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Modeling the impacts of changes in freight demand, infrastructure improvements and policy measures on a metropolitan region

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Submitted by:

Lazar N Spasovic
Professor

Wen Zhang
Associate Professor

New Jersey Institute of Technology
University Heights, Newark, NJ, 07103

Paul Truban
New Jersey Department of Transportation - Bureau of Freight Planning and Services

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16. Abstract

In this research, a policy framework was developed and used as a tool to determine the impacts of change in truck traffic on a regional level as a result of policy change. To achieve the objective, three demand models were used in the framework which is built on the principle of behavioral route choice and mode-choice assignment problem. The problem is represented in more realistic context by using stochastic route-choice behavior for multi-user groups and uses logit model to describe their behavior. The models have been formulated as mathematical programs with non-linear objective functions with linear constraints.

The framework was applied to the real-world case study in New Jersey area. The developed framework answers the question of how much the change in truck demand affects the region regarding monetary costs such as safety, congestion, environment, and pavement damage. The research further provides an insight of the change in travel behavior as a result of policy decision and its effect on communities. The study is built on the data that is readily available to planning agencies and can be further enhanced with improved data availability.

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Chapter 1 - Introduction

Research Objective

The Moving Ahead for Progress in the 21st Century Act (MAP-21), directed the Department of Transportation (DOT) to develop a comprehensive State Freight Plan that outlines immediate and long-range plans for freight-related transportation investments. However, for states to design and implement investment policies, there is a need for a policy framework to evaluate the impact of truck traffic. The lack of structure makes it difficult for states and metropolitan planning organizations (MPOs) to evaluate alternative strategies when multiple stakeholders with conflicting objectives are involved.

The primary objective of this study is to develop a framework to determine the regional impacts of changes in truck traffic due to policy changes. Transportation policies can have a significant effect on every aspect of life. Travelers tend to choose their routes based on the lowest travel cost and can therefore, be considerably affected by increased congestion and alternative modes. It can also influence trip distribution. Three transportation demand models have been used in this study. The benefit of this approach is that the models consider both route choice and mode choice and formulate these preferences in well-defined supply-demand functions to yield equilibrium solutions.

The policy framework developed in this study addresses the following issues:

- Present the complex implications that a policy can have on a region
- Quantify the mobility and safety impacts of policies
- Quantify the infrastructure improvement and maintenance impacts of policies.
- Evaluate the implications of different transportation policies and planning decisions.
- Quantify the following costs: roadway network congestion; crashes; roadway infrastructure maintenance and environmental impacts.
- Quantify the impact of mode choice on a roadway network on regional and corridor levels.

The research presented in this study is significant from both theoretical and practical perspectives. It integrates demand and supply functions in network equilibrium models that also incorporate decision-making process. The impacts of these decisions on safety and the environment are quantified. The proposed approach is based on Federal Highway Administration (FHWA) methodology and ITS Deployment Analysis System (IDAS). The framework can be used to evaluate the impact of different policies on congestion, safety, emissions, and pavement. The framework can, therefore, be used to answer questions of interest to transportation planners and decision makers. The simulation results from this research thus reveal valuable insights that will help policymakers design policies and investment strategies. As ports are major freight generators, the study is focused on the movement of cargo to and from port areas. A macroscopic simulation modeling approach is used to quantify regional freight movements.

Although various studies have been developed using freight demand models, they lack a comprehensive approach that accounts for all costs associated with mode choice and changes in demand. The study also integrates demand and supply functions in network equilibrium models that incorporate the decision-making process.

Background

Global Trade and Role of Ports in International Trade

The United States is the world's largest economy[1], and is among the top three global trading markets that rely on the import of raw materials and the export of finished goods[2]. International trade in goods and services increased by 2.85% in exports, and 3.41% of assets in 2014 compared to previous years[3]. This growth has promoted the importance of the maritime shipping industry and port activities. One in every eleven containers engaged in global commerce is either bound for or originating from the United States[4].

Seaports are gateways to domestic and international trade, connecting the United States to the world. According to the American Association of Port and Authorities (AAPA), ports currently handle more than 2 billion tons of domestic trade and import/export annually and are expected to double by 2020. Ports also contribute more than $3.15 trillion to the Gross Domestic Product (GDP) generating nearly 13.3 million jobs. The completion of the Panama Canal project in 2016, and increasing international trade and movement of goods at 3.4 percent per year is placing pressure on ports to increase their capacities to handle containerized cargo[5]. The projected container traffic growth at East Coast and Gulf Coast ports will likely outpace container traffic at the West Coast ports after 2015[6].

States Role and Responsibility

Statewide freight plans outline investments, strategies and pilot programs targeted towards advancing policy changes. They also aim to establish relationships with municipalities, counties, and the logistics industry, to ensure that collaborative solutions are developed to target critical areas impacting the freight industry. Annual proceeds from taxes and fees dedicated to the Highway Trust Fund have fallen below annual expenditures in recent years 7. Due to these budget shortfalls, state and local authorities face a challenge to maintain the roadway network without continued support from the Federal government. States provide nearly half of all surface transportation funding and are facing tough times. The primary sources of financing: vehicle fuel tax, vehicle registration fees, driver license fees, sales taxes on motor

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[1] International Monetary Fund – World Economic Outlook (http://money.cnn.com/news/economy/world_economies_gdp/)

[2] International Trade – Wikipedia, Largest countries by total international trade (http://en.wikipedia.org/wiki/International_trade)

[3] U.S. Census Bureau and U.S. Bureau of Economic Analysis, Economic and Statistics Administration, U.S. Department of Commerce, Washington, DC (http://www.census.gov/foreign-trade/statistics/highlights/Congressional.pdf)

[4] U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics, America's Container Ports: Linking Markets at Home and Abroad. Washington, DC: 2011.

[5] U.S Department of Transportation, Federal Highway Administration, Office of Freight Management and Operations, Freight Facts and Figures 2013.

[6] Freight Transportation and Economic Development: Planning for the Panama Canal Expansion, February 2012 (http://www.nado.org/wp-content/uploads/2012/03/panama.pdf)

[7] Testimony – Status of the Highway Trust Fund, Office of Congressional Budget, July 23, 2013.

vehicles, heavy truck use taxes, traffic violation fines and similar taxes, are insufficient. The fund has accumulated $14.8 billion in debt and without significant policy reforms; the situation is going to worsen further[8].

Freight System in New Jersey

According to the New Jersey Comprehensive Statewide Freight Plan, 621 million tons of freight worth $860 billion moves in, out, within and through New Jersey annually. Trucks, waterborne and rail account for 75, 18 and 7 percent of goods moved, by weight, respectively. The plan recognizes trends in goods movement and presents strategies and actions geared towards improving the ability to provide for more efficient movement of goods. Roadway and rail infrastructure projects address safety, maintenance, and capacity issues. Other policies include supporting extensions of port operating hours, introducing delivery during non-business hours, supporting open road tolling, and encouraging statewide agencies to identify additional issues.

Substantial investments are being made by the State and terminal operators into improving navigation, transportation infrastructure and adding new terminal capacity at the Port of Newark/Elizabeth, the largest port-of-entry on the East Coast and the third largest in the nation. The construction and investment commitment of over $3.45 billion between 2013 and 2018 is designed to produce over 4,800 direct jobs annually and over $5.6 billion in business income[9]. These investments are geared towards accommodating the arrival of mega-ships after the expansion of the Panama Canal.

The $300 million investment in rail infrastructure and equipment demonstrates the State's intention to improve the freight rail system to accommodate additional cargo. New Jersey has approximately 1,000 miles of rail freight lines serving customers by short-line regional and national railroads[10]. The New Jersey Department of Transportation (NJDOT) has a vital interest in preserving and improving the rail freight infrastructure. Eighteen freight railroads, divided into three classes, currently operate within the State of New Jersey.

- Class I Railroads – Norfolk Southern (NS), CSX Transportation (CSXT) and the Canadian Pacific Railway (CP)
- Class II Regional Railroad – The New York, Susquehanna, and Western Railway (NYS&W)
- Class II and III Local Railroads, and
- Seven Switching and Terminal Railroads – Consolidated Rail Corporation (Conrail).

The Class I railroads account for over 67 percent of the rail mileage in New Jersey, with CSXT and NS operating close to 250 and 160 trains daily, respectively. According to the Department of Commerce

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[8] Spiral of Debt, A report published by Regional Plan Association – The Unsustainable Structure of New Jersey's Transportation Trust Fund, March 2010.

[9] The Economic Impact of the New York-New Jersey Port Industry – A. Strauss-Wieder Inc, Analyzes for informed decision making, February 2014 (http://nysanet.org/wp-content/uploads/Economic_Impact_Study_FINAL_2012.pdf)

[10] New Jersey Statewide Freight Rail Strategic Plan – Moving New Jersey Forward – June 2014 (http://www.state.nj.us/transportation/freight/plan/pdf/FRSP.pdf)

economic models, every dollar spent on investments in freight railroads (tracks, equipment, locomotives, bridges, etc.) yields $3 in economic output. Freight railroads directly employ over 1,100 people in New Jersey alone. Also, each $1 billion of rail investment creates more than 17,000 jobs. According to the New Jersey Statewide Freight Rail Strategic Plan, the overall freight demand is expected to grow by about 64% between 2007 and 2035, and rail freight by about 48% during the same period.

With limited resources to build new capacity, it is important to improve the existing multimodal transportation infrastructure to meet current standards with a goal to accommodate freight growth. The Statewide Freight Strategic Plan presents the following priority recommendations to address current shortcomings of the system.

- Upgrade secondary and light density lines to handle the current industry standard 286,000 lb. (286 K) rail cars;
- Upgrade capacity and access to the rail yards;
- Upgrade tunnel and bridge height restrictions that prevent the movement of double-stack container rail cars;
- Improve connectivity between northern and southern New Jersey;
- Enhance connectivity between Class I and the short line railroads

Challenges Faced by New Jersey

New Jersey faces unique challenges; the surface transportation is not only the backbone that supports the state's economy but also provides businesses with a high level of mobility. However, the mobility is being constrained by the increasing level of congestion impacting businesses, shippers and manufacturers, and ultimately consumers. A report published in January 2015 by TRIP – A National Transportation Research Group estimates that traffic congestion costs New Jersey residents a total of $5.2 billion annually in lost time, $3.7 billion in additional operating costs, and $2.9 billion due to traffic crashes. These congestion costs translates to $1,951 per licensed driver.

The strategic location of New Jersey as a "Crossroads of the East" creates critical links in shipping routes and commerce. Every year, $423 billion in goods are shipped from sites in New Jersey, and another $350 billion in goods are shipped to sites in New Jersey, mostly by trucks[11]. Movement of these goods through trucks significantly affects the life cycle of the roadways. To build and enhance as a growing and dynamic state, New Jersey needs either additional revenues or an alternate solution to reduce the costs. Without a substantial boost in federal, state and local highway funding, the state's ability to improve the condition of its transportation system and economic development is not possible.

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[11] Bureau of Transportation Statistics (2010), U S Department of Transportation. 2007 Commodity Flow Survey, State Summaries (http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/commodity_flow_survey/2007/states/new_jersey/index.html)

Report Organization

This report is organized into seven chapters. Chapter 1 describes the current issues related to freight increases especially at ports and challenges faced by agencies to provide sustainable infrastructure with limited funding availability. Chapter 2 discusses the efforts of previous studies and is divided into three broad categories: a) overview of policy directions used to manage increasing truck traffic, b) freight demand modelling and c) externalities associated with truck movements. Chapter 3 describes the data collection effort with focus on the regional transportation model that was utilized for this analysis. Chapter 4 describes the methodological framework and presents three freight demand models which are used to identify the regional impacts of trucks. Each of these demand models is discussed in detail in this section along with its solution algorithm. Chapter 5 presents a case study that applies the proposed framework described in Chapter 4 to Port Newark and the northern New Jersey area that forms a perfect test bed to implement the framework to analyze policies and their impacts on a regional highway network. Chapter 6 discusses the results of the case study and the regional implications of a policy. Chapter 7 presents the conclusions.

Chapter 2 - Literature Review

This chapter presents a review of both academic literature and professional reports toward quantifying the truck impacts. In Section 2.1, an overview of policy directions is discussed to address increasing truck traffic and alternatives policies under consideration. The policy guidelines are further classified into three broad categories: operational strategies, vehicle size and configurations, and investment in alternative infrastructure. The next Section 2.2, discusses truck impacts in the areas of congestion, environment, pavement, and safety.

Overview of Policy Directions

Broad policy directions are discussed in a National Cooperative Highway Research Program (NCHRP 314) regarding strategies for managing increasing truck traffic. The study focuses on adverse effects of growing freight transportation via highways and discusses national freight truck policies by conducting surveys of various stakeholders, including state departments of transportation (DOTs) and metropolitan planning organizations (MPOs). The report identified the particular challenges being addressed, planning activities being undertaken, management strategies being considered and factors influencing the policies. The most prevalent issues reported from responses were congested urban highways, pavement deterioration, environmental issues, and safety. Some of the potential strategies discussed to resolve these problems range from improved design to regulatory policies. Three major directions highlighted in the study are operational strategies, vehicle size, and configuration, investments in alternative infrastructure.

Operational Strategies

Seaports manifest significant transportation activity, with regards to the movement of goods. This movement of goods offloaded from the container ships is then mostly carried by the trucks. For instance, based on the Port of NY/NJ Comprehensive Port Improvement Plan, it is estimated that the 85% of container volume is being carried by trucks alone and container throughput has increased by 67.7%[12] over two decades. The increased volume not only affects the efficiency of operations but also impacts surrounding roadway network. Therefore, port significance expands beyond the harbor area and improved services to accommodate the demand for goods affect the infrastructure capacities in the region. To study the interaction between the ports and surface transportation, the literature focuses on studies that include communication between port operations and surface transportation system. Spasovic et al. (2015) published a report on quantifying the impact of port-related trucks on highway operations by using microscopic simulation model in VISSIM. The study explored the impact of gate operational strategies on queues, delays within the port area and estimated that an increase in 45% truck demand could cause queues to spill over on highways near the harbor area.

Jeffery. K (2012) studied the similar impact of operational strategies on congestion and improved air quality. The proposed model developed traffic simulation capable of measuring the impact of various gate strategies on congestion at the terminal gates before and after gate policies were being implemented. Based on the results of the study, it was concluded that majority of delays occur at gate terminals and

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[12] http://www.panynj.gov/port/trade-stats.html

extending terminal gate hours can be an effective strategy to reduce congestion at gates as well as within the roadway network. To test if high levels of congestion can be reduced at truck terminals, Dougherty (2010) evaluated the impact of gate strategies on a container terminal's roadside network using microsimulation. The objective of the study was to develop simulation model capable of testing different gate strategies to evaluate the possible reduction in congestion in the terminal vicinity. Results of the research showed that to maintain an efficient level of service, the percentage of truck demand needs to be shifted to off-peak weekday and weekend hours. To model the interrelationship between vessel and truck traffic at the marine container terminal, Moinni (2010) developed analytical and a simulation model to relate sea and landside activities by exploring the factors which influence them. The study provided evidence that there is a strong relationship between the truck traffic at the gates and the apron container's volume at the marine terminal.

To assess the effectiveness of extended hours of operation and potential obstacles for its implementation at the port, Spasovic et al. (2009) conducted a study at Port of Newark/Elizabeth (PNE). The report identified operating characteristics and business objectives of stakeholders involved in container transport and found that extended operations were not highly successful. Some of the reasons were that truckers do not have a place to deliver a container during off-peak which prevents them from utilizing the extended gate services. The study concluded that for successful implementation of extended hours, all parties in the logistic chain need to brace it. A similar study conducted by Holguin-Veras and Michael Silas (2008) researched the effects of alternative freight delivery hours as a means to reduce peak hour congestion. It found that road pricing by itself is of limited use to shift truck traffic to non-congested times of the day. The study was based on the empirical evidence of 'Evaluation Study of the Port Authority of New York and New Jersey's (PANYNJ) Time of Day Initiative' and concluded that policies targeting both carriers and receivers are essential to make the off-peak deliveries feasible option.

Puglisi (2008) developed federated simulation model from two different computer models (Rockwell Arena and PTV VISSIM). The study analyzed four different scenarios (base, increase in trucks, the increase in containers and increase in both) which used performance measures such as delays experienced by trucks and containers. The results from the simulation experiments provided a unique ability to capture the interactions between the port and the roadway network. In addition to simulation studies being conducted, Giuliano at al. (2005) evaluated gate terminal appointment system at the Los Angeles/Long Beach ports in response to California Assembly Bill (AB) 2650. The legislation permitted terminals to adopt two operational strategies (gate appointment and off-peak operating hours) as means of avoiding fines for truck queues and reduce environmental impacts. The study monitored the appointment system over 16 month period in which extended interviews with managers, field observations at terminals, trucking company survey and publicly available data on port operations were studied. The paper concluded that the use of appointment system varied greatly depending upon operating policies of individual terminals and there was no evidence that the operational strategy has affected queuing at marine terminal gates or significantly improved air quality. Haveman et al. (2004) conducted a study which discussed California's Global Gateways: Trends and Issues which emphasized on the growing congestion problems near the ports. In addition to the congestion, trucks moving containers in and out of ports produced significant pollution and impacts passenger cars idled by traffic delays.

