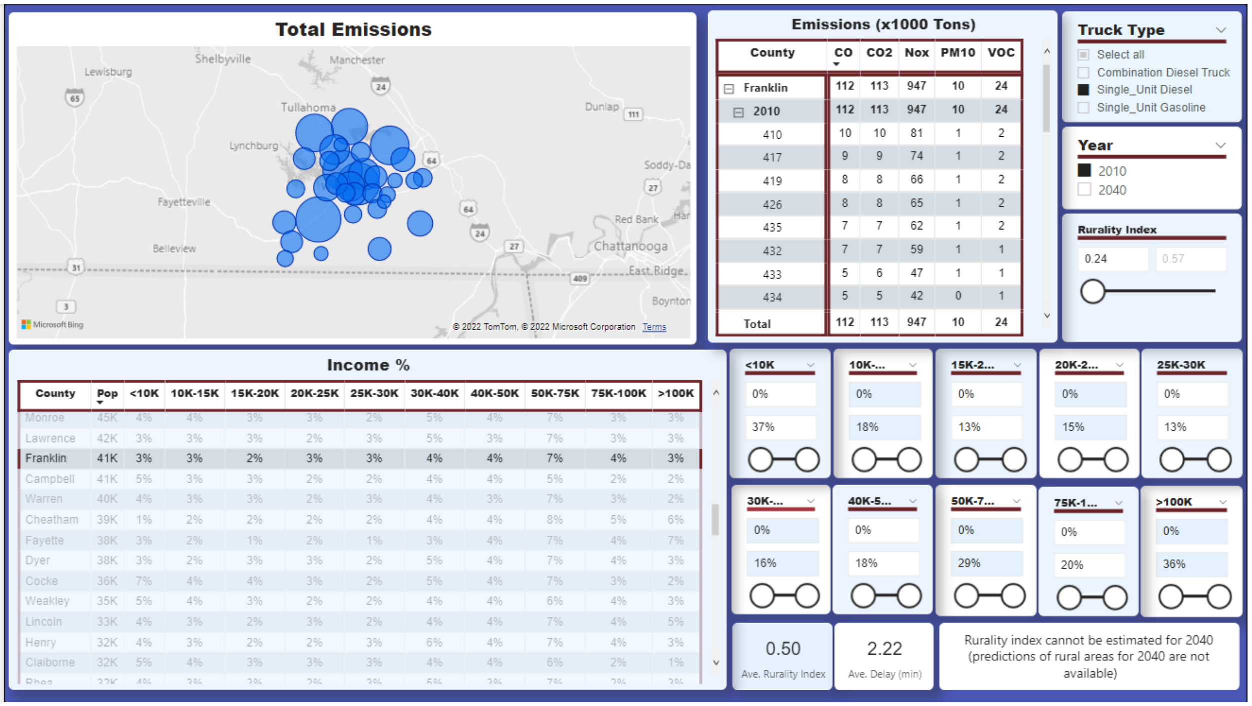


Figure 7-9 Income and Emission Statistics for Franklin County in 2010

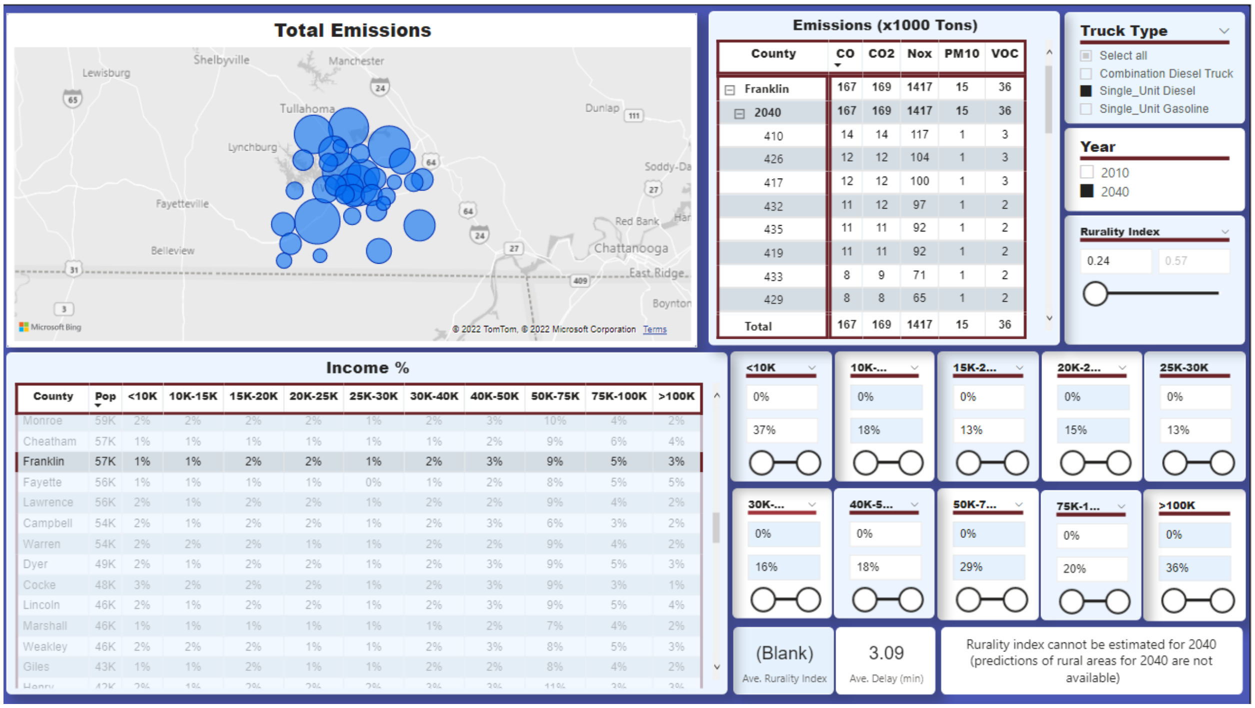


Figure 7-10 Income and Emission Statistics for Franklin County in 2040

As shown in Figure 7-11and Figure 7-12, most of the population in Franklin County have an education level of 9th grade and above in 2010 and 2040. The county is also forecasted to have 0 percent of the population with educational level of less than 4th grade in 2040 (Figure 7-12).