Vehicle Size and Configurations

MAP-21 required the Department of Transportation (DOT) to conduct a comprehensive truck size and weight limits study. The study used state-of-the-art analysis and modeling approaches to determine the impacts of truck size and weight configurations on pavements, bridges, safety and other areas. A report to Congress, "Comprehensive Truck Size and Weight Limits Study," was released in April 2016 that focused on the magnitude of potential impacts if changes were implemented. The DOT concluded that no changes to federal policy should be made at this time due to the lack of available data to make accurate assessments. The study found that the potential reduction in vehicle miles traveled would be small, and concluded that, if federal vehicle weight limits were increased to 91,000 pounds, an investment of $1.1 billion would be needed to upgrade and repair the 4,800 bridges considered in the analysis.

A study conducted by DOT in 2000, claimed that 80,000-pound five-axle combination trucks cover only 80 percent of the cost of their damage to highways, and trucks weighing more than 100,000 pounds cover only 50 percent of their cost[13]. Further increases in truck size and weight would lead to even greater underpaid taxes and fees. However, "grandfather" provisions in the federal law allows states to permit vehicles beyond legal limits and collect taxes to compensate for additional damage, however, these additional fees do not cover the full cost of the actual damage done to infrastructure. Dunning et al. (2016) reviewed state DOT policies for overweight truck fees and pertinent stakeholders' perspectives and found that legislators and lobbyists, rather than engineering analysis, frequently govern the setting of overweight taxes and fines. These charges are not logically related to the damage inflicted on infrastructure and the cost incurred to maintain pavement and bridges. There are established exceptions, but the permitting rules are inconsistent from state to state and are problematic to interstate overweight trucking operations. Harmonization can resolve inconsistencies and assist businesses to make appropriate mode choice and routing decisions and set policies to account for damage fees.

Dey et al. (2014) estimated pavement and bridge damage cost caused by overweight trucks. Damages increased significantly when vehicles exceeded legal weight limits. The study compared fee types and found that a flat rate per truck trip damage cost recovery fee, would range from 67% less to 293% more compared to an axle-based fee. A weight-based damage fee would range from 67% less to 331% more compared to a truck type based fee. The study concluded that careful analysis is necessary before selecting a single fee type. Chowdhury (2013), investigated the impact of heavy vehicle traffic on pavements and bridges in South Carolina and developed policy recommendations based on technical analysis. The study found that damage costs were higher than the overweight fees recovered and concluded that permit fees would vary between $24 and $175 per trip based on truck types, or $65 per trip for a single flat fee. Adams et al. (2013) at the University of Wisconsin – Madison concluded that single trip permits for oversize/overweight fees do not capture the damage caused by overweight loading. Following the enactment of MAP-21, a pilot program in Vermont raised the size and weight limits on its interstate highways for one year beginning December 2009 and compared traffic, infrastructure impacts, and energy consumption. The study concluded that the pavement damage on the Vermont Interstate system increased by 12% which translated into a significant increase in pavement maintenance costs and more frequent work zones. Sadeghi et al. (2007) developed a deterioration model for flexible pavement

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[13] "Addendum to 1997 Federal Highway Cost Allocation Study Final Report" (2000)

and ticketing formulation for overweight vehicles. The study concluded that that the revenue collected from fines by road authorities were inadequate compared to the pavement damage, particularly if the excess load exceeded allowable limits by twenty percent.

Some research suggests that increasing the truck size and weight can accommodate greater volumes of freight with the same number of trucks and thus increase productivity. Woodrooffe (2016) compared United States truck size and weight policy with international standards and found that federal size and weight limits are the lowest and most restrictive compared to Australia, Canada, Mexico, New Zealand and the European Union. Bereni et al. (2010) projected a stagnant policy resulting in the U.S. trailing all developed nation concerning mass freight efficiency per unit. The study claimed that both Canadian and Mexican tractor semi-trailers are more efficient than the 80,000 lb U.S. vehicle by 44% and 53%, respectively. Woodroffe et al. (2009) concluded that not all transport companies could make use of heavier and longer trucks, however a 10% reduction in fuel consumption for the same freight task could be achieved. In 2006, the Minnesota DOT led a project to assess changes in truck size and weight laws that would benefit the economy while protecting infrastructure and safety. The study recommended weight limit increases that included several vehicle configurations under special permit. Under the proposed vehicle configuration, fewer truck trips would be needed leading to significantly lower transport costs. Also, additional axles would result in less pavement wear, and surplus brake capacity would be better than for five-axle tractor-trailers. The proposed vehicle configuration however, would increase bridge postings and future design cost modestly.

Transportation Research Board Special Report 227 (1990) discussed new trucks for greater productivity and less road wear. The most attractive configuration would be nine-axle double- trailers and estimated that lower truck freight costs would attract about four percent of rail ton-miles. As a result, rail would lose five percent of its gross revenue. Hymson (1978) discussed that the size and weight of trucks has a significant influence on mode share and concluded that if truck capacity increased to 90,000 lbs, truck operational costs would decline by 16.8 percent, and would cost railroads up to $2 billion to remain cost competitive. Lemp et al. (2011) used ordered probit models to examine the impact of the vehicle, occupant, driver and environmental characteristics on injury outcomes involving heavy trucks, with a particular focus on long combination vehicles (LCVs). The results suggested that fatalities and severe injuries increase with the number of trailers but fall with increasing truck length and gross vehicle weight ratings (GVWR). Adams et al. (2009) considered the safety impacts of various vehicle configurations: 6-axle, 7-axle and 8-axle combinations, compared to 5-axle tractor-semitrailer. The greatest improvements in safety were projected for 6-axle 98,000 lb tractor-semitrailer, 7-axle 97,000 lb tractor-semitrailer, and 6-axle 90,000 lb tractor-semitrailer.

Harkey et al. (1992) observed differences in truck operation based on vehicle width: 102 and 96 inches, and the impact on other traffic. Data was collected on rural two-lane and multi-lane roads that included curve and tangent sections under varying traffic conditions. Measures of effectiveness included lateral placement, edge line encroachments, and lane encroachment of trucks and vehicles, and were based on one hundred hours of videotape. Wider trucks had significantly higher rates of edge line encroachment and tended to drive closer to the centerline than narrow trucks. Zegeer et al. (1990) examined the operations of multiple vehicle configurations assigned to rural roads with restrictive geometry. Trailer lengths of 40, 45, and 48-ft and twin trailer combinations with 28-ft trailers were observed on rural two-lane roads in California and New Jersey under a mix of lane widths, shoulder widths, and horizontal and vertical alignments. Statistical testing was done to compare changes in speed, lateral placement and other operational differences and were based on radar and photography. The results showed that 48-ft tractor-semitrailer and twin-trailer combination caused operational changes and potential safety issues for oncoming motorists as a result of extreme maneuvers. The authors recommended restricting those vehicles to wide, well-maintained roads.

Adams et al. (2009) tested various vehicle configurations and estimated the cost of congestion on non-interstate and interstate highways. Researchers argued that cost savings can be achieved through fewer trucks on the road because of increased size and weight. This reduction in truck volume would reduce delays for all vehicles, especially on urban roads. The study stated that 6-axle 98,000 lbs., 7-axle 97,000 lbs. and 6-axle 90,000 lbs., combinations would result in the greatest cost savings. Cambridge Systematics (2006), in a study prepared for Minnesota DOT, concluded that cost savings ranged from $0.05 million per year for single unit trucks limits of 80,000 lbs. to $0.23 million per year for the 97,000 lbs. 7-axle tractor-semitrailer. Another combination of 6-axle and 8-axle twin configuration were estimated to be $0.18 and $0.08 million per year, respectively. Special Report 267: Regulation of Weights, Lengths, and Widths of Commercial Motor Vehicles (2002) presented previous study findings of congestion costs and concluded that prior studies have oversimplified the complex interaction between trucks and other vehicles in the traffic stream. Changing traffic volumes and the dimensions and acceleration abilities of trucks will change how other motorists drive, affecting the acceleration and braking patterns of other vehicles.

Investment in Alternative Infrastructure

Increasing truck traffic has led public agencies to explore alternative freight modes: rail, waterborne, and air freight. The Port of Long Beach commissioned a study in April 2016 to ship more incoming cargo to the Inland Empire via short-haul rail. It was estimated that 750 daily truck trips could be shifted to short-haul rail[14]. One of the major reasons was the congestion in the region which ranked first nationally and was estimated to be 81 wasted hours per commuter per year[15].

Kawamura et al. (2016) studied the economic benefits of productivity increases through truck-to-rail mode shift. The research applied an equilibrium model for the Chicago region to analyze the impacts of reduced congestion on productivity. The study found that the productivity of the trucking sector grew by 20 percent and capital and labor costs of rail were reduced due to the increase in mode share. Freight railway infrastructure is privately financed however significant public benefits: reduced congestion, environmental impacts, and reduced fuel consumption, can be achieved by investment in the rail network. The “Heartland Corridor Clearance Project”, completed in 2010, was a public-private partnership among Norfolk Southern, federal and state agencies to invest in increasing vertical clearances to allow double-stacked container trains to travel between the Port of Virginia and Columbus, Ohio. The benefits of the project included: increased corridor capacity, reduced rail travel distance by 250 miles, improved highway safety and reduced commercial truck traffic. It also made the Port of Virginia more attractive to

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[14] http://www.polb.com/news/displaynews.asp?NewsID=1542

[15] http://inrix.com/wp-content/uploads/2016/03/INRIX_2015_US_Scorecard_Infographic.pdf

international shippers and inland terminals. "The Chicago Region Environmental and Transportation Efficiency (CREATE)" also involved significant cooperation between the railroad industry and public agencies. The program was formed in 2003 and included multi-modal infrastructure improvements to address congestion choke points in the Chicago region. Seventy projects, at an estimated cost of $3.2 billion, including upgrading tracks, grade separations, operation visibility improvement, and safety enhancements, were completed. The benefits included reduced traffic congestion on highways, reduced fuel consumption and emissions from l trucks and improved pavement conditions. A case study in Fort Worth, Texas addressed the rail congestion issue by investing in rail infrastructure. Approximately 100 passenger and freight trains traveled through the area each day and the delays exceeded 90 minutes per train. The project helped the efficient movement of trains through enhanced signals and improved track alignment.

The Pennsylvania DOT, in coordination with Conrail, took a bold initiative to modernize port and regional transportation facilities in the 1980s. The department “cleared” 163 obstacles by undercutting rail right-of-ways and raising vertical clearances on signal bridges to accommodate double-stack container train served by the Port of Philadelphia. The project reduced shipping costs and improved service and also provided new competitive rail alternatives as well as new economic development opportunities. In addition to the Port of Philadelphia, the Port of Norfolk also uses these double stack rail lines with trains to the Midwest moving across Pennsylvania. Ports in Wilmington and Baltimore are also seeking to obtain access to the network. International experience includes the "Betuweroute Freight Line", a 160-km of freight-only rail line constructed at a cost of $5 billion. The project included five tunnels with a total length of 18-km and 130 bridges to accommodate double-stack trains. The infrastructure project was supported by the European Commission was to discourage long-distance truck movements across Europe.

NCHRP Report 586 presents guidance on evaluating the potential feasibility, cost, and benefits of investing in rail freight to reduce highway congestion from truck traffic. The report provides a three-phase approach for evaluating rail freight solutions including preliminary assessment, detailed analysis, and decision making. Tsamboulas (2016) discussed the assessment of rail infrastructure investments and presented two approaches for evaluation: Economic and Financial. The economic evaluation focused on socio-economic benefits and the financial analysis focused on financial viability. The financial analysis is performed only if the socioeconomic evaluation is positive. Protopapas et al. (2012) evaluated two major methodologies: benefit-cost analysis and economic impact analysis, for rail projects. The authors analyzed, evaluated, synthesized and mildly critiqued the state of the practice in conducting the analysis of freight rail projects. The study recommended that further research is needed in the areas of modal share, diversion potential, performance monitoring, and quantifying externalities.

Freight Demand Modelling

Several research studies have stated that freight demand methods lag behind when compared to passenger forecasting (Jansuwan et al. 2016, Knudson et al. 2011, Samimi et al. 2010, Giuliano et al. 2010). As freight demand continues to grow, agencies face greater pressure to develop improved approaches to track and analyze freight flows (Greaves et al. 2008, Chow et al. 2010). The estimation of freight flow is based on the routing of shipments across alternate modes and falls under the category of an assignment problem. Network flows are determined with an objective to minimize generalized cost for each shipment between given origin and destination (O/D). The process is also called an equilibrium assignment, and models have been studied and represented in mathematical form. Frank and Wolfe (1956) formulated the problem as a quadratic program that solves convex combination algorithm. This algorithm was further modified by Von Hohenbalken (1975) into simplicial decomposition algorithm. The algorithm was later modified into restricted version (Hearn et al. 1987) and a disaggregated version (Larsson and Patriksson, 1992). The modifications and improvements of the Frank-Wolf algorithm can be further cited in studies of equilibrium assignment problem by Leblanc et al. (1975, 1979, 1981, and 1985). The above studies of traffic assignment problem and solution algorithm were mainly developed for automobile traffic (Sheffi 1985).

Studies that considered the assignment formulation in freight transportation were discussed by Winebrake et al. (2008). The study proposed a geospatial intermodal freight transportation model in a GIS platform that combined modes: road, rail, and waterways, into a single network with modal transfer points. Each links was associated with travel time, cost and emissions to find the minimum delivery time and cost for all O/D pairs. Comer et al. (2010) investigated the use of marine vessels instead of heavy duty trucks and suggested opportunities to improve the performance of freight through infrastructure and economic incentives.

Network equilibrium models deal with the interaction between the modes in which users were being assigned to the minimum cost route. The problem determines the auto impedances, while transit impedances are kept fixed during optimization (Dafermos 1972 and Florian 1997). Tatineni et al. (1993) presented a combined trip distribution, mode split, and assignment model. The simultaneous trip distribution-mode split and assignment models are robust in dealing with intermodal and mixed mode trips in the network equilibrium context and have been successfully implemented (Fernandez et al. 1994, Adbulaal et al. 1997).

Externalities Associated with Truck Movement

The broad range of potential strategies for managing truck traffic, as discussed in the previous section, can only be successful if the impact of trucks is quantified appropriately. Impacts include traffic congestion: increased travel time and fuel consumption, environmental impacts, increased infrastructure deterioration, decreased road safety, loss of productivity and decreased quality of life. These impacts are examined in detail in this section.

Congestion

The cost of congestion is a function of two variables: delay cost and fuel cost. Delay cost is defined as extra travel time due to congestion. It is calculated using an average value of travel time. Fuel cost is defined as the additional cost of fuel spent while vehicles are traveling under congested conditions and is estimated as the average cost per gallon of fuel consumption[16].

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[16] http://ntl.bts.gov/lib/8000/8700/8729/congestion.pdf

Growth in the freight sector is a major contributor to congestion, especially in urban areas where it affects the timeliness and reliability of freight transportation. The Urban Mobility Report 2015 estimated truck congestion costs of $28 billion in 2014 dollars including operating time and wasted fuel. Trucks constitute only 7 percent of urban travel, but account for 18 percent of the cost of urban congestion. The New York-New Jersey-Connecticut tri-state area had urban congestion costs of $15 million, the highest in the country. Taylor et al. (2012) estimated the cost of congestion in Washington State. Surveys of freight-dependent businesses and seven IMPLAN models were used to calculate the costs of congestion and estimate the annual economic impact. The costs of congestion included additional trucking and inventory costs. The study concluded that consumers were likely to pay 60 to 80% of the cost of congestion. The Chicago Metropolitan Agency for Planning (2008) estimated a cost of $7.3 billion a year in wasted time and fuel because of traffic congestion including $1 billion a year in the freight sector. The study used Texas Transportation Institute (TTI) 2005 data to estimate 60,000 heavy truck-hours of delay per day at a cost of $66.83 per truck-hour. Spasovic et al. (2000) conducted a study to estimate mobility and the cost of congestion in New Jersey. The methodology was based on improvements to the TTI study that used the Highway Performance Monitoring System (HPMS) database. Performance measures included Roadway Congestion Index (RCI), Travel Congestion Index (TCI), Travel Delay, Congestion Cost and Congestion Cost per Licensed Driver. Traffic congestion in New Jersey cost $4.9 billion annually of which 75 % was attributed towards auto and bus users and 25% for trucks. On an individual basis, the cost of congestion was $880 per licensed driver.

Weisbrod at al. (2003) conducted a study to examine how various producers of goods and services were sensitive to congestion. The study used statistical model analysis for areas of Chicago and Philadelphia to demonstrate productivity loss associated with congestion. The result of the analysis showed sensitivity to traffic congestion varies by industry and complete representation of real monetary cost includes productivity costs related to travel-time variability, freight inventory, logistics and just-in-time production processes. Eisele at al. (2013) estimated urban freight congestion costs by developing methodologies and measures to quantify the impact of congestion. The method adopted in the study used HPMS data and historical speed data from INRIX to estimate wasted time, expressed as person-hours of delay, and diesel fuel, expressed as gallons wasted. The study documented the development and application of methodologies to quantify the impacts of congestion on the trucking industry.

Environment

Increased congestion in urban areas impacts the environment. Air pollutants such as nitrogen dioxide (NO_2), particulate matter (PM), carbon dioxide (CO_2), and carbon monoxide (CO) are some of the major source of pollutants from motorized traffic. Previous studies (Scora et al. 2010, Brodrick et al. 2004) have shown that trucks have higher emission rates than other vehicles. Bigazzi et al. (2013) examined the characteristics of light duty (LD) and heavy duty (HD) effects of travel demand elasticity by vehicle class on total emissions. The author used emission "break even" travel demand elasticity condition which was defined as the condition for which total emissions are unaffected by average travel speed increases as a result of induced travel demand volume. Based on the results of modeled pollutants (greenhouse gas, CO, NO_x PM, and hydrocarbons) the study concluded that heavy duty vehicle emission rates increase proportionally more rapidly in congested condition compared to light duty vehicle rates, because heavy duty emission rates were more sensitive to average speed. Brodrick et al. (2004) evaluated the effects of vehicle operation, weight, and use of air conditioning on pollutants by heavy duty trucks. The study measured pollutants such as NO_2, HC, and CO from an on-road test of heavy duty trucks in which six modes of speed variations were conducted. The results concluded that increase in gross vehicle weight from 52,000 lb to 80,000 lb increases NO_2 by approximately 40% (grams per mile) during acceleration. These results were found to be consistent with the simulation model results from National Renewable Energy Laboratory's ADVISOR model. A statistical test of ANOVA and regression analysis identified the relationship between variables and emissions.

Figliozzi (2011) focused on the analysis of CO_2 for levels of congestion and time-definitive demands. The data was archived from freeway sensors, time-dependent vehicle routing algorithms, customer characteristics and applied to the Portland area as a case study. The study focused on carrier route planning as well as the trade-off among congestion, depot location, customer characteristics and CO_2 emissions. The experiment results were based on three scenarios: uncongested or base case; congested case; and uncongested case with limited speeds of 44 mph on freeways and 30 mph on local streets. Depot location and changes in travel speed impacted CO_2 emissions. In conclusion, congestion impacts on emissions are significant for commercial vehicles and it is possible that emissions decrease with increases in total route distance if there is an increased proportion of freeway travel.

Particulates ($PM_{2.5}$) are another major pollutant and a leading cause of cardiovascular and respiratory disease, and is reported (Bell 2012, Lena et al. 2012) to be the highest on-road emitter from heavy duty trucks. Perugu et al. (2016) used spatial regression-based truck activity model, mobile source emission, and Gaussian dispersion model to estimate urban truck related $PM_{2.5}$. The spatial regression based truck activity model involved two stages. The first stage was based on training data that creates the spatial regression model. The second stage optimized the truck demand using model outputs and trip distribution matrices. The results are further used in an emissions model that used bottom-up method approach to calculate link-specific emissions based on link level activity and emission rates. The study applied a dispersion model to estimate the downwind concentration of air pollutants emitted from traffic using mathematical simulation (U. S. EPA, 2004). The methodology was validated on the Cincinnati urban area, and the results found that 71 percent of urban overall mobile-source $PM_{2.5}$ was caused by trucks.

Hatzopoulou et al. (2010) integrated activity-based demand models with traffic emission and dispersion models. The study used microsimulation activity-based travel demand model for the Greater Toronto Area to calculate vehicle emissions. These emissions were then used as input to a Gaussian dispersion model. Exhaust emissions of nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic compounds (VOC) and carbon dioxide (CO_2) were modeled for light duty vehicles, and resulting concentrations were compared with air pollution monitoring data. The study concluded that the spatial and temporal variations in the level of emissions can be understood and allocation of emissions to grid cells can be applied appropriately. Liao et al. (2010) analyzed the change in CO_2 emissions from established ports to emerging ports. The study applied an activity-based method for estimating CO_2 emissions and developed four scenarios with 30%, 50%, 80% and 100% change in market share for the emerging port of Taipei. CO_2 was estimated by multiplying activity intensity (ton-km) by the truck emission factor (155 g/ton-km). The study concluded that changing inland container shipment routes by shifting the port of call can reduce CO_2 emissions.

Leena et al. (2002) documented the high volume of truck traffic in the Port of New York and New Jersey area and concluded that low-income residents experience higher exposure to pollutants. Kozawa et al. (2009) evaluated the air pollution impacts of goods movement in communities adjacent to the Port of Los Angeles and Long Beach. Mobile platforms outfitted with real-time monitoring instruments measured black carbon (BC), Nitric Oxide (NO), Hydrocarbons and Ultrafine (UFP) particles. Two routes were used during the study: the residential route and the Port/Freeway/Truck Route, for measuring the pollution concentration at the neighborhood level and the impact of heavy duty diesel trucks, respectively. The concentration of pollutants (BC, NO, UFP) were two to five times higher within 150 m of freeways and arterial roads that carried a significant amount of diesel trucks. Because of the wind direction, similar impacts were observed throughout the urban area.

Pavement

Pavement damage due to heavy vehicles is a function of vehicle weight, axle configuration and roadway design. Heavy truck traffic results in pavement damage significantly greater than passenger vehicles[17]. The Congressional Budget Report (2011) "Spending and Funding for Highways" estimated that pavement damage by trucks ranged from 5 to 55 cents per mile. Highway impact assessments are broadly classified into highway cost allocation (HCA) and pavement damage costs (PDC). Highway cost allocation compares revenues collected from various highway users to the expenses incurred by them in order to assess the equity of the existing highway user tax structure and identify changes if needed. It typically covers a broad range of costs including maintenance, repair, reconstruction, congestion, crash and environmental costs (FHWA 1982, 1997, 2000). In contrast, PDC considers only costs associated with pavement reconstruction, rehabilitation, and maintenance.

Highway Cost Allocation

NCHRP Report 378 discusses the practices being used in highway cost allocation studies. The two broad methods were an incremental method, developed by Oregon in 1937, and the federal method which had a mixed approach to pavement rehabilitation. The federal method had been widely accepted because the incremental method gave an undeserved benefit of economies of scale to heavier vehicles. The most significant improvement in the federal method during the 1990s was the application of the National Pavement Cost Model (NAPCOM) which made the model practical to be used by all states. However, some states have conducted their own cost allocation studies. In total, 32 states have performed at least 87 cost allocation studies since the first research was conducted[18]. Bruzelius (2004) reviewed four alternative methods: econometric approach, direct approach, indirect approach and Club and Equity approach, to estimate marginal infrastructure costs. Agbelie et al. (2016) investigated the responsibility for the cost of highway infrastructure and contribution of revenue from highway users in Indiana. The framework of the study included both attributable costs and shared costs. Attributable costs were allocated based on: vehicle classes, equivalent single axle loads, equivalency factor and passenger car equivalent, while shared costs were assigned based on vehicle miles traveled adjusted for vehicle width. Of the thirteen vehicle classes defined by the FHWA, passenger car classes 1 to 4were overpaying and truck classes 5 to 13 were

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[17] Shirley, Chad. "Spending and Funding for Highways." (2011).

[18] https://www.oregon.gov/das/OEA/Documents/2015report.pdf

underpaying. In particular, vehicle class 2 (automobile) paid 10% more while vehicle class 9 (five-axle truck) underpaid by 19%.

Pavement Damage Cost (PDC)

Pavement damage cost studies are classified into empirical and engineering approaches (Ahmed et al. 2014, Murillo-Hoyos et al. 2014). The empirical approach is based on the statistical relationship between observed pavement maintenance, rehabilitation, and reconstruction costs, and pavement variables: age, surface type, traffic condition and climate. The engineering approach is based on the derivation of the cost function with road-use variables and is also called a bottom-up approach (Bossche et al. 2001). Bai et al. (2010) conducted a study in southwest Kansas that focused on truck traffic associated with the meat industry and developed a systematic pavement damage estimation procedure which synthesized methodologies including the Highway Economic Requirement System (HERS) and American Association of State Highway and Transportation Officials (AASHTO) methods. The study used empirical models developed by AASHTO which relates physical lives of pavements to truck axle loads (Tolliver 2000). The equations of this model were further embedded in a pavement deterioration model developed by HERS. Total damage costs associated with trucks was calculated by multiplying the unit cost per equivalent single axle load (ESAL) to total annual ESAL generated by the industry. Pavement damage costs were estimated to be $1,727 per roadway mile or $0.02 per truck-mile.

Saber et al. (2009) evaluated the effects of heavy truck operations on repair costs of highways in Louisiana. The research focused on additional rehabilitation costs to road damage caused by hauling overweight vehicles carrying sugar cane. The study consider FHWA vehicle classes 9 and 10 and three gross vehicle weights (80,000 lbs, 100,000 lbs, and 120,000 lbs) to create five scenarios. The net present worth for each scenario was then evaluated at 5% per year interest rate for 20 years. The study concluded that annual fees of $100 per vehicle are not adequate to recover the costs imposed by these trucks and fees should be increased to $5,545 per vehicle. Dey at al. (2014) estimated pavement and bridge costs caused by overweight trucks and focused on two types of fee structures: flat fee and axle based. When axle distribution is ignored in the flat fee structure, trucks did not pay a fair share to the damage imparted by them. Weight-based fee structures varied from 2 to 14 cents per ton-mile.

Timm et al. (2007) developed a framework that combined the Mechanistic-Empirical Pavement Design Guide (MEPDG) and life cycle cost analysis to determine pavement damage. The framework was used to demonstrate some alternative loading scenarios that included weight distribution, permitting specific axles and considering legal limits to 97,000 lbs. All three scenarios were tested against flexible and rigid pavements with traffic volumes ranging from 250 to 8,000 trucks per day. The study showed that small changes in weight distribution resulted in significant impact on pavement damage. It also revealed that costs increased when the volume of permitted axle exceeded 10 percent of the total legal loaded shaft. Gibby at al (1990) evaluated the impact of trucks on pavement maintenance costs and analyzed two types of models: linear and multiplicative. The model development process suggested that linear models offered negative coefficients and were a poor fit however multiplicative models provided good fits. Using the multiplicative model, the study evaluated various factors influencing pavement maintenance cost and concluded that heavy truck traffic causes approximately 90 times more maintenance costs compared to passenger cars. Average maintenance cost per heavy truck (five or more axle) is $7.60 per mile per year compared to 8 cents per mile per year for passenger cars.

Roadway Safety

The economic cost of motor vehicle crashes, estimated to be $242 billion in 2010, includes lost productivity, medical expenses, legal and court costs, emergency service costs (EMS), insurance administration cost, congestion costs, property damage and workplace losses[19]. Crashes involving large trucks are more harmful than other crashes because of their size and weight. Every year more than 4,000 people are killed and nearly 100,000 injured in crashes involving large trucks[20]. Miller et al. (1991) computed economic costs based on threat-to-life severity. The crash severity scale was based on the medical classification of injury developed by physicians and ranged from 0 (uninjured) to 6 (fatal). The study estimated vehicle type cost by multiplying average costs per highway crash victim by severity class times the distribution of casualties in crashes sorted by heaviest vehicle. The study assumed that the allocation of injury classification did not vary with vehicle type. Levy et al. (1998) and Miller (1999) improved the study by computing crash cost by vehicle type with larger sample size data from 1982-1992. The costs differentiation among the different vehicle types were more clearly defined.

Zaloshnja et al. (2003) focused on crash costs for large trucks. The study used data from the Fatality Analysis Reporting System (FARS) and General Estimates System (GES) with several adjustments to reflect more accurate crash severities. The adjustments were made because GES recorded injury in KABCO scale and was found to be inconsistent among different states (Miller at al. 1991, Blincoe et al. 1992). The average costs per crash by vehicle type and crash severity was computed at 4% discount rate and included the major crash cost categories. Average costs, expressed in year 2000 dollars, were $59,153 per crash for trucks weighing more than 10,000 pounds and increased to $88,483 per crash for tractor-tractors. It was estimated that the average annual cost of large trucks involved in crashes during 1997-1999 exceeded $19.6 billion: $6.6 billion for productivity losses, $3.4 billion in resource costs and $ 9.6 billion in quality of life losses. Lyman et al. (2003) evaluated large truck crashes versus the risk per unit of travel over a 25 year period (1975-1999). To determine the trends in occupant death, the study calculated occupant fatalities per 100,000 population, per 10,000 licensed drivers, per 10,000 registered trucks and 100 million vehicle-miles of travel. The demographic data used for the study was obtained from the Census Bureau (2001) and estimates of vehicle miles traveled, licensed drivers and large truck registration were obtained from FHWA. The results showed a 12% increase in death rate for passenger vehicle occupants for crashes involving a large truck. The truck occupant death rate decreased by 49%, from 4.52 per million truck-miles in 1975 to 2.3 per million truck-miles in 1999, due to stricter safety inspections, commercial driver licensing and increases in seat belt usage.

Forkenbrock (1999) focused on external costs: crash, emissions, noise, operation, and maintenance, for truck freight transportation. External costs accounted for 13.2% of private costs and to internalize the cost, user fees should be increased threefold. Crash costs were estimated to be approximately $25 per 100 million vehicle miles and $15 million per 100 million vehicle miles for passenger car and large trucks,

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[19] https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812013

[20] http://saferoads.org/wp-content/uploads/2015/07/2015-02-06-Large-Truck-Fact-Sheet.pdf

respectively. Although the cost was less for large trucks, the fatal accident rate was one-third greater than passenger cars. Hagemann et al. (2013) focused on the crash related costs of commercial vehicles due to delay and property damage. The delay cost included additional travel time, fuel consumption and emission resulting from the crash caused traffic queues. Property damage cost was based on Insurance Services Office (ISO) data that described insurance claims from commercial vehicles. It was estimated that average property damage costs varied based on truck size ranging from $9,740 to 21,795 per incident. The estimates for the delay due to crashes was obtained from Traffic Software Integrated System Corridor Simulation (TSIS-CORSIM) model and varied based on roadway type and severity of the incident. On average the additional travel time costs were $12,996, emission costs were $302, and fuel consumption costs were $675 per crash.

Chapter 3 - Data Collection

The North Jersey Regional Transportation Model –Enhanced (NJRTM-E), currently employed by the North Jersey Transportation Planning Authority (NJTPA), was used as the demand forecasting tool. The model is a four-step transportation model implemented within the Cube software platform and is capable of analyzing short/long range transportation plans. The model covers the thirteen counties in Northern New Jersey and the surrounding areas of New York and Pennsylvania. The model consists of roadway network covering 55,230 links in forty 40 counties.

Highway Network and Impedance Estimation

The network is developed as a series of nodes and links, where nodes are shaping points to align the network links. Each link represents data that can be defined into three broad categories – a) physical/operational variables b) Identification variables c) performance variables. The identification variables contain the information for identification purpose only and are used as a part of the network display. The performance variables include information regarding traffic counts and the year they were gathered. These variables are used for reference purpose when comparing traffic forecasts to the base year conditions. For impedance estimation, highway path-building procedure is used to accumulate impedance including auto travel time, terminal time and tolls for each origin-destination zonal pair. The path-building process is performed for peak and off-peak periods and the impedance values are stored as a series of matrix files referred as "skim" files. The process was developed to provide necessary travel time estimates for several model components including trip generation, trip distribution, and mode choice. The selection of the minimum path for each zonal pair was based solely on the highway travel time since time is the primary component influencing travel determination. The inclusion or exclusion of highway link in the minimum path is mode specific (SOV, HOV, and Truck) and is controlled by the "LINKTYPE" variable. This serves as "permission" code to utilize the individual links based on travel mode and during highway assignment process as well.