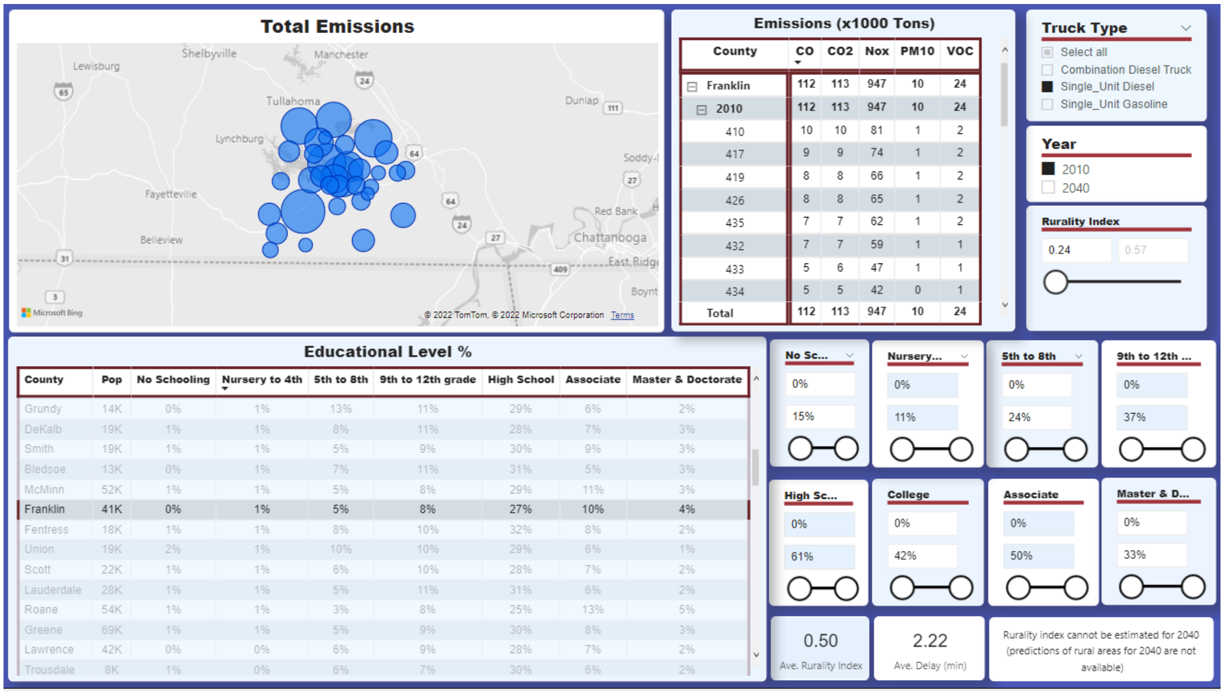


Figure 7-11 Educational Level and Emission Statistics for Franklin County in 2010

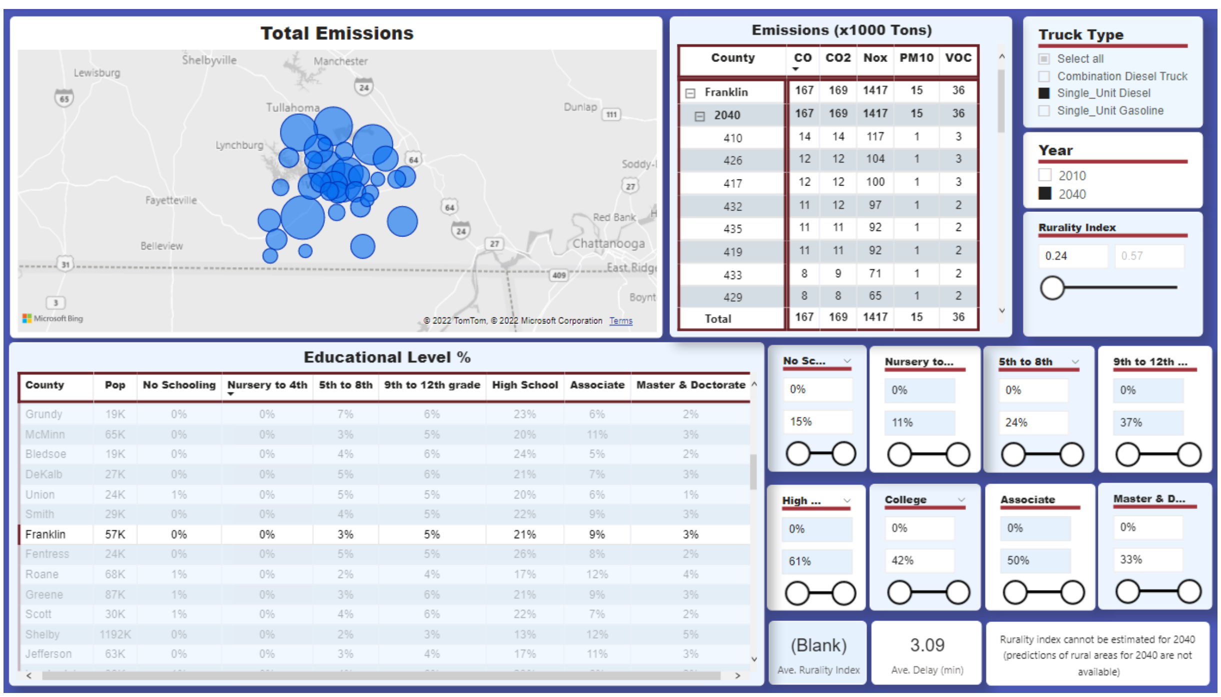


Figure 7-12 Educational Level and Emission Statistics for Franklin County in 2040

The research team also focused on distribution of age-gender and externalities such as emissions. Figure 7-13 shows that the highest and lowest percentage of age groups was 50 to 59 and 80 years old respectively for Franklin County in 2010. Age data projections were not available for 2040.