Truck Trip Generation

The methodology adopted for truck trip estimation relies on an earlier model developed by New Jersey Department of Transportation (NJDOT) Statewide Truck Model. The trucks are classified into three broad categories: 1) commercial (2 axle-four tire), 2) medium (2 axle-six tire) and 3) heavy trucks (3+ axle). The trucks are allowed to use entire NJTPA highway network except for roadways with truck restriction. Trip generation was performed internally at the zonal level using employment, household and truck terminals as independent variables. Employment was primarily used for trip generation however special generators in the form of truck terminals, warehouses, and pipeline terminals were used when employment poorly estimated truck trips. These particular generators also served as an attractor for long-haul truck trips entering the region.

Even though the model covered a large area (regional buffer around the NJTPA region), there were still some truck trips that were generated outside the region. To include these trips, external zones (Figure 3.1) represented entry points (or gateways) into the region and included major highways at the border of the study area. They were solely used for modeling long haul truck movements. Dummy links with a restriction of truck usage only were created and connected to the nearby highway links. The intermodal truck facilities were also included as "external gateways" in the model and were estimated primarily with observed data. Truck trips generated from these external stations were estimated primarily with current observed data from NJDOT classification count at external locations. These external trips were portioned into four categories: EI (highway based external to internal), EIMC (intermodal facility external to internal), and EIE (external-internal-external) and EE (external to external). As the names suggest, the external to internal truck trips represent trips to and from internal zones and the external zones. Similarly, EIMC represents truck trips that are going to an internal zone and intermodal facility such as Port Newark. The next category EIE refers to the truck trips that are external to external movements but are routed through an intermediate truck terminal where loads are combined or transferred before it continues out of the region to the final destination. The balancing of attractions was scaled to ensure that at least one attraction is available for each truck trip production. For simulation purpose, all externally-related trips are assumed to be ‘produced' at the external zone and ‘attracted' at the internal zones.

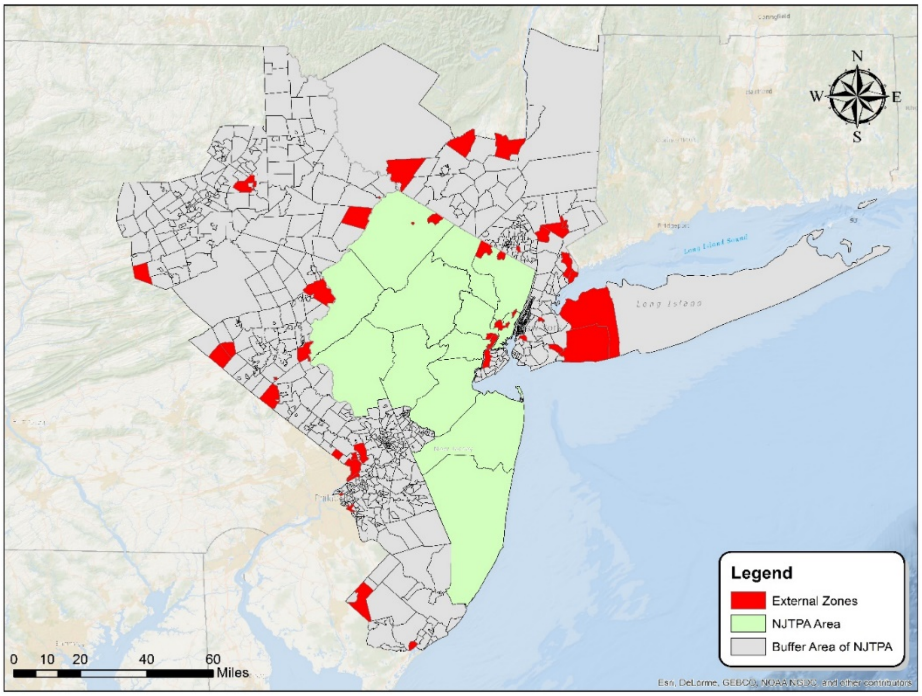

Figure 3.1: External zone surrounding NJTPA area and intermodal terminals

A standard gravity model is being used for the trip distribution. The model distributes trips proportional to the magnitude of productions and attractions at the origin and destination zones and inversely to the distance (or spatial separation) between the zones. The truck trip distribution model was validated to traffic counts available from trans-Delaware River and trans-Hudson River trips.

Time of Day Trip Estimation

While the trip generation process was developed on a 24-hour basis, the trip distribution process varied based on peak or off-peak conditions. The final highway trip assignment was performed separately by time-of-day for four periods: Morning Peak Period, Evening Peak Period, Midday, and Overnight, to account for congestion effects on route choice. The household survey trip distribution by time-of-day as shown in Table 3.1.

Table 3.1: Household Survey Trip Distribution by Time-of-Day

Start and End Time		Home-Based Work (HBW)	Home-Based Non-Work (HBNW)	Non-Home-Based (NHB)	All Trips
0:00	0:59	0.1%	0.2%	0.0%	0.4%
1:00	1:59	0.1%	0.1%	0.0%	0.1%
2:00	2:59	0.0%	0.0%	0.0%	0.0%
3:00	3:59	0.1%	0.0%	0.0%	0.2%
4:00	4:59	0.3%	0.1%	0.0%	0.4%
5:00	5:59	1.0%	0.3%	0.1%	1.3%
6:00	6:59	3.2%	1.4%	0.2%	4.8%
7:30	7:59	4.7%	4.6%	0.6%	9.9%
8:00	8:59	2.7%	4.7%	1.3%	8.7%
9:00	9:59	0.7%	2.2%	1.1%	4.0%
10:00	10:59	0.4%	2.1%	1.4%	3.9%
11:00	11:59	0.6%	2.6%	2.0%	5.2%
12:00	12:59	0.7%	2.2%	2.4%	5.3%
13:30	13:59	0.6%	2.1%	1.9%	4.6%
14:00	14:59	1.1%	3.8%	1.9%	6.8%
15:00	15:59	2.0%	4.6%	2.0%	8.6%
16:00	16:59	2.9%	3.8%	1.9%	8.6%
17:00	17:59	2.7%	4.4%	1.4%	8.5%
18:00	18:59	1.3%	3.7%	1.2%	6.2%
19:00	19:59	0.6%	3.3%	0.8%	4.7%
20:00	20:59	0.4%	2.3%	0.5%	3.1%
21:00	21:59	0.4%	1.9%	0.4%	2.7%
22:00	22:59	0.3%	0.9%	0.2%	1.4%
23:00	23:59	0.1%	0.3%	0.1%	0.6%
Total		**27.0%**	**51.5%**	**21.5%**	**100.0%**

Since the peak periods comprised of multiple hours of time frame, the capacity which is defined as hourly capacity was converted to various hour capacities. The factors used during the highway assignment to convert hourly capacity to period specific link capacity were based on the ratio of peak-hour traffic to the total traffic in that period. Table 3.2 below shows the total percentage and peak percentage based on Table 3.1 for each period split and capacity factors calculated based on it.

Table 3.2: Capacity Factors Based on Time Split

Period (1)	Length (2)	Duration (3)	Peak Hour (4)	Total % (5)*	Peak Hour % (6)**	Capacity Factor =(6)/(5)
AM	3 Hours	6:00 AM-9:00 AM	7:30 AM-8:30 AM	23.43%	10.38%	0.4430
MD	6 Hours	9:00 AM-3:00 PM	11:30 AM-12:30 AM	29.79%	5.46%	0.1833
PM	3 Hours	3:00 PM-6:00 PM	4:30 PM-5:30 PM	25.73%	9.08%	0.3529
NT	12 Hours	6:00 PM-6:00 AM	7:00 PM-8:00 PM	21.05%	4.70%	0.2233
Total	24 Hours			100.00%		

*Total percentage based on duration (3) from Table 3.1
**Total percentage based on peak hour (4) from Table 3.1

The allocation of truck trips (heavy, medium) for each time was retained from North Jersey Regional Transportation Model while commercial truck trips were allocated from data obtained from New York Metropolitan Transportation (NYMTC) Best Practice Model (BPM). Table 3.3 shows the truck trip distribution by time-of-day below:

Table 3.3: Truck Trip Time-of-Day Distribution

Period	Truck Type		
	Medium	Heavy	Commercial
AM	20.0%	17.0%	6.2%
Midday	24.0%	42.0%	28.2%
PM	34.0%	17.0%	56.2%
Night	22.0%	24.0%	9.4%
Total	100.0%	100.0%	100.0%

In the next step of highway assignment medium and commercial trucks are considered as auto trips, specifically as non-home-based single occupancy vehicles. The trucks therefore considered in highway assignment are only heavy trucks.

Highway Assignment

In the state-of-the-practice traffic assignment methods, the capacity is constrained on travel speeds or travel times are specified by utilizing volume-delay functions (VDFs) or link congestion functions (LCFs). In another word, these features express travel time (travel cost) as a function of traffic volume. Similarly improved volume-delay function is used in the model. The model studied previous single volume delay functions, such as BPR which were based on varying speeds and per lane capacity values by facility and area type. However, to consider delay associated with queuing, a hybrid of 2000 HCM volume-delay functions and a simplified queuing formula was adopted. The formula is defined as below:

$$T_F = T_O * \left(1.0 + a * \left(\frac{V}{C}\right)^b\right) + \left(\frac{120}{2}\right) * (1 - \left(\frac{C}{V}\right))$$

Where: a and b are coefficients which vary by facility type

V/C is volume to capacity ratio

The following data tables were used as part of the development and application of the modeling framework. The source of each data table is noted beneath the table.

Data Tables

Various data tables related to fuel consumption, vehicle mix, fuel cost, emission rates, vehicle impact costs, and crash rates and costs are contained in this section. For the environmental calculations, it was necessary to obtain vehicle fuel consumption rates as a function of speed and vehicle type. There rates were obtained from the Intelligent Transportation System Development Analysis System (IDAS) and are summarize in Table 3.4.

Table 3.4: Fuel Consumption Rate by Vehicle Type (Gallons/VMT)

Speed Range		Auto	Gasoline Truck	Diesel Truck
0	**5**	0.54	0.65	0.45
5	**10**	0.182	0.31	0.696
10	**15**	0.123	0.181	0.489
15	**20**	0.089	0.135	0.297
20	**25**	0.068	0.118	0.185
25	**30**	0.054	0.12	0.131
30	**35**	0.044	0.133	0.11
35	**40**	0.037	0.156	0.112
40	**45**	0.034	0.185	0.122
45	**50**	0.033	0.223	0.136
50	**55**	0.033	0.264	0.153
55	**60**	0.034	0.31	0.17
60	**65**	0.037	0.374	0.187
65	**70**	0.043	0.439	0.204
70	**75**	0.052	0.511	0.221
75	**80**	0.052	0.511	0.221

Source: IDAS Manual

It was then necessary to estimate a standard vehicle classification mix to be applied on all roadways in New Jersey: light duty gasoline vehicle (LDGV), light duty gasoline truck class 1 (LDGT1), light duty gasoline truck class 2 (LDGT2), light duty gasoline truck class 1 and 2 (LDGT), heavy duty gasoline vehicle (HDGV), light duty diesel vehicle (LDDV), light duty diesel truck (LDDT), heavy duty diesel truck (HDDT), and motorcycles (MC). This estimation was done using data from the New Jersey Congestion Management System (NJCMS) data and is summarized in Table 3.5.

Table 3.5: Percentage of Vehicle Classification Based on Fuel Type

Mode	Vehicle Class									Total
	LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC	
Auto	59.55%	30.01%	9.88%	39.89%	0.00%	0.18%	0.05%	0.00%	0.33%	100.00%
Truck	0.00%	0.00%	0.00%	0.00%	25.00 %	0.00%	0.00%	75.00%	0.00%	100.00%

Source: New Jersey Congestion Management System (NJCMS)

For the financial calculations, monthly average fuel prices were obtained from the Energy Information Administration data and are summarized in **Table 3.6**.

Table 3.6: Monthly Average Fuel Prices

Month	Gasoline	Diesel
Jan-2014	$3.392	$3.893
Feb-2014	$3.434	$3.984
Mar-2014	$3.606	$4.001
Apr-2014	$3.735	$3.964
May-2014	$3.750	$3.943
Jun-2014	$3.766	$3.906
Jul-2014	$3.688	$3.884
Aug-2014	$3.565	$3.838
Sep-2014	$3.484	$3.792
Oct-2014	$3.255	$3.681
Nov-2014	$2.997	$3.647
Dec-2014	$2.632	$3.411
Average	**$3.442**	**$3.829**

Source: U.S. Energy Information Administration, 2014

For the environmental calculations, it was necessary to obtain vehicle emission rates as a function of speed and vehicle type. Vehicle emission rates were also obtained from IDAS for three pollutants: carbon monoxide (CO), hydrocarbons (HC) and nitrous oxide (NO). The vehicle emission rates are summarized in Table 3.7, Table 3.8 and Table 3.9, respectively.

Table 3.7: Carbon Monoxide (CO) Emission Rates from IDAS Manual in Grams per Mile

Speed Range		LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC
0	5	53.734	57.648	67.915	60.728	52.812	4.350	4.873	32.912	138.014
5	10	28.616	31.373	36.961	33.049	38.128	3.236	3.624	24.479	68.118
10	15	19.533	21.871	25.766	23.040	25.887	2.269	2.542	17.166	36.915
15	20	15.978	18.153	21.386	19.122	18.575	1.666	1.866	12.601	25.538
20	25	12.914	14.927	17.585	15.724	14.085	1.280	1.434	9.682	19.718
25	30	9.983	11.798	13.899	12.428	11.287	1.030	1.153	7.787	15.884
30	35	7.974	9.654	11.374	10.170	9.558	0.867	0.970	6.555	13.058
35	40	6.512	8.093	9.534	8.525	8.554	0.764	0.855	5.776	11.005
40	45	5.398	6.905	8.135	7.274	8.090	0.704	0.789	5.328	9.628
45	50	4.552	6.001	7.070	6.322	8.086	0.680	0.762	5.143	8.795
50	55	4.363	5.800	6.833	6.110	8.541	0.687	0.770	5.198	8.631
55	60	5.162	6.737	7.937	7.097	9.534	0.727	0.814	5.498	12.788
60	65	7.160	9.079	10.696	9.564	11.247	0.805	0.901	6.087	23.181
65		8.359	10.485	12.352	11.045	12.699	0.872	0.977	6.596	29.417

Source: IDAS Manual

Table 3.8: Hydrocarbon (HC) Emission Rates from IDAS Manual in Grams per Mile

Speed Range		LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC
0	5	7.059	8.242	9.837	8.720	10.474	1.089	1.526	4.396	11.606
5	10	2.885	3.400	4.048	3.594	5.549	0.899	1.260	3.632	7.976
10	15	1.883	2.196	2.601	2.318	3.755	0.712	0.998	2.875	6.243
15	20	1.507	1.751	2.068	1.846	2.805	0.576	0.807	2.327	5.590
20	25	1.250	1.465	1.723	1.542	2.222	0.477	0.668	1.925	5.256
25	30	1.055	1.256	1.472	1.320	1.857	0.403	0.565	1.628	5.032
30	35	0.921	1.112	1.298	1.168	1.614	0.349	0.488	1.408	4.860
35	40	0.821	1.007	1.170	1.056	1.449	0.308	0.432	1.244	4.730
40	45	0.743	0.925	1.073	0.970	1.336	0.278	0.390	1.124	4.644
45	50	0.683	0.862	0.997	0.902	1.259	0.257	0.360	1.038	4.600
50	55	0.658	0.836	0.966	0.875	1.205	0.243	0.340	0.981	4.593
55	60	0.678	0.856	0.990	0.896	1.175	0.234	0.329	0.947	4.735
60	65	0.746	0.926	1.076	0.971	1.166	0.231	0.324	0.934	5.092
65		0.787	0.969	1.129	1.017	1.170	0.232	0.325	0.936	5.305

Source: IDAS Manual

Table 3.9: Nitrogen Oxide (NOx) Emission Rate from IDAS Manual in Grams per Mile

Speed Range		LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC
0	5	1.728	2.054	2.508	2.190	3.125	1.834	2.094	11.096	0.819
5	10	1.407	1.673	2.043	1.784	3.248	1.572	1.795	9.512	0.720
10	15	1.292	1.535	1.875	1.637	3.410	1.322	1.510	8.000	0.686
15	20	1.247	1.481	1.809	1.580	3.571	1.153	1.316	6.973	0.725
20	25	1.252	1.461	1.784	1.558	3.733	1.041	1.189	6.298	0.797
25	30	1.280	1.467	1.791	1.564	3.894	0.974	1.113	5.894	0.875
30	35	1.300	1.471	1.796	1.569	4.055	0.945	1.079	5.716	0.941
35	40	1.314	1.474	1.800	1.572	4.217	0.949	1.084	5.745	0.990
40	45	1.324	1.476	1.803	1.574	4.378	0.989	1.129	5.982	1.023
45	50	1.340	1.489	1.818	1.588	4.540	1.067	1.218	6.456	1.059
50	55	1.487	1.697	2.073	1.810	4.701	1.193	1.363	7.219	1.198
55	60	1.678	1.971	2.408	2.102	4.862	1.382	1.579	8.366	1.371
60	65	1.869	2.245	2.742	2.395	5.024	1.660	1.896	10.046	1.544
65		1.984	2.410	2.943	2.570	5.121	1.878	2.145	11.366	1.647

Source: IDAS Manual

Mitigation cost data for each of the three pollutants: carbon monoxide (CO), hydrocarbons (HC), and nitrous oxide (NOx) were also obtained from the IDAS manual and are summarized in Table 3.10.