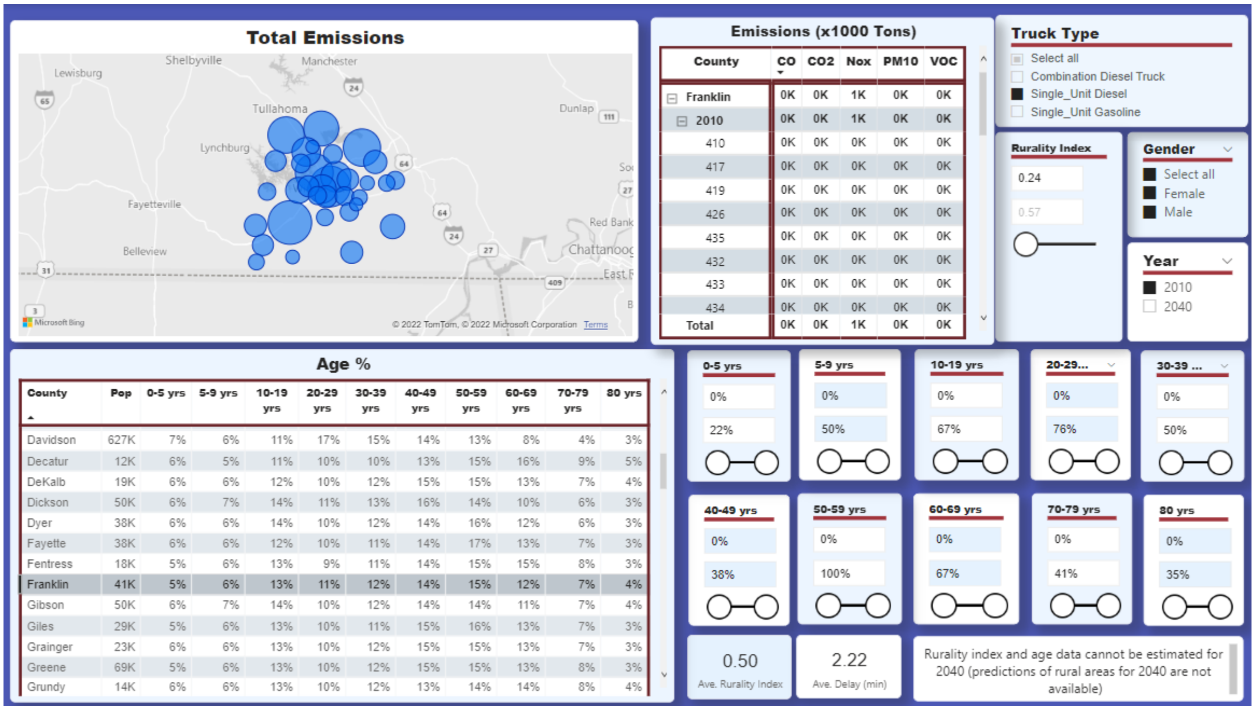


Figure 7-13 Age - Gender and Emission Statistics for Franklin County in 2010

7.3. Equity Analysis

As discussed in Chapters 5 and 6, equity indices were estimated for different socioeconomic population groups (i.e., race, educational level, gender, and income) and freight related externalities (i.e., emissions, accidents, and congestion). In this subsection, these indices are presented and briefly discussed for Franklin County. As shown in Figure 7-14, the Black, Asian, and American Indian have the lowest equity with respect to emissions in both 2010 and 2040, although a slight increase is observed for 2040. Very small differences in equity are observed with respect to congestion (for both 2010 and 2040), while accident equity shows similar patterns to emissions. Note that accident data projections are not available for 2040.

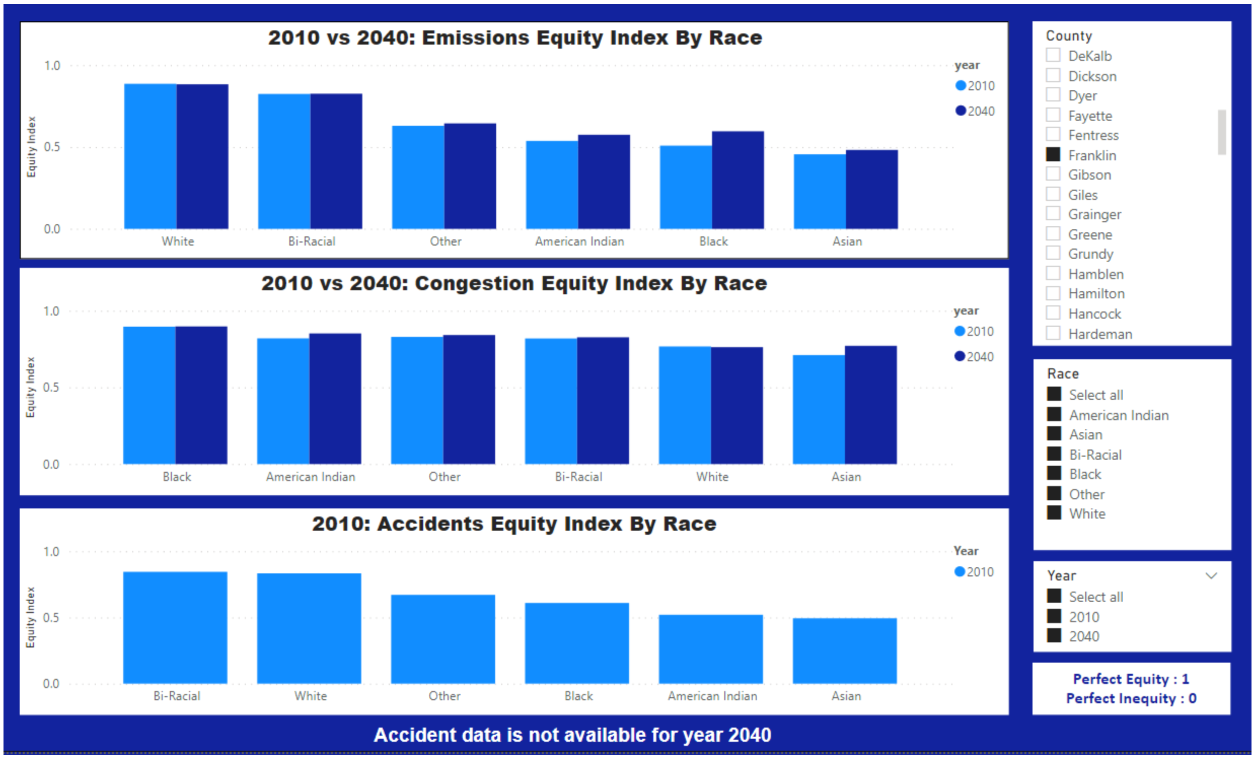


Figure 7-14 Equity Index by Race and Externality for Franklin County

Figure 7-15 shows equity estimates by gender for emissions, congestion, and accidents. No significant differences exist on equity between genders.

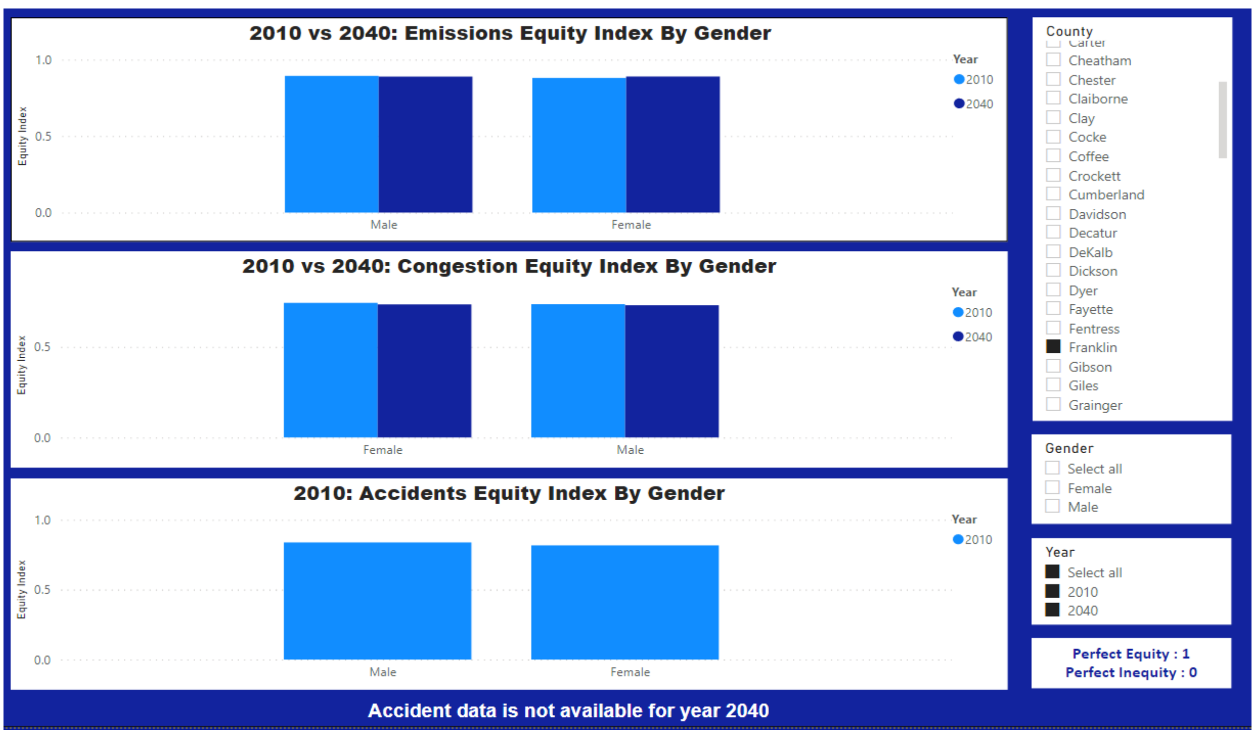


Figure 7-15 Equity Index by Gender and Externality for Franklin County

Figure 7-16 shows the equity estimates for the different educational levels with "4th grade and below" and "5th grade to high school" receiving the lowest and highest values of equity for all externality types for both 2010 and 2040, respectively.

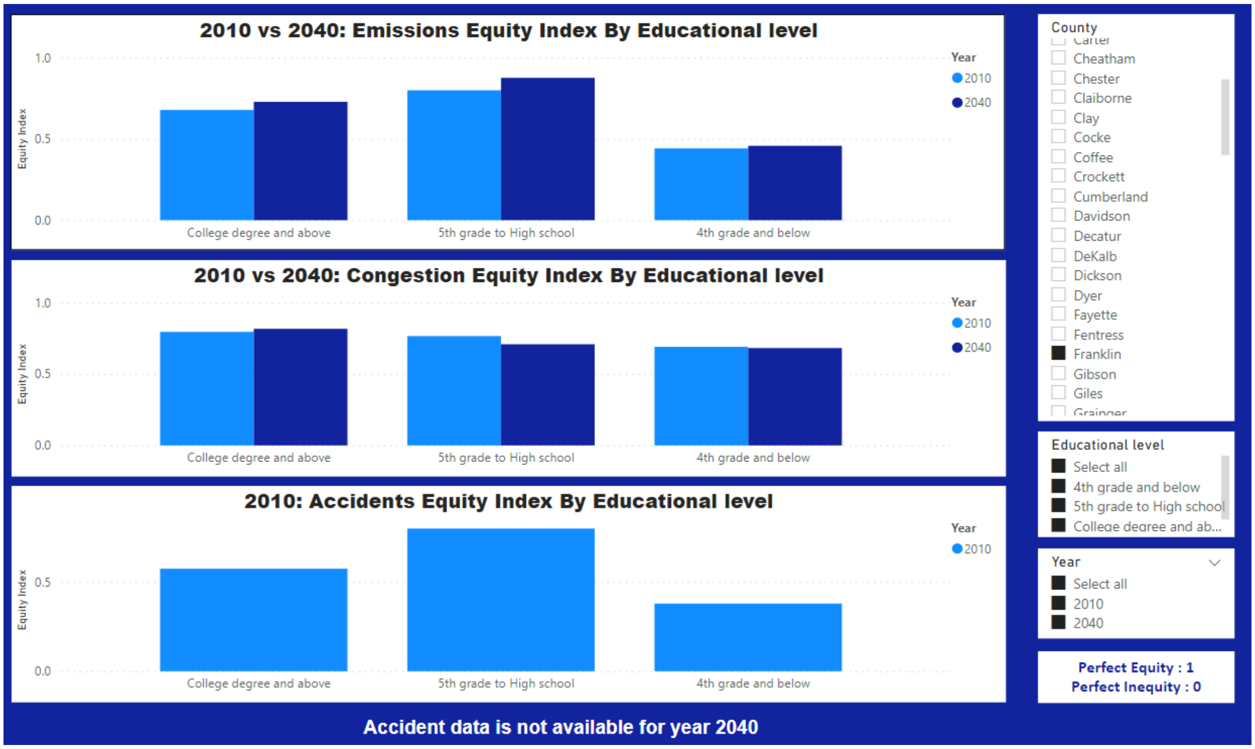


Figure 7-16 Equity Index by Educational Level and Externality for Franklin County

Figure 7-17 shows the equity index in terms of income. The highest equity index in terms of emissions and congestion and accidents belongs to the population with income between 50k to 75k, 75k-100k, and 25k-50k, respectively. However, the lowest equity index in terms of emission and congestion belongs to the population with income higher than 100k in Franklin County, although the differences are not significant.