Table 3.10: Mitigation Cost of Pollutants

Emission	Default Value ($/ton)
CO	$3,889
HC/ROG	$1,774
NOx	$3,731

Source: IDAS Manual

Data for estimated pavement impact costs associated with each vehicle class was obtained from the FHWA and are summarized in Table 3.11.

Table 3.11: Federal Cost Responsibility for 3R (Reconstruction, Rehabilitation and Resurfacing)

Vehicle Class	Operating Weight	Dollars per mile
Autos		0.00063
Pickups/vans		0.00075
Buses		0.01203
All Passenger Vehicles		0.00069

Single Unit Trucks	<25,001 pounds	0.00758
Single Unit Trucks	25,001 - 50,000 pounds	0.03291
Single Unit Trucks	>50,000 pounds	0.16368
Sub-Total Single Unit Trucks		0.01585
Combination Trucks	<50,001 pounds	0.01023
Combination Trucks	50,001 - 70,000 pounds	0.02811
Combination Trucks	70,001 - 75,000 pounds	0.05312
Combination Trucks	75,001 - 80,000 pounds	0.06969
Combination Trucks	80,001 - 100,000 pounds	0.11716
Combination Trucks	> 100,001 pounds	0.26138
Sub-Total Combination Trucks		0.03644
Sub-Total Trucks		0.02784
Total - All Vehicles		0.00271

Source: FHWA

Crash rate data was obtained for three different accident types: Fatal, Person Injury, and Property Damage Only. Crash rates for each of the three accident types are typically higher for arterials than freeways because of the greater number of vehicle and pedestrian conflicts at signalized and unsignalized intersections. In addition, crash rates are typically higher at higher volume/capacity ratios because of the greater density of vehicles and the limited time and space available to avoid a crash. Crash rates were obtained from the IDAS Manual and are summarized in Table 3.12.

Table 3.12: Crash Rates by Crash Type (Crashes/Million Vehicle Miles Traveled)

V/C Ratio	Fatality Rates (Fatalities per Million Veh-Mi)				Injury Rates (Injuries per Million Veh-Mi)				Property Damage (PDO) Rates (PDO per Million Veh-Mi)			
	Auto		Truck		Auto		Truck		Auto		Truck	
	Free-way	Arterial	Free-way	Arterial	Free-way	Arterial	Free-way	Arterial	Free-way	Arterial	Free-way	Arterial
0.09	0.0066	0.0177	0.0066	0.0177	0.4763	1.6991	0.4763	1.6991	0.6171	2.4736	0.6171	2.4736
0.19	0.0066	0.0177	0.0066	0.0177	0.4763	1.6991	0.4763	1.6991	0.6171	2.4736	0.6171	2.4736
0.29	0.0066	0.0177	0.0066	0.0177	0.4763	1.6991	0.4763	1.6991	0.6171	2.4736	0.6171	2.4736
0.39	0.0066	0.0177	0.0066	0.0177	0.4763	1.6991	0.4763	1.6991	0.6171	2.4736	0.6171	2.4736
0.49	0.0066	0.0177	0.0066	0.0177	0.4763	1.6991	0.4763	1.6991	0.6171	2.4736	0.6171	2.4736
0.59	0.0066	0.0177	0.0066	0.0177	0.4763	1.6991	0.4763	1.6991	0.6171	2.4736	0.6171	2.4736
0.69	0.0066	0.0177	0.0066	0.0177	0.4763	1.6991	0.4763	1.6991	0.6171	2.4736	0.6171	2.4736
0.79	0.0066	0.0177	0.0066	0.0177	0.5318	1.6991	0.5318	1.6991	0.7183	2.4736	0.7183	2.4736
0.89	0.0066	0.0177	0.0066	0.0177	0.5318	1.6991	0.5318	1.6991	0.7183	2.4736	0.7183	2.4736
0.99	0.0066	0.0177	0.0066	0.0177	0.677	1.6991	0.677	1.6991	0.8365	2.4736	0.8365	2.4736
1.00	0.0066	0.0177	0.0066	0.0177	0.706	1.6991	0.706	1.6991	0.9192	2.4736	0.9192	2.4736

Source: IDAS Manual

The average cost for each of the crash types is needed as part of the financial calculations. The data was obtained from the Highway Safety Improvement Program and are summarized in Table 3.13.

Table 3.13: Crash Cost by Injury Severity Level

Injury Severity Level	Comprehensive Crash Cost
Fatal	$4,008,900
Disabling Injury [A]/ Incapacitated	$216,000
Evident Injury [B]/ Moderate Injury	$79,000
Possible Injury [C]/ Minor Injury	$44,900
PDO [Property Damage]	$7,400

Source: Highway Safety Improvement Program (HSIP)

Chapter 4 - Modeling Framework Development

This chapter develops a framework using transportation demand models to analyze the impact of trucks on a regional transportation network. Transportation policies and strategies can influence both demand and supply and transportation demand models are excellent tools to evaluate the supply chain system. This chapter is divided into three sections. The first section presents an overview of the methodology. The second section discusses the framework development, and the third section presents each of the freight transportation models.

Methodology Overview

Transportation policies are used to address imbalances between demand and supply. To better understand the regional impacts of a policy, one needs to understand the linkage between demand and supply. Figure 4.1 below shows the controlling factors on the demand and supply sides.

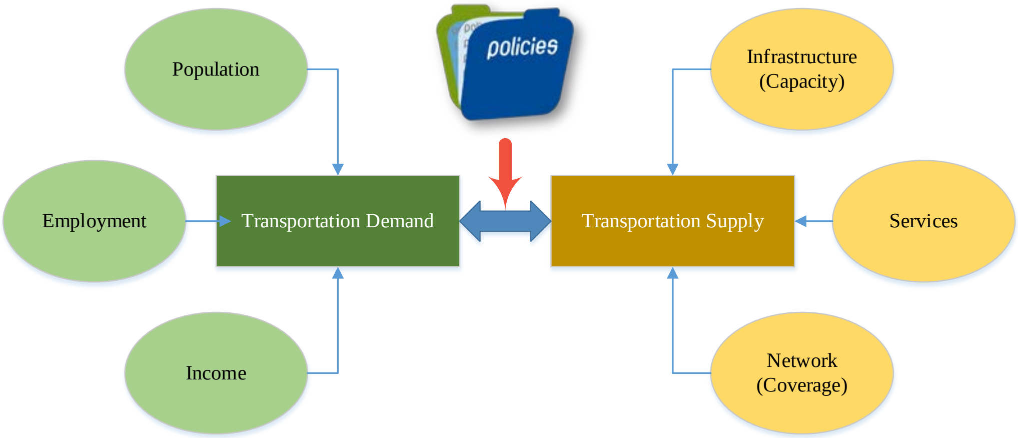

Figure 4.1: Transportation demand and supply and their controlling factors

Demand and supply are highly interdependent, and there is a direct relationship to the controlling factors. For example, as population increases, there is greater need for consumer goods. If the employment rate increases, more people will need to commute to work. Higher incomes will lead to an increased number of non-work trips. On the supply side also, increased capacity leads to a better system. A denser network provides greater opportunities for route choice.

Regional transportation models incorporate both demand and supply to provide a systematic analytical platform to evaluate alternatives in a controlled environment. Traditional "four step" travel demand models use a set of procedures to predict trips made within the region[21]. The first step, 'trip generation', analyzes population and socioeconomic parameters: auto ownership, household income, etc., to estimate trip productions and attractions. The second step, trip distribution, predicts trip interchanges

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[21] https://www.fhwa.dot.gov/planning/tmip/publications/other_reports/snapshot_travel_modeling/ch01.cfm

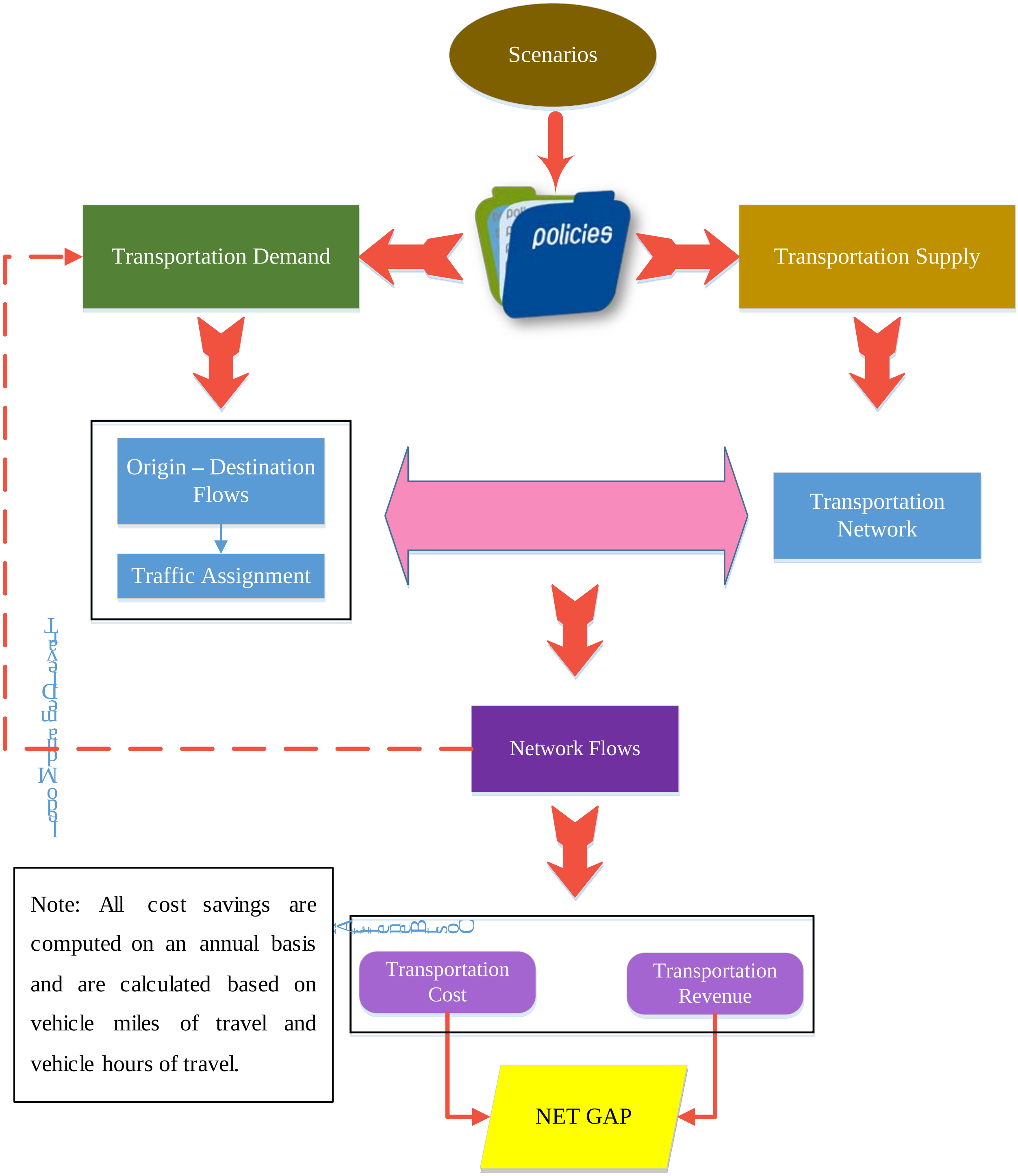
between origins and destinations within the region. The third step, modal split, projects the division of trips between available modes; and in the last step, traffic assignment, modal trips are assigned to actual paths. This study focuses on the formulation and solution of traffic assignment and its interaction with mode choice. The assignment problem computes link impedances and then load the trips to the network by utilizing the minimum impedance path. Volume is accumulated on each link that comprise the path until the entire trip table has been loaded.

Changes in transportation policy can impact the demand and supply of transportation networks and significantly influence traveler behavior to select a mode or path resulting in changes to traffic volume on all links. The loaded volumes on the network, therefore, can be used to evaluate transportation costs as a consequence of a policy scenario.

Conceptual Development of the Framework

The framework uses transportation policy as an input. The relationship between freight transportation demand and supply is modeled by developing three freight demand models. The models are used to simulate changes to the movement of freight through the network due to a policy change. A cost-benefit analysis, based on an economic theory, calculates the user cost, environmental and safety benefits with the policy change compared to the baseline case that represents the status quo.

The framework, shown in Figure 4.2, can therefore, be used to analyze 'what if' scenarios that quantify the change in truck demand on a regional network as a result of policy changes. Each step of the framework is explained in detail in the following sections.



Note: All cost savings are computed on an annual basis and are calculated based on vehicle miles of travel and vehicle hours of travel.

Figure 4.2: Policy framework

Freight Demand Models

Overview

Three freight demand models build on the interaction of congestion and travel decisions that result in the flow of vehicles in the network (Sheffi 1985). This approach relies on modeling the interaction between congestion and travel decisions to reach equilibrium, and are based on nonlinear optimization techniques. The first model is based on an assignment where freight gets allocated to the minimum cost path and the shipper mode preference is not taken into account. The second model is a logit model and the customer mode preference for truck and rail are taken into consideration based on service and cost. The third model is a variable demand model where the amount of freight varies as a function of travel time and an increase in travel time on the minimum cost path reduces demand.

Before discussing the formulation of each model in detail, the following notations and definitions have been used:

O, D = Origins and destinations within the network.

ij = Origin-destination pairs

a, p = Links (arcs) and paths in the network respectively

f_a, h_p = Flow on link a (per unit time) and flow on path p respectively

L, P, P_i = The set of links, set of paths and set of paths leading from node i respectively

δ_{ap} = Binary parameter that equals 1 if link a is part of path p, otherwise 0.

$c_a (f_a)$, c_p = Cost of travel on link a (function of flow on the link) and cost of traveling on path p respectively

c^*_p = Minimum cost of travel on path p

c_a = Unit (average) generalized cost of travel on link a

$C_a = C_a (f)$ where f is vector of all link flows

$c_a = c_a (f_a)$ monotonically increasing cost function of flow on link as shown in Figure 4.3

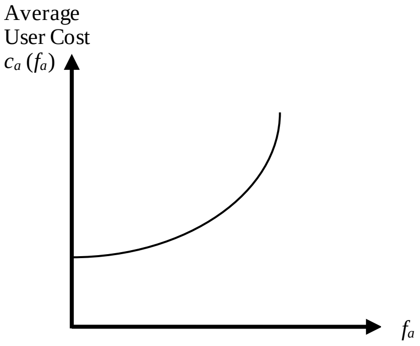


Figure 4.3: Average cost link performance function concerning flow

Definition of Work Flow Pattern

For each origin-destination (O/D) pair, at user equilibrium, the travel cost on all used paths are equal, and are less than or equal to the cost of any unused path. Therefore, paths connecting O/D pairs can be divided into two groups: paths that carry flow and paths that do not carry flow. The mathematical representation is shown below:

$$C_{p_1} = C_{p_2}$$

i.e. $C_{p_m} \leq C_{p_{m+1}} \leq C_{p_{m+2}} ...... \leq C_{p_n}$

Where:

$h_{p_j} \geq 0, \quad j = 1, 2, ..., m$ Utilized path

$h_{p_j} = 0, \quad j = m+1, m+2, ..., n$ Unutilized path

C_p = average unit cost on path $p = \sum_{a \in P} \delta_{ap} C_a$

Conceptual Formulation of the Model

The theoretical formulation of the model is based on the equivalent minimization method and involves the formulation of a mathematical program where the solution is the user equilibrium flow pattern. This concept is applied to allocate trips to paths until no further improvements in average travel cost are possible for travelers to switch paths for the following set of conditions:

- The flow on each link is a sum of the flows on all paths that contain the link
- The number of trips between an origin and destination pair is equal to the sum of the flows of all paths that connect that particular origin and destination pair
- The model allocates trips across all modes
- All link and path flows must be positive

The route choice models are based on the following assumptions

- User equilibrium models assume that motorists know all link travel times with certainty whereas stochastic user equilibrium models assume that each motorist may perceive a different travel time and act accordingly.
- At equilibrium, no traveler can improve its average travel cost by switching paths
- There are no artificial limits imposed on the link flow, but the flow is governed by link flow-capacity functions

Model 1 – Assignment Model

This model uses user equilibrium to assign freight to the network. It assumes that every motorist will minimize their travel cost. Multiple paths are considered at the time of trip assignment and trips are assigned based on minimized cost. Travel cost changes as link flows change so that at equilibrium condition, the travel cost on all used paths connecting origin–destination (O-*D*) pairs will be less than or equal to unused paths. The travel cost on a particular path is the sum of the travel time on all links comprising the path. Similarly, the flow on each link, or arc, is the sum of the flows on all paths going through the link, or arc.