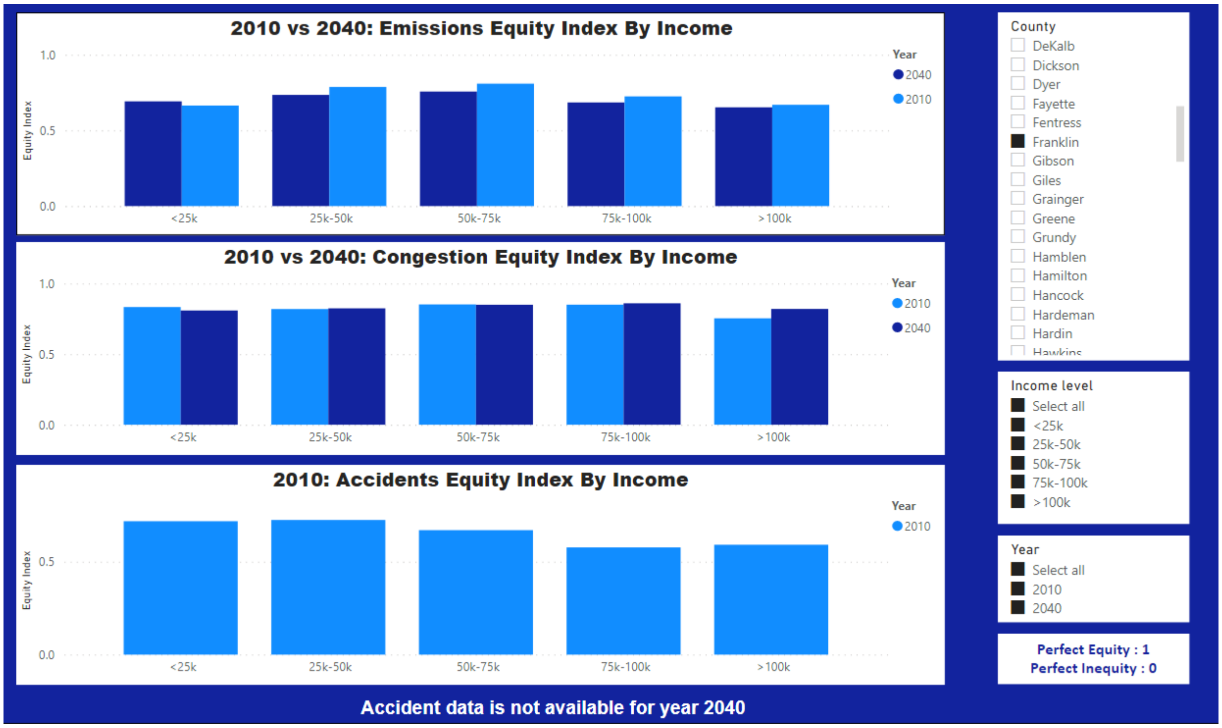


Figure 7-17 Equity Index by Income Level and Externality for Franklin County

Figure 7-18 shows the equity indices with respect to the total tonnage and value and the externalities. As seen in Figure 7-18, the equity index in terms of tonnage increases while the equity index in terms of freight value decreases from 2010 to 2040. All equity indices though, irrespective of year and externality, are below 0.5 and, in the majority, below 0.3.

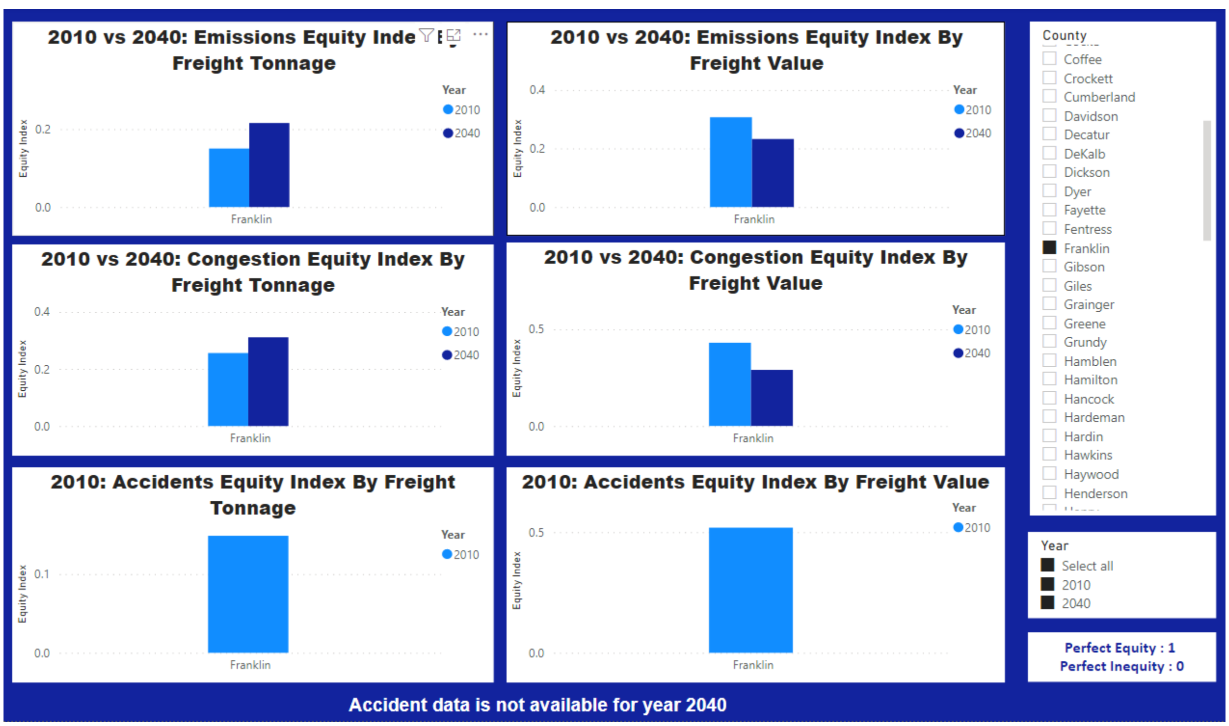


Figure 7-18 Equity Index by Freight Tonnage/Value and Externality for Franklin County

7.3.1. Top and Bottom Equity Counties by Race

In this subsection, the top 10 and bottom 10 counties in terms of equity index by race and emissions for 2010 and 2040 are presented. The same analysis can be performed using the developed tools for the remaining socioeconomic data (i.e., income level, gender, and educational level) and externalities (i.e., accidents and congestion).

Table 7-1 through Table 7-4 show the ranking of the equity index for the Asian, White, Black, and Indian population by emissions. Houston (0.838) and Jackson (0.915) are the highest ranked counties for the Asian population with respect to emissions in 2010 and 2040, respectively. It should be noted that these two counties with the highest equity ranking are two of the most rural areas with a 0.54 rurality index. On the other hand, Hickman (E.R.E.I.=0.064) and Decatur (E.R.E.I.=0.061) are the counties with the lowest equity in 2010 and 2040, respectively. As the results show, the equity index for Hickman County, which was listed as the top bottom county in 2010, will increase by 55.1 percent in 2040. Decatur County, listed as the top bottom county in 2040, will also have the biggest decrease of equity by 22.65 percent by 2040. These results show that Decatur may be a county for policy/infrastructural development to improve equity. Table 7-1 also highlights the ranking of four major counties in Tennessee, including Davidson, Shelby, Knox, and Hamilton (Chattanooga). As is shown there, Hamilton has the best equity index and Shelby has the worst equity index among them for both 2010 and 2040. The highest and lowest equity increases were for Knox and Davidson County by 18.31 percent and 10.85 percent, respectively.

Table 7-1 Ranking of the Race-Emission Equity index (Asian)

Asian					
Top 10 Counties		**Bottom 10 Counties**		**Biggest Increase percent**	**Biggest Decrease percent**
2010	**2040**	**2010**	**2040**	**2010-2040**	**2010-2040**
Houston (0.838)	Jackson (0.915)	Hickman (0.064)	Decatur (0.061)	Hickman (55.1)	Decatur (-22.65)
Jackson (0.79)	Johnson (0.855)	Decatur (0.078)	Haywood (0.072)	Greene (48.76)	Washington (-13.5)
Moore (0.744)	Houston (0.816)	Haywood (0.083)	Hickman (0.1)	Johnson (48)	Haywood (-12.86)
Hancock (0.681)	Monroe (0.787)	Henderson (0.13)	Pickett (0.15)	Grundy (37.61)	Cheatham (-12.55)
Montgomery (0.667)	Jefferson (0.778)	Greene (0.131)	Henderson (0.155)	Marshall (36.75)	Clay (-6.58)
Cheatham (0.636)	Moore (0.775)	Pickett (0.14)	Fayette (0.189)	Crockett (30.7)	Benton (-6.47)
Rutherford (0.63)	Montgomery (0.756)	Weakley (0.165)	Benton (0.194)	Weakley (29.92)	Fayette (-5.36)
Jefferson (0.625)	Hancock (0.753)	Humphreys (0.176)	Greene (0.195)	Monroe (27.41)	Carroll (-4.47)
Monroe (0.618)	Morgan (0.731)	Fayette (0.2)	Weakley (0.214)	Morgan (26.01)	Lincoln (-4.33)
Hawkins (0.615)	Loudon (0.725)	Benton (0.207)	Humphreys (0.216)	Anderson (24.89)	Hamblen (-3.33)
Davidson, Hamilton, Knox and Shelby County Equity and Rank: Emissions and Asian Population					
Hamilton (0.522, #31)	Hamilton (0.598, #25)	Shelby (0.322, #23)	Shelby (0.367, #24)	Knox (18.31, #29)	Davidson (10.85, #43)
Davidson (0.472, #43)	Davidson (0.523, #44)	Knox (0.435, #42)	Knox (0.515, #49)	Hamilton (14.61, #42)	Shelby (13.89, #53)
Knox (0.435, #54)	Knox (0.515, # 47)	Davidson (0.472, #53)	Davidson (0.523, #52)	Shelby (13.89, #43)	Hamilton (14.61, #54)
Shelby (0.322, #73)	Shelby (0.367, #72)	Hamilton (0.522, #65)	Hamilton (0.598, #71)	Davidson (10.85, #53)	Knox (18.31, #67)

Table 7-2 shows the ranking of counties for the emissions equity index for the White population. Lawrence and DeKalb Counties are identified as the first top ranked counties in terms of equity with an index value of 0.932 and 0.961 for 2010 and 2040, respectively. Hickman County is the first bottom ranked in terms of equity index for both 2010 and 2040. In addition, Table 7-2 shows that Campbell County has the highest value of equity increase by 12.45 percent and Decatur County has the biggest decrease of equity by 8.75 percent. Table 7-2 also highlights the ranking of four major counties in TN, including Davidson, Shelby, Knox, and Hamilton (Chattanooga) with rurality index of 0.23, 0.24, 0.27, and 0.30, respectively. Knox has the best equity index and Shelby has the worst equity index among the four counties for both 2010 and 2040. In addition, the highest equity increase belongs to Shelby County with 10.95 percent (which makes it the 5th highest equity index increase among 95 counties).

TABLE 7-2 RANKING OF THE RACE-EMISSION EQUITY INDEX (WHITE)