Solution Algorithm: The solution of the user equilibrium model is based on heuristic equilibration techniques of incremental assignment. A portion of the O-D matrix is loaded at each iteration. To account for behavioral route choice, the algorithm uses a stochastic network loading mechanism to determine the distribution of travelers using each path. The probability of selecting each alternative route is computed and the flow is assigned accordingly. The advantage of using this network loading technique is its sensitivity to small changes in the network. Travel times are updated and the generalized cost, a function of time and operating cost, is computed. In the next iteration, an additional portion of the O-D matrix is loaded onto the network, and process is repeated. The steps used in the solution algorithm follow.

Step 0: Each origin-destination (ij) entry into equal portions (N) i.e. (set ij^n = ij/N). Set *n*=1 and $f_a^0 = 0, \quad \forall a.$

Step 1: Update. Set $c_a^n = c_a(\mathrm{f}_a^{n-1}), \quad \forall a.$

Step 2: Incremental loading using all-or-nothing assignment based on {c_a^n}, but using only trips rates ij^n for each O-D pair. The network loading involves computing the probability ($\Pr^{ij}$) of alternate routes and assigning the flow pattern for current *n*th iteration {u_a^n}.

Step 3: Flow summation for *n*th iteration is the sum of flows from previous iteration plus the flow from the current iteration. Set $f_a^n = f_a^{n-1} + u_a^n 0, \quad \forall a.$

Step 4: Stopping rule. If *n*=N, stop (the current set of link flows is the solution); otherwise, set *n*=*n*+1 and go to **Step 1**.

Model 2 – Combined Modal Split/Assignment Model

The second model is an improved version of Model 1 that accounts for customer preference in mode choice in addition to route choice. Travelers are influenced by a set of characteristics associated with each mode and are maximizing satisfaction from a set of alternatives (in this case truck vs. rail). The model analyzes a network equilibrium problem that includes both truck and rail modes and the solution includes flow patterns over both the roadway and rail networks for each O-D pair. The problem is referred to as combined modal split/traffic assignment problem. Some of the assumptions for this model follow:

- The selected O-D pairs in the network are connected by both rail and roadway modes

- The level of service offered by rail is independent of the roadway network
- The capacity of rail is large enough so that congestion effects on rail do not occur
- At equilibrium, travel time on both modes: road and rail, are equal if both modes are used.

Solution Algorithm: The solution in this model achieves the user equilibrium condition between the two modes in addition to the equilibrium over the basic network. Travel times on both modes: rail and truck, are equal if both modes are being used. If only one mode is used, its travel time is lower than the unused mode. The steps used in the solution algorithm follow:

Step 0: Each O-D (ij) entry into equal portions (N) i.e. (set $ij^n = ij/N$). Set *n*=1 and $f_a^0 = 0, \ \forall a.$

Step 1: Update. Set $c_a^n = c_a(\mathrm{f}_a^{n-1}), \ \forall a.$

Step 2: Logit Model. Calculate probability (p_m) for O-D pair (ij) which has an alternate mode (m) of transportation. In this case, the probability is calculated for trucks. If no alternative mode of transportation is available for O-D, go to **Step 4**.

Step 3: Calculate trips (T_{ij}^m) for a mode (m) for O-D pair (*ij*)

Step 4: Incremental loading is to perform all-or-nothing assignment based on { c_a^n }, but using only trips rates ij^n for each O-D pair. The network loading involves computing the probability ($\Pr^{ij}$) of alternate routes and assigning the flow pattern for current *n*th iteration { u_a^n }.

Step 5: Flow summation for *n*th iteration is the sum of flows from previous iteration plus the flow from the current iteration. Set $f_a^n = f_a^{n-1} + u_a^n 0, \ \forall a.$

Step 6: Stopping rule. If *n*=N, stop (the current set of link flows is the solution); otherwise, set *n*=*n*+1 and go to **Step 1**.

Model 3 – Variable Demand Assignment Model

The third model accounts for the change in demand as a result of increased congestion in which case either the traveler may decide to use a different mode of travel or forgo the trip altogether. The notion is that as demand is a function of travel time on least cost on the path and would decrease marginally if the travel time increases. In most cases, the demand function would be the same for all origin-destinations, however, may vary concerning population size, income, retail activities, etc. for destination nodes. The function can, therefore, be expected to be monotonically decreasing in the O-D travel time. The problem addressed in this model is thus to find the link flows, travel times and the O-D trip rates that satisfy user equilibrium condition. At this condition, the travel times on all used paths between any O-D pair are equal and also less than travel times on unused path. Also, it satisfies the demand function concerning O-D trips.

Solution Algorithm: The proposed solution algorithm relaxes the fixed demand assumption in earlier models. Note: Find an initial feasible flow pattern f_a^n, ij^n for each O-D pair.

Step 0: Each origin-destination (ij) entry into equal portions (N) i.e. (set ij^n = ij/N). Set *n*=1 and $f_a^0 = 0, \ \forall a.$

Step 1: Update. Set $c_a^n = c_a(\mathrm{f}_a^{n-1}), \ \forall a.$

Step 2: Compute the change in demand (Φ_{ij}) with respect to change in cost (ΔC^*_{ij}) for origin (*O*) destination (*D*) pair (*ij*).

Step 3: Incremental loading is to perform all or nothing assignment based on change in demand (Φ_{ij}) and { c_a^n }, but using only trips rates ij^n for each O-D pair. The network loading involves computing the probability ($\Pr^{ij}$) of alternate routes and assigning the flow pattern for current *n*th iteration { u_a^n }.

Step 4: Flow summation for *n*th iteration is the sum of flows from previous iteration plus the flow from the current iteration. Set $f_a^n = f_a^{n-1} + u_a^n 0, \ \forall a.$

Step 5: Stopping rule. If *n*=N, stop (the current set of link flows is the solution); otherwise, set *n*=*n*+1 and go to step 1.

Network Flows

The demand models discussed above are based on the principle of the decision-making process in selecting mode and route between origins and destinations. The method loads the trips on the network, and the volumes of the trip interchange are accumulated on each link until the entire trip table has been loaded. Traffic flows on the network are used to compute the vehicle miles of travel (VMT) and vehicle hours of travel (VHT). VMT reflects the amount of travel by vehicle type, and VHT reflects the amount of time spent on the roadway network. These performance measures are key metrics in transportation planning and are used in policy decisions for infrastructure investments[22]. Some of the advantages of using these performance measures follow:

- VMT can act as a primary indicator of traffic flow for policy makers and transportation professionals and has been widely accepted by agencies[23].
- The measures can be used to influence policy in many ways. For example, providing more attractive alternative modes can help reduce VMT.
- VMT has a direct relationship with other parameters including congestion, emissions, and safety.

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[22] http://www.dot.ca.gov/hq/tpp/sb743.html

[23] https://www.fhwa.dot.gov/policyinformation/travel_monitoring/tvt.cfm

- VHT demonstrates extra time spent, and thus relates to the economic impact to drivers and businesses of lost productive time, wasted fuel and added maintenance costs[24].

These performance measures have been used to quantify regional impacts and are inputs to the cost-benefit analysis discussed in the following section.

Cost Benefit Analysis

Cost-benefit analysis in the framework is based on the method where benefits are computed as reduced transportation costs. The benefits can be quantified in monetary terms and used to evaluate the cost-effectiveness of the system. VMT and VHT are used to determine the various user costs and agency costs, including: travel time, fuel consumption, vehicle emissions, pavement, and safety. This section introduces the key components of the framework used to calculate overall cost-benefit analysis. The cost calculation for each category is described below:

Travel Time Cost

The value of travel time is a critical factor in evaluating the benefits of transportation infrastructure investment. Travel time cost can be calculated by multiplying VHT by the value of time for autos and trucks. VHT was calculated from the network flows of the demand model and the value of travel time was calculated based on federal guidelines. The calculations are summarized below:

Step 1: Determine the value of travel time for passenger cars and trucks

Step 2: Determine the average occupancy for passenger cars and trucks

Step 3: Determine the annual vehicle hours of travel for passenger cars and trucks

Step 4: Calculate the travel time cost using the equation below:

$$TTC = \sum_{m} TTC_m = TTC_{Auto} + TTC_{Truck} \qquad \textbf{\textit{(Equation 4.1)}}$$

Where

m = Vehicle class (Auto and Truck)

$$TTC_{Auto} = V_{Auto} * (VHT_{Auto} * \mathrm{O})$$

$$TTC_{Truck} = V_{Truck} * VHT_{Truck}$$

Notation:

TTC = Total travel time cost ($)

TTC_{Auto}, TTC_{Truck} = Travel time cost for autos and trucks ($)

V_{Auto}, V_{Truck} = Average value of time for autos and trucks ($/person-hour)

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[24] https://psrc.github.io/trends/2015/10/14/delay/

VHT_{Auto}, VHT_{Truck} = Vehicle hours of travel for autos and trucks (vehicle-hours)

O = Average vehicle occupancy rate (persons/vehicle)

Fuel Consumption Cost

Fuel consumption is a function of the vehicle flow parameters: fuel consumption per mile, vehicle type (passenger car or heavy truck), fuel type (gasoline or diesel), and speed. Values of each of these parameters are obtained from various sources. The calculations are summarized below:

Step 1: Determine the fuel consumption rate (in gallons/vehicle-mile)

Step 2: Determine the percentage of vehicles by vehicle class

Step 3: Determine the average fuel price ($/gallon)

Step 4: Fuel consumption cost can be calculated using the equation below:

$$FCC = \sum_{m} FCC_m = FCC_{Auto} + FCC_{Ttuck} \qquad \textit{(Equation 4.2)}$$

Where

m = Vehicle class (Auto and Truck)

$$FCC_{Auto} = \sum [FCR_{Auto}^{Speed} * VMT_{Auto}^{Speed} * (P_G * P_{AG} + P_D * P_{AD})]$$

$$FCC_{Truck} = \sum \{VMT_{Truck}^{Speed} * [(\mathrm{FCR}_{TruckGasoline}^{Speed} * P_G * P_{TG}) + (\mathrm{FCR}_{TruckDiesel}^{Speed} * P_D * P_{TD})]\}$$

Notation:

FCC = Total fuel consumption cost ($)

FCC_{Auto}, FCC_{Truck} = Fuel consumption cost for autos and trucks respectively ($)

$\mathrm{FCR}_{Auto}^{Speed}, \mathrm{FCR}_{TruckGasoline}^{Speed}, \mathrm{FCR}_{TruckDiesel}^{Speed}$ = Fuel consumption rate for autos, truck gasoline and truck diesel by speed band (gallon/vehicle-mile)

P_G, P_D = Average price of gasoline and diesel fuel ($/gallon)

$P_{AG}, P_{AD}, P_{TG}, P_{TD}$ = Percentage of auto gasoline, auto diesel, truck gasoline and truck diesel

$VMT_{Auto}^{Speed}, VMT_{Truck}^{Speed}$ = Vehicle miles of travel by autos and trucks by speed band (miles).

Emissions Cost

Vehicles emit pollutant materials throughout their lifecycle and are broadly classified into primary and secondary pollutants[25]. Primary pollutants are emitted directly into the atmosphere whereas secondary pollutants are a result of chemical reactions between primary pollutants in the air. The major primary pollutant such as carbon monoxide (CO) and secondary pollutants such as hydrocarbons (HC), nitrogen

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[25] Center for Disease Control and Prevention Agency

oxides (NOx) are being considered in this research. These pollutants are necessary to be considered because they are directly related to fossil fuel consumption, which is highly dependent on vehicle characteristics, travel speed, and road characteristics. The steps below show the progress of the calculation:

Step 1: Determine the emission rate for Carbon monoxide (CO), Hydrocarbons (HC) and Nitrogen oxides (NOx)

Step 2: Determine the percentage of vehicle class in model fleet

Step 3: Determine the cost of mitigation for the pollutants (CO, NOx, and HC)

Step 4: Emission cost can be calculated using the equation below:

$$EC = \sum_{m} EC_m = EC_{Auto} + EC_{Truck} \qquad \textbf{\textit{(Equation 4.3)}}$$

Where

m = mode of travel (Auto and Truck)

$$EC_{Auto} = {}^{Auto}EC_{CO} + {}^{Auto}EC_{HC} + {}^{Auto}EC_{NO_X}$$

Where

$${}^{Auto}EC_{CO} = \sum \{VMT^{Speed}_{Auto} * [((P_{AG} * ER^{Speed}_{COG}) + (P_{AD} * ER^{Speed}_{COD})) * \mathrm{MC}_{CO}]\}$$

$${}^{Auto}EC_{HC} = \sum \{VMT^{Speed}_{Auto} * [((P_{AG} * ER^{Speed}_{HCG}) + (P_{AD} * ER^{Speed}_{HCD})) * \mathrm{MC}_{HC}]\}$$

$${}^{Auto}EC_{NO_X} = \sum \{VMT^{Speed}_{Auto} * [((P_{AG} * ER^{Speed}_{NO_X G}) + (P_{AD} * ER^{Speed}_{NO_X D})) * \mathrm{MC}_{NO_X}]\}$$

And

$$EC_{Truck} = {}^{Truck}EC_{CO} + {}^{Truck}EC_{HC} + {}^{Truck}EC_{NO_X}$$

Where

$${}^{Truck}EC_{CO} = \sum \{VMT^{Speed}_{Truck} * [((P_{TG} * ER^{Speed}_{COG}) + (P_{TD} * ER^{Speed}_{COD})) * \mathrm{MC}_{CO}]\}$$

$${}^{Truck}EC_{HC} = \sum \{VMT^{Speed}_{Truck} * [((P_{TG} * ER^{Speed}_{HCG}) + (P_{TD} * ER^{Speed}_{HCD})) * \mathrm{MC}_{HC}]\}$$

$${}^{Truck}EC_{NO_X} = \sum \{VMT^{Speed}_{Truck} * [((P_{TG} * ER^{Speed}_{NO_X G}) + (P_{TD} * ER^{Speed}_{NO_X D})) * \mathrm{MC}_{NO_X}]\}$$

Notation:

EC = Total emission cost ($)

EC_{Auto}, EC_{Truck} = Emission cost for autos and trucks ($)

${}^{Auto}EC_{CO}, {}^{Auto}EC_{HC}, {}^{Auto}EC_{NO_X}$ = Emission cost of autos for CO, HC and NOx ($)

${}^{Truck}EC_{CO}, {}^{Truck}EC_{HC}, {}^{Truck}EC_{NO_X}$ = Emission cost of trucks for CO, HC, and NOx ($)

$VMT_{Auto}^{Speed}, VMT_{Truck}^{Speed}$ = Vehicle miles of travel by autos and trucks by speed band (vehicle-miles).

$P_{AG}, P_{AD}, P_{TG}, P_{TD}$ = Percentage of auto gasoline, auto diesel, truck gasoline, and truck diesel

$ER_{COG}^{Speed}, ER_{HCG}^{Speed}, ER_{NO_X G}^{Speed}$ = Emission rates of CO, HC and NOx for vehicles using gasoline by speed band (grams/mile)

$ER_{COD}^{Speed}, ER_{HCD}^{Speed}, ER_{NO_X D}^{Speed}$ = Emission rates of CO, HC and NOx for vehicles using diesel by speed band (grams/mile)

$\mathrm{MC}_{CO}, \mathrm{MC}_{HC}, \mathrm{MC}_{NO_X}$ = Mitigation cost of CO, HC and NOx ($/gram)

Pavement Cost

Pavement damage depends on the following factors: vehicle weight, axle configuration and roadway design. A study conducted by the U.S. General Accounting Office (GAO) determined that road damage caused by trucks was over a thousand times higher than that of autos[26,27]. To compute the costs incurred by vehicle class, the FHWA conducted a cost allocation study.[28] The study allocated costs per mile by vehicle class for pavement reconstruction, rehabilitation and resurfacing based on the contribution to pavement distress. The calculations are summarized below:

Step 1: Determine the average pavement cost per mile by vehicle class [$ per mile]

Step 2: Pavement cost can be calculated using the equation below:

$$PC = \sum_{m} PC_m = PC_{Auto} + PC_{Truck} \qquad \textbf{\textit{(Equation 4.4)}}$$

Where

m = Vehicle class (Auto and Truck)

$PC_{Auto} = VMT_{Auto} * UCI_{Auto}$

$PC_{Truck} = VMT_{Truck} * UCI_{Truck}$

Notation:

PC = Total pavement cost ($)

PC_{Auto}, PC_{Truck} = Pavement improvement cost responsibility by autos and trucks

VMT_{Auto}, VMT_{Truck} = Vehicle miles of travel by autos and trucks (vehicle-miles).

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[26] http://archive.gao.gov/f0302/109884.pdf
[27] https://truecostblog.com/2009/06/02/the-hidden-trucking-industry-subsidy/
[28] https://www.fhwa.dot.gov/policy/hcas/final/

UCI_{Auto}, UCI_{Truck} = Unit cost of pavement improvement for autos and trucks ($/mile)

Safety Cost

The purpose of identifying monetary value for the crash is to place a perspective of economic losses and societal harm that results from crashes. Most often accidents are broadly classified into fatal accidents, injury accidents and property damage only accidents. Highway Safety Improvement Manual published by Federal Highway Administration determines the cost of the crash using Value of Statistical Life (VSL). VSL provides fractional values when assessing the benefit of preventing an injury based on Maximum Abbreviated Injury Scale (MAIS) developed by the Association for the Advancement of Automotive Medicine. However, police in most states use "KABCO" injury scale developed by National Safety Council (NSC). This scale also uses severity level for estimating the monetized value of crash cost and is being used in this research. The cost of accidents are therefore calculated using vehicle miles traveled, average crash rates based on the type of injury, v/c ratios, functional class of roadway and recommended monetized values. The following steps can be followed to calculate the accident cost:

Step 1: Determine the average crash rates based on the type of injury or incident

Step 2: Determine the recommended monetized value for crashes

Step 3: Calculate the total cost of crashes using the equation below:

$$SC = \sum_{m} SC_m = SC_{Auto} + SC_{Truck} \qquad \textbf{\textit{(Equation 4.5)}}$$

Where

m = Vehicle class (Auto and Truck)

$$SC_{Auto} = VMT_{Auto} * [({}^{Auto}CR_F^{FC} * UC_F) + ({}^{Auto}CR_I^{FC} * UC_I) + ({}^{Auto}CR_P^{FC} * UC_P)]$$

$$SC_{Truck} = VMT_{Truck} * [({}^{Truck}CR_F^{FC} * UC_F) + ({}^{Truck}CR_I^{FC} * UC_I) + ({}^{Truck}CR_P^{FC} * UC_P)]$$

Notation:

SC = Total safety cost ($)

SC_{Auto}, SC_{Truck} = Safety cost for autos and trucks respectively ($)

VMT_{Auto}, VMT_{Truck} = Vehicle miles of travel by autos and trucks (vehicle-miles).

${}^{Auto}CR_F^{FC}$, ${}^{Auto}CR_I^{FC}$, ${}^{Auto}CR_P^{FC}$ = Average auto crash rate for fatal, injury and property damage incidents by roadway functional class (per million/vehicle-mile)

${}^{Truck}CR_F^{FC}$, ${}^{Truck}CR_I^{FC}$, ${}^{Truck}CR_P^{FC}$ = Average truck crash rate for fatal, injury and property damage incidents by roadway functional class (per million/vehicle-mile)

UC_F, UC_I, UC_P = Unit cost of fatal, injury and property damage incidents ($/incident)

Toll Revenue

Tolls are a valuable source of revenue to both build and maintain roads. Expected benefits include reduced congestion, predictable trip times and lower taxes. Tolls involve the imposition of a per-use fee on motorists for a given highway facility. Motorists are charged a flat-rate or a rate based on the distance traveled. Toll revenues are calculated by multiplying the traffic volume by mode (auto/trucks) and the respective toll rates.

Step 1: Determine the toll rates by vehicle class (auto/trucks)

Step 2: Determine the volume traveling between interchanges

$$TR = \sum_{m} TR_m = TR_{Auto} + TR_{Truck} \qquad \textbf{\textit{(Equation 4.6)}}$$

Where

m = Vehicle class (Auto and Truck)

$TR_{Auto} = VT_{Auto} * N_{Auto}$

$TR_{Truck} = VT_{Truck} * N_{Truck}$

Notation:

TR = Total revenue collected from tolls ($)

TR_{Auto}, TR_{Truck} = Toll revenue from autos and trucks respectively ($)

VT_{Auto}, VT_{Truck} = Toll rates for auto and trucks respectively ($)

N_{Auto}, N_{Truck} = Number of autos and trucks passing the toll booth respectively

Chapter 5 - Scenario Analysis

The chapter discusses the application of the framework to real-world scenarios to determine the regional impacts of changes in truck traffic. The case study is divided into five parts: 1) The geographic location and its regional influence; 2) Scenarios description; 3) Application of scenarios within Cube environment; 4) Data used during cost-benefit analysis, and 5) The regional impact of each scenario.

Geographic Location and Regional Influence

The geographic location of the case study includes the thirteen counties of northern New Jersey and the surrounding region. The region includes Port Newark and Port Elizabeth, which sit side by side within the cities of Newark and Elizabeth just east of the New Jersey Turnpike. According to the American Association of Port Authorities (AAPA), ports in this region are considered to be the largest importers/exporters on the east coast and support a variety of business enterprises. In addition to the maritime ports, the region serves as a "land bridge" to move containers from west coast ports through trans-continental rail shipments of containers and other commodity flows.

Since the port is a significant generator of trucks, the case study focused on port area. The major trucking corridors are the New Jersey Turnpike, I-287, I-78, I-80, I-295 and NJ Route 17[29]. The North Jersey Transportation Planning Authority (NJTPA) maintains a regional transportation demand model, the North Jersey Regional Transportation Model – Enhanced (NJRTM-E) that was used as the starting point for this study. The NJRTM-E use the Citilabs Cube transportation planning software and includes more than 6.5 million origin-destination pairs for each of four time periods: morning peak period, midday, evening peak period, and overnight, by three vehicle types: SOV, HOV, and Truck, and four trip purposes: home-based work (HBW), home-based shopping (HBS), home-based other (HBO) and non-home based (NHB). The network consists of 57,171 links and 2553 zones for year 2015 and 57,286 links for year 2040. The ports lie within four traffic analysis zones: 1693, 1694, 444, and 445, and three special trip generator zones: 570, 571, and 1800, as shown in Figure 5.1. The study area, shown in pink, includes 1590 zones within the NJTPA region, shown in green.

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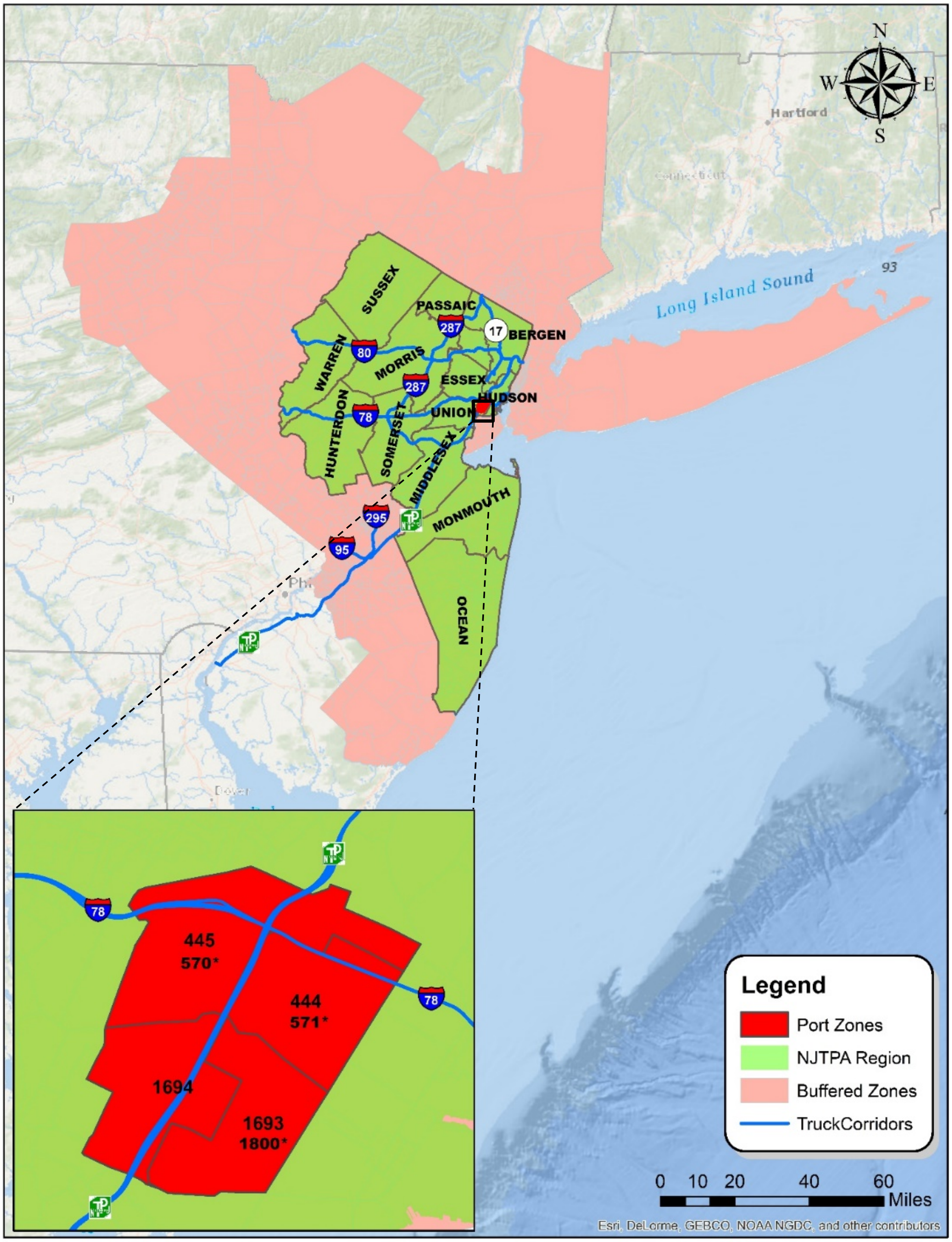
[29] The New Jersey Comprehensive Statewide Freight Plan – September 2007



Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

Figure 5.1: Blown up look at the port Newark and Elizabeth zones

Even though the NJRTM-E includes a buffer region comprised of the adjacent New York / New Jersey metropolitan area, there were still some truck trips that were generated outside the buffered region.

These trips are represented by external zones as shown in **Figure 5.2** that act as entry points (or gateways) into the region. These external zones serve as background volumes from outside the region in addition to the truck volumes generated within the region.

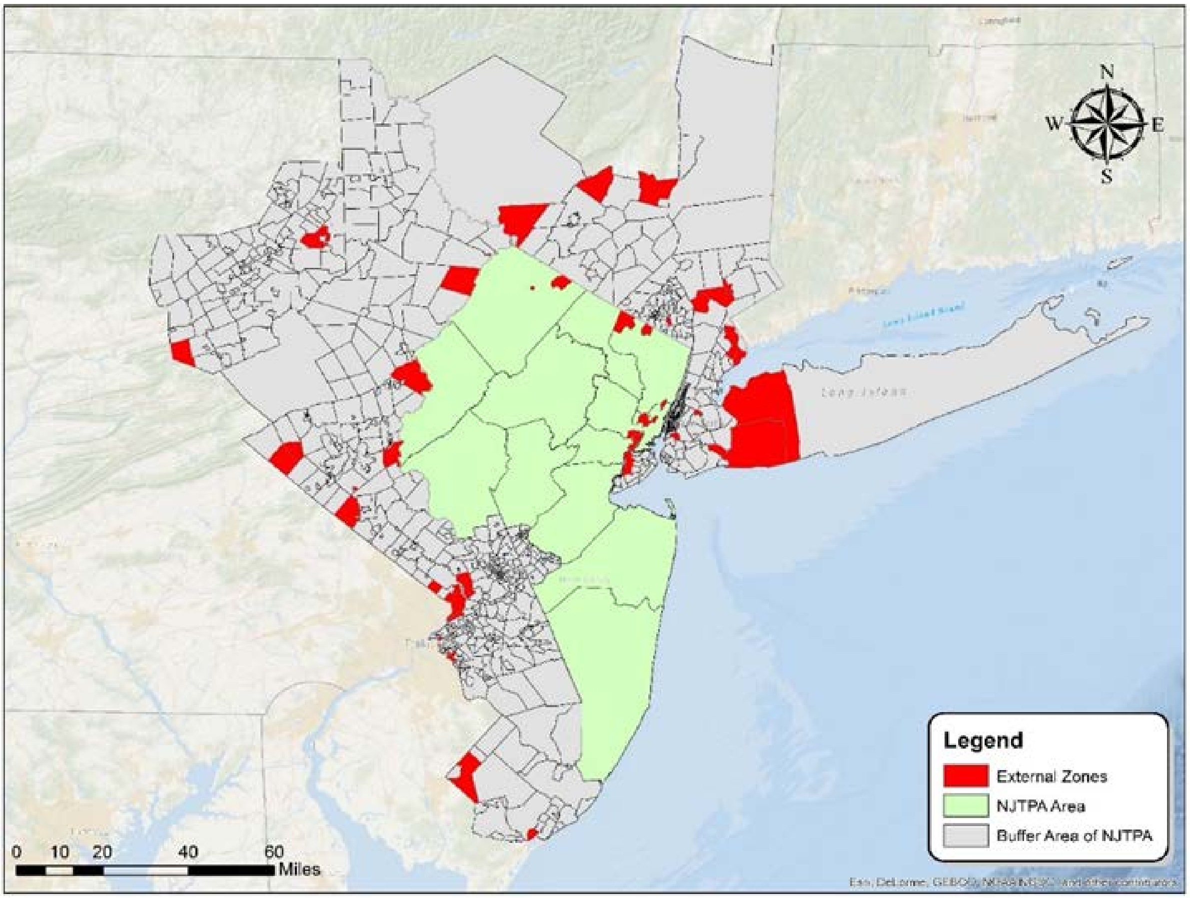


Figure 5.2: External zones surrounding NJTPA area

Corridor Profile

Among the major trucking corridors within the region, I-78 is considered as an essential link for freight movement to and from port facilities in Newark. The I-78 freight corridor crosses the Delaware River, serving warehousing and distribution centers in Eastern Pennsylvania (Allentown, Bethlehem, Macungie, and Harrisburg). The route stretches 67.8 miles from the Pennsylvania border to New York City crossing five counties: Warren, Hunterdon, Somerset, Union, and Essex. The corridor has recently emerged as the major competitor to I-95. The cluster of low-cost warehouse and distribution centers and lack of tolls along with lower traffic volumes make the I-78 corridor attractive. In addition to serving as a major conduit for freight flows, the corridor also serves the densely populated New York City metropolitan market via the Holland Tunnel. The I-78 corridor can therefore greatly influence not only freight flows but also the adjacent communities. The corridor serves as a perfect example to quantify changes in truck traffic that occur on a regional network when a new policy is implemented.

Toll Policy

State agencies are free to impose tolls on roads, bridges, and tunnels that have been built and maintained without federal funds but limit the imposition of tolls on existing federal-aid highways including Interstate Highways. The Congressional Budget Office (CBO) projects that after FY2020 the gap between surface transportation revenues and spending will average $20 billion annually[30]. The search for additional revenue to fill this gap will likely generate renewing interest in expanding toll financing. A recent report published by the Congressional Research Service (August 2016) discussed the possibility of authorizing states to toll federal-aid highways, or to allow portions of an interstate to be converted to a toll road. It is expected that this policy would change truck travel patterns on a regional and local level as they try to avoid tolls. The proposed framework is used as a tool in the case study to analyze the relationship between changes in truck traffic to answer "what if" scenarios and address some key questions.

- Will the toll roads have sufficient traffic willing to pay a toll?
- How does the availability of non-tolled routes allow motorists to evade tolls?
- Which travelers are expected to be affected most?
- Will the generated revenue be enough to cover expenditures?

With the recent federal policy encouraging the use of tolling to attract investment and generate revenue, tolls can be expected to be implemented on some non-tolled interstates. It is, therefore, important to investigate the impact of these changes on truck travel patterns.

Description of Scenarios

Three scenarios are discussed in this section: Baseline Scenario, Scenario I, and Scenario II. Each of these three scenarios includes the baseline traffic condition for year 2015 and the future year traffic conditions of 2040. The future year network includes all committed regional transportation improvements. A brief description of each scenario is presented in Table 5.1 with detailed descriptions in the following sections. The scenarios are based on the NJRTM-E.