White					
Top 10 Counties		Bottom 10 Counties		Biggest Increase percent	Biggest Decrease percent
2010	2040	2010	2040	2010-40	2010-40
Lawrence (0.932)	DeKalb (0.961)	Hickman (0.233)	Hickman (0.232)	Campbell (12.45)	Decatur (-8.75)
DeKalb (0.932)	Jackson (0.939)	Benton (0.237)	Benton (0.233)	Coffee (11.48)	Carroll (-8.36)
Overton (0.923)	Rhea (0.938)	Henderson (0.283)	Decatur (0.283)	Unicoi (11.29)	Washington (-6.08)
Maury (0.918)	Lawrence (0.931)	Humphreys (0.288)	Humphreys (0.291)	Hardeman (10.95)	Overton (-5.69)
Macon (0.916)	Fentress (0.923)	Decatur (0.31)	Fayette (0.299)	Shelby (10.95)	Fayette (-5.46)
McNairy (0.916)	Gibson (0.922)	Fayette (0.316)	Henderson (0.301)	Lauderdale (10.43)	Lincoln (-4.97)
Warren (0.916)	Warren (0.92)	Haywood (0.401)	Haywood (0.416)	Cumberland (10.01)	Johnson (-4.75)
Scott (0.907)	Macon (0.919)	Shelby (0.443)	Giles (0.473)	Morgan (10)	Cannon (-3.56)
Rhea (0.9)	Scott (0.913)	Lake (0.452)	Lake (0.474)	Hardin (7.35)	Maury (-2.89)
Johnson (0.897)	Blount (0.911)	Cumberland (0.459)	Shelby (0.492)	Stewart (7.34)	McNairy (-2.85)
Davidson, Hamilton, Knox and Shelby County Equity and Rank: Emissions and White Population					
Knox (0.765, #51)	Knox (0.779, #53)	Shelby (0.443, #8)	Shelby (0.492, #10)	Shelby (10.95, #5)	Knox (1.87, #45)
Davidson (0.682, #70)	Hamilton (0.699, #68)	Hamilton (0.678, #25)	Davidson (0.699, #27)	Hamilton (3.19, #38)	Davidson (2.45, #50)
Hamilton (0.678, #71)	Davidson (0.699, #69)	Davidson (0.682, #26)	Hamilton (0.699, #28)	Davidson (2.45, #46)	Hamilton (3.19, #59)
Shelby (0.442, #88)	Shelby (0.492, #86)	Knox (0.765, #45)	Knox (0.779, #43)	Knox (1.87, #51)	Shelby (10.95, #92)

Table 7-3 shows the ranking of counties for the emissions equity index for the Black population. Results show that Cheatham is the first top ranked county (0.749) in 2010 and it retains that spot for 2040 with an equity index value of 0.8 (slight increase). This county has 0.43 rurality index and transported 0.31 percent of total tonnage in 2012 and it is forecasted to transport 0.39 percent of total tonnage in 2040. Bledsoe County has the highest value of equity increase by 78.36 percent and Humphreys County has the biggest decrease of equity by 24.32 percent. Table 7-3 also highlights that Shelby and Davidson County have a better ranking compared to other two listed major counties with ranking of 25 and 23 in 2010 and 2040, respectively. In addition, Hamilton County has the worst equity index among the four major counties for both 2010 and 2040.

TABLE 7-3 RANKING OF THE RACE EQUITY INDEX (BLACK) BY EMISSION

Black					
Top 10 Counties		Bottom 10 Counties		Biggest Increase percent	Biggest Decrease percent
2010	2040	2010	2040	2010-40	2010-40
Cheatham (0.749)	Cheatham (0.8)	Wayne (0.099)	Humphreys (0.115)	Bledsoe (78.36)	Humphreys (-24.32)
Grundy (0.727)	Monroe (0.786)	Morgan (0.106)	Hickman (0.124)	Carter (62.96)	Johnson (-21.75)
Grainger (0.722)	Grainger (0.726)	Hickman (0.109)	Wayne (0.126)	Giles (50.91)	Fayette (-14.32)
Fayette (0.677)	Grundy (0.724)	Bledsoe (0.132)	Decatur (0.151)	Morgan (49.16)	Trousdale (-9.86)
Union (0.672)	Moore (0.717)	Coffee (0.135)	Morgan (0.158)	Robertson (46.38)	Washington (-6.39)
Monroe (0.656)	Chester (0.709)	Decatur (0.136)	Unicoi (0.179)	Fentress (39.88)	Pickett (-3.74)
Moore (0.636)	Union (0.709)	Humphreys (0.152)	Coffee (0.181)	Henderson (38.42)	Crockett (-3.29)
Overton (0.625)	McNairy (0.674)	Greene (0.155)	Anderson (0.197)	Lincoln (37.87)	Meigs (-2.76)
Meigs (0.598)	Overton (0.652)	Unicoi (0.169)	Greene (0.212)	Greene (37.28)	Van Buren (-1.43)
DeKalb (0.591)	Warren (0.636)	Giles (0.176)	Van Buren (0.216)	Lewis (36.74)	Carroll (-1.29)
Davidson, Hamilton, Knox and Shelby County Equity and Rank: Emissions and Black Population					
Shelby (0.498, #25)	Davidson (0.557, #26)	Hamilton (0.348, #44)	Hamilton (0.404, #42)	Davidson (21.57, #23)	Shelby (5.66, #31)
Davidson (0.458, #29)	Shelby (0.526, #28)	Knox (0.386, #52)	Knox (0.435, #52)	Hamilton (15.99, #40)	Knox (12.71, #48)
Knox (0.386, #44)	Knox (0.435, #44)	Davidson (0.458, #67)	Shelby (0.526, #68)	Knox (12.71, #48)	Hamilton (15.99, #56)
Hamilton (0.348, #52)	Hamilton (0.404, #54)	Shelby (0.498, #71)	Davidson (0.557, #70)	Shelby (5.66, #65)	Davidson (21.57, #73)

Table 7-4 shows the ranking of counties for the emissions equity index for the American Indian population for 2010 and 2040. Hancock and Lewis Counties have the highest equity index for 2010 and 2040 (0.886 and 0.897, respectively). Haywood County has the worst equity index for both 2010 and 2040. This county has a rurality index of 0.52 and was responsible for transporting 0.44 percent and 0.42 percent of total tonnage in 2012 and 2040. Moreover, Haywood County has the highest value of equity increase by 31.84 percent and Johnson County has the biggest equity decrease by 24.58 percent. Table 7-4 also demonstrates that Knox and Hamilton Counties have the best equity index among the four major counties for 2010 and 2040, respectively. Shelby County has the worst equity index among the four major counties for both 2010 and 2040 with a ranking of 47 and 58, respectively. Davidson and Knox Counties show the highest equity increase and decrease from 2010 to 2040 by 16.22 percent and 10.33 percent, respectively.