Table 5.1: Description of Scenarios

Scenarios	Year 2015	Year 2040
Baseline	Fixed demand, **No tolls on I-78**, Alternate mode not available	
I	Fixed Demand, **Tolls on I-78**, Alternative mode not available	
II	Fixed Demand, **Tolls on I-78, Alternate mode (Rail)** available	

Baseline Scenario

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[30] Congressional Budget Office, Projections of Highway Trust Fund Accounts Under CBO's March 2016 Baseline, March 2016, https://www.cbo.gov/sites/default/files/51300-2016-03-HighwayTrustFund.pdf. The $20 billion figure represents the average annual gap between projected receipts from the motor fuels and other excise taxes that flow into the Highway Trust Fund (HTF) and the anticipated cost of maintaining the surface transportation program at its current "baseline" level.

According to the NJTPA, commodity flows are projected to grow by 43% from 473 million tons in 2015 to 675 million tons in 2040[31] Truck travel on portions of I-78 are expected to increase by 2,500-3,000 trucks per day. Travel demand for 2040 represents an overall increase in 14.7% for auto traffic and 18.7% for truck traffic compared to year 2015.

Scenario I

In this scenario, tolls are introduced in both directions on I-78 and travel demand is assumed to be fixed similar to the base case. The sensitivity of toll by time-of-day was not considered. The scenario uses, generalized cost user equilibrium to choose the minimum generalized cost path calculated using impedance costs (travel time + toll cost + operating cost). Route choice is computed separately by trip purpose (HBW, HBS, HBO, and NHB) and vehicle type (Autos and Trucks). The scenario assumes that no other mode of transportation is available for shippers and all trips will be assigned on the highway network. The approach allows the scenario to be sensitive to the socioeconomic background of commuters and uses stochastic route choice behavior. Freight is also assigned to the minimum cost path.

Scenario II

This scenario considers an alternative freight mode being available in addition to the tolls mentioned in Scenario I. This scenario assumes that shippers will choose their preferred mode: rail or truck, based on travel time and cost and that demand is fixed. Rail capacity is presumed to be sufficient to handle the additional diversion of truck freight to rail.

Application of Policy Scenarios

The scenarios were tested by modifying the NJRTM-E modeling process as needed. The Cube software allows users to provide instructions for performing planning operations via scripts that run the Network, Matrix and Highway programs within the cube environment. Each scenario is discussed in this section along with a flow chart showing the process. A feedback loop with an iterative process is adopted to allow the trips to be assigned to present a more accurate representation of the level of congestion.

Baseline Scenario

The baseline scenario uses three inputs for the highway assignment process as shown in Figure 5.3. The network consists of links and nodes and contains data on roadway characteristics. The trip table represents the demand between origins and destinations by trip purpose vehicle type. Turn prohibitions are used to add travel time to certain turning movements, such as left turns, or to prohibit them.

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[31] http://www.njtpa.org/planning/regional-studies/completed-studies/2040-freight-industry-level-forecasts/2040-freight-forecasts/freightprofile-njtparegion

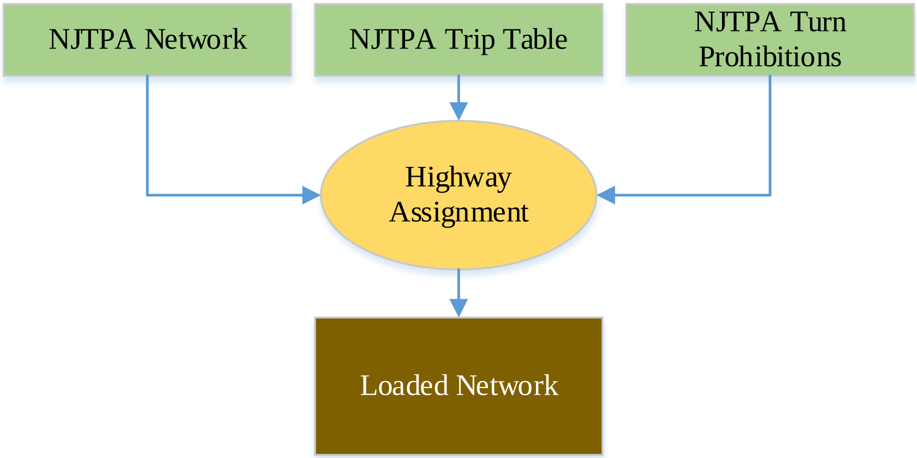

Figure 5.3: Flowchart of assignment process for baseline scenario

Scenario I

The scenario modifies the baseline scenario to incorporate toll route choice in the highway assignment process. It uses a binary logit model, shown below, to distribute trips between the toll and non-toll route for given origin-destination trips in each iteration of the equilibrium assignment process. The model structure is applied separately for each trip purpose and vehicle type. It is based on the utility function that estimates the tradeoffs between the generalized costs and also considers the traveler's characteristics.

$$Toll\ Share = \frac{1}{(1+\exp^{(\alpha * \Delta T + \beta * GC + c + etcbias)})}$$

Where

α = time coefficient (per min)

ΔT = time savings between toll road and non-toll road (mins)

β = cost coefficient (per $)

GC = generalized cost including the toll cost and operating cost ($)

c = toll bias constant

etcbias = bias towards selecting toll routes with electronic toll collection (ETC)

The relationship between the α and β coefficient creates an implied value of time and varies with trip purpose and vehicle type. The flowchart presented in Figure 5.4 shows the step by step process.

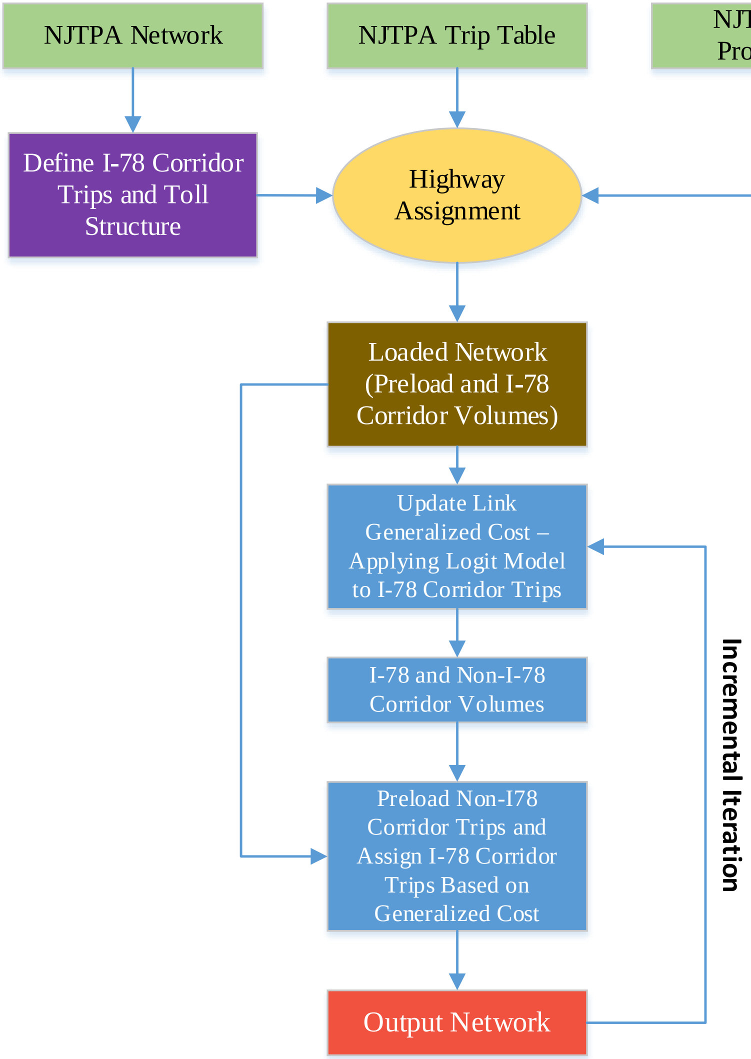

Figure 5.4: Flowchart of assignment process for Scenario I

The steps of the flowchart are described below:

- Define the I-78 toll road links within the network
- Define the origin-destination pairs that would be potential I-78 toll road users. Skim the network based on minimum travel time and identify if the O-D pair includes any I-78 links
- Determine the number of actual I-78 toll road users. It is assumed that trips that are not potential I-78 toll road users are preloaded on the network since their path is not subject to change. Skim the network to compute the generalized cost for potential I-78 toll road users via both the I-78 toll and Non-I-78 non-toll paths. The logit model is then applied to divide the trips between the two paths.

- Assign the potential I-78 toll road users and continue the process until equilibrium is achieved.

Scenario II

In addition to route choice, a freight mode choice is introduced in this scenario. Freight choice is couched in a utility function where the attributes are transport rate and travel time and a logit model is applied to perform the mode choice. The process is shown in the flowchart in **Figure 5.6**. The selected O-D pairs represent the major freight supply nodes in Eastern Pennsylvania and the Port of Newark and Elizabeth and are shown in **Figure 5.5**. These zones represent the external zones that serve the Leigh Valley area in Pennsylvania that includes nearly 59 million square feet of industrial property and the Bethlehem Intermodal Terminal served by the Norfolk Southern Railroad. Additionally, the region has attracted major retailers such as Wal-Mart and Zulily Inc investing millions of dollars[32].

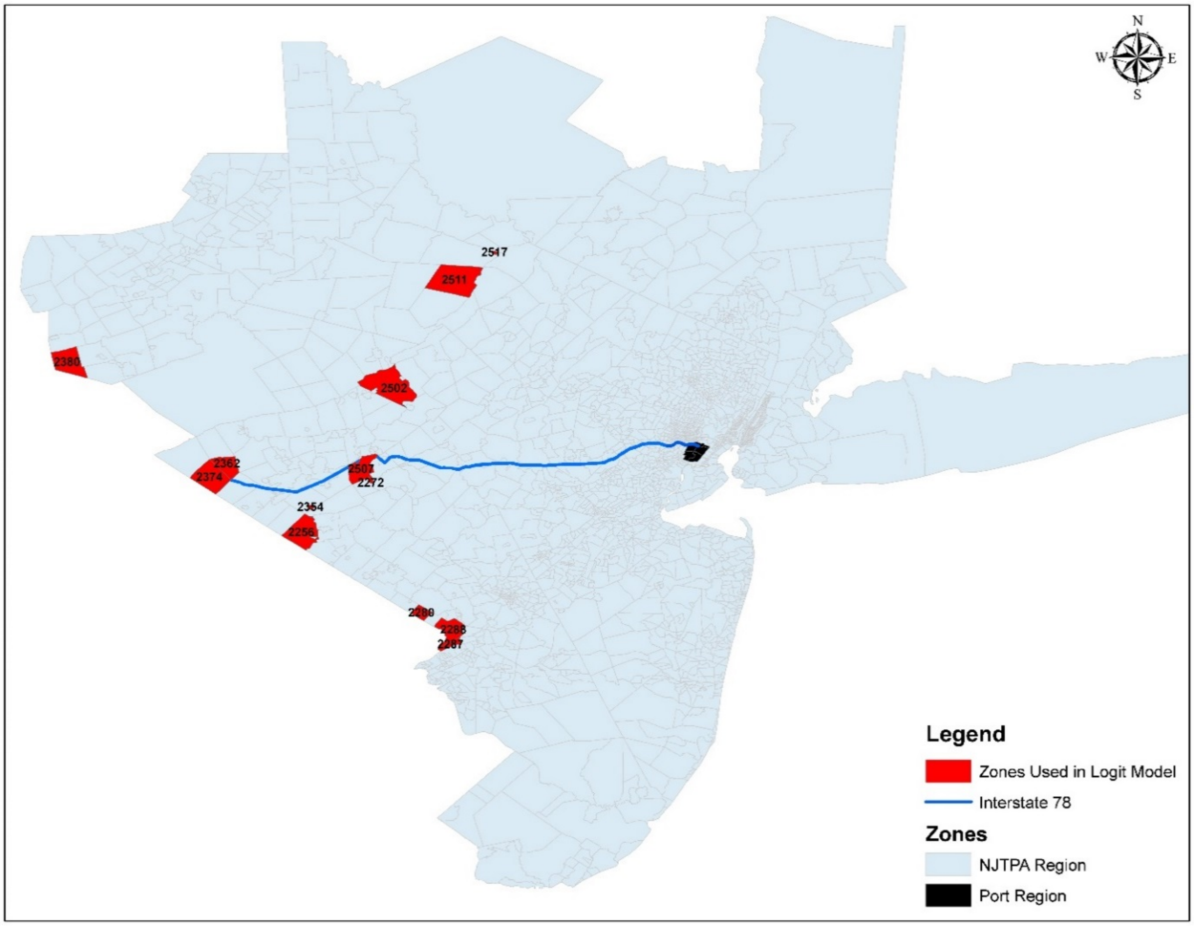

Figure 5.5: Selected zones in scenario II for mode split assignment process

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[32] http://lehighvalley.org/pennsylvania-wins-national-recognition-with-help-from-the-lehigh-valley/

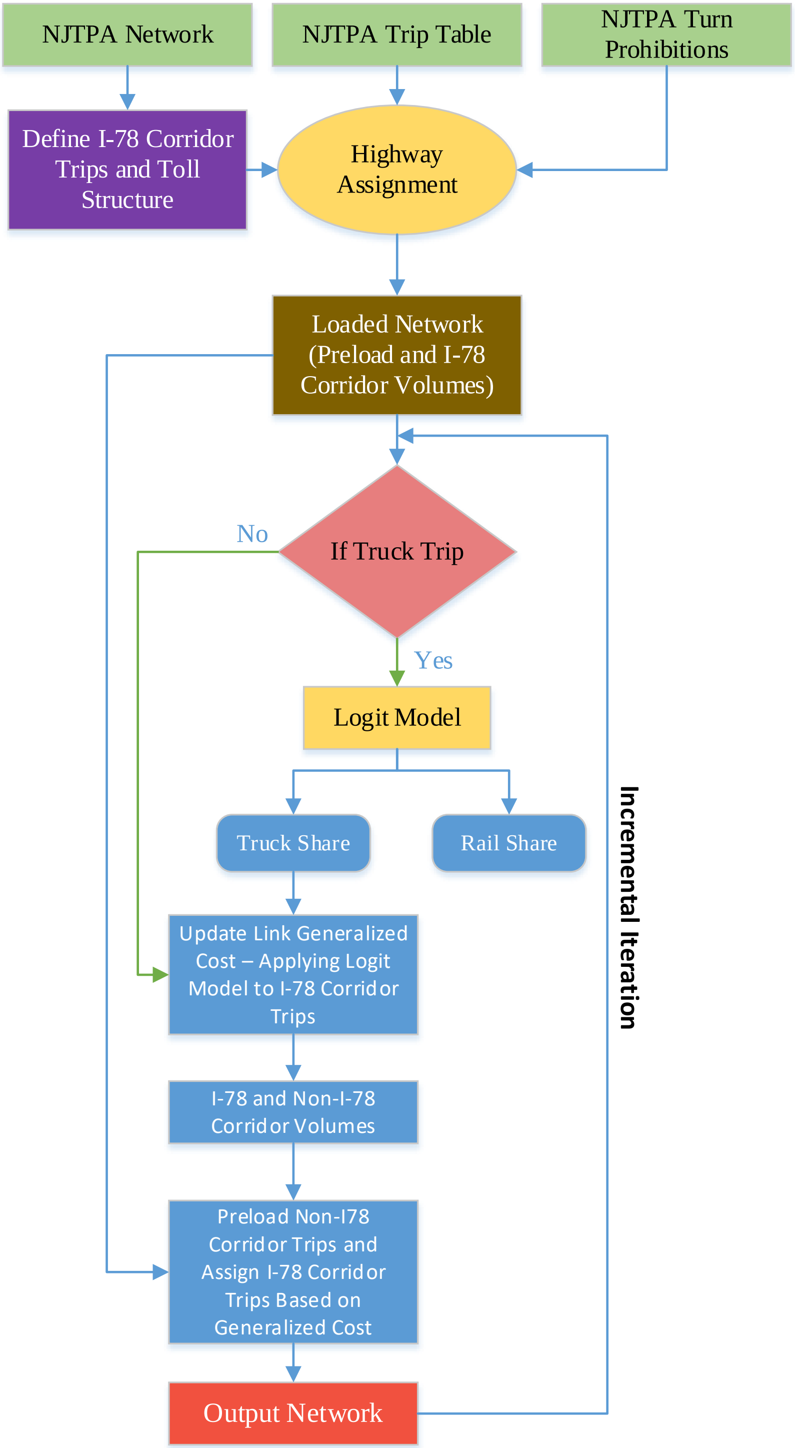

Figure 5.6: Flow