TABLE 7-4 RANKING OF THE RACE EQUITY INDEX (AMERICAN INDIAN) BY EMISSION

American Indian					
Top 10 Counties		Bottom 10 Counties		Biggest Increase percent	Biggest Decrease percent
2010	2040	2010	2040	2010-40	2010-40
Hancock (0.886)	Lewis (0.897)	Haywood (0.055)	Haywood (0.072)	Haywood (31.84)	Johnson (-24.58)
Union (0.858)	Hancock (0.882)	Henderson (0.137)	Henderson (0.141)	Hardin (28.76)	Clay (-4.98)
Lewis (0.838)	Union (0.875)	Hickman (0.165)	Hickman (0.206)	Gibson (28.49)	Sumner (-4.27)
Trousdale (0.826)	Overton (0.843)	Decatur (0.248)	Decatur (0.257)	Cumberland (26.37)	Williamson (-4.13)
Overton (0.82)	Trousdale (0.84)	Dyer (0.253)	Van Buren (0.281)	McNairy (26.35)	Stewart (-3.63)
Meigs (0.789)	Meigs (0.825)	Van Buren (0.29)	Dyer (0.312)	Hickman (25.41)	Van Buren (-3.34)
Williamson (0.769)	Robertson (0.82)	Fentress (0.299)	Fayette (0.328)	Lauderdale (23.94)	Moore (-1.1)
Robertson (0.769)	Polk (0.795)	Perry (0.3)	Fentress (0.346)	Putnam (23.93)	Lincoln (-0.94)
Carroll (0.74)	Wilson (0.793)	Fayette (0.308)	Perry (0.349)	Dyer (23.47)	Hancock (-0.55)
Cheatham (0.736)	Jackson (0.79)	Lake (0.319)	Benton (0.364)	Giles (21.89)	Campbell (-0.45)
Davidson, Hamilton, Knox and Shelby County Equity and Rank: Emissions and American Indian Population					
Knox (0.64, #23)	Hamilton (0.727, #23)	Shelby (0.534, #47)	Shelby (0.617, #58)	Davidson (16.22, #71)	Knox (10.33, #51)
Hamilton (0.637, #24)	Knox (0.707, #28)	Davidson (0.566, #62)	Davidson (0.658, #64)	Shelby (15.58, #69)	Hamilton (14.13, #65)
Davidson (0.566, #34)	Davidson (0.658, #32)	Hamilton (0.637, #72)	Knox (0.707, #68)	Hamilton (14.13, #65)	Shelby (15.58, #69)
Shelby (0.534, #49)	Shelby (0.617, #38)	Knox (0.64, #73)	Hamilton (0.727, #73)	Knox (10.33, #51)	Davidson (16.22, #71)

Chapter 8 Conclusions

This project had multiple objectives to achieve the goal of developing data analytics tools that can support the work of transportation planners, engineers, practitioners, and local/regional agencies to identify and evaluate alternatives for freight investments to simultaneously improve freight movements and quality of life of the communities they serve. During the project, various freight externalities (e.g., economic, social, and environmental) by mode and locality and mitigation strategies of effective freight practices and technologies were identified and tabulated alongside with their effectiveness, implementation difficulty, and cost. An online matrix was developed to promote the use of the work completed through this project to maximize the impact. In addition to tabulating and quantifying the externalities from freight movements in the state of Tennessee at the county and TAZ levels, the research team estimated various equity indices to help identify areas of high concern. Equity indices were developed for race, gender, educational level, and income with respect to emissions, congestion, and accidents (at the County level). A data analytics website containing the equity indices, along with various socioeconomic descriptors and freight movements (both in terms of tonnage and value by commodity type and mode), was developed to allow easy access to the data. The functionality of the tools developed during the project was modified, customized, and fine-tuned (with the input of TDOT's project technical advisory committee) to achieve the goals and objectives of the project. Additionally, the results of this research were shared with public and private entities to increase awareness of the project. The developed report and data analytics tool can support planning, tactical, and operational freight improvements at the state and local level to simultaneously optimize freight movements and minimize their externalities (e.g., environmental, congestion, health) to the communities they serve.

The information and data collected, analyzed, and synthesized, and the tools developed during this project will support TDOT to 1) Analyze critical areas of low equity due to freight movements; 2) Select and prioritize investments to improve freight movements in Tennessee that minimize externalities while benefiting economic and equitable growth for the rural communities; and 3) Improve representation of equity in multimodal transportation planning.

Findings

This study revealed a high number of mitigation strategies with varying levels of effectiveness, cost, and implementation difficulty. These strategies vary by mode and externality type, usually address more than one externality at the same time and were qualitatively ranked to capture the potential for addressing each. Quantitative values can only be estimated on a case-by-case basis as they depend on locality, traffic conditions, terrain, population density, weather etc. In most cases, to estimate quantitative measures for a mitigation strategy a full study supported by modelling and/or simulation analysis will be needed. The proposed qualitative ranking can be used to develop a list of the most promising strategies to be evaluated in detail through modeling and/or simulation analysis. As expected, environmental impacts mitigation was the most researched topic while noise from freight movements and its mitigation strategies was the least researched topic. One of the major themes in the literature was the lack of data on commercial vehicles that directly affects the estimation of the externalities. It is very common, for planning agencies to rely on data from models as opposed to observed data when estimating negative externalities from commercial vehicles (e.g., congestion, emissions, noise). With respect to equity, results from this research suggests that freight movement equity differences between counties in Tennessee vary significantly ranging from a maximum of approximately 0.8 to a minimum of 0.02 (with a value of one corresponding to perfect equity). African American and Asian population groups are the most inequitable when it comes to freight movements while no significant difference between genders and income levels (except for emissions for the income categories) was observed. Finally, results from the study identified the low educational levels (4th grade and below) population as the group as the most inequitable for all externalities.

Recommendations

The research team recommends that the developed guidebook and tools are incorporated into the existing TDOT freight planning manual as a reference for researchers, consultants and contractors and are also shared with the MPOs in the state. The mitigation strategies, equity and freight movement data, included in the deliverables of this project, support identification of solutions with the highest return on investment with respect to minimizing negative externalities and inequalities that are the product of freight movements. The research team also recommends that TDOT hosts a series of workshops for local agencies (e.g., MPOs) to showcase the guidebook and tools. During the workshops local agency personnel can be trained on how to use the developed guidebook, tools and data produced by this research to support mitigation of negative freight externalities and identify areas of low equity. The research team recommends that future research can focus i) linking the mitigation strategies and its impact on freight equity, ii) including noise data in the estimation of equity, iii) comparing freight equity measures in areas with and without a significant amount of last mile deliveries by non-motorized transport vehicles, and iv) understand the effectiveness of the mitigation strategies on local communities (especially those with high inequity).

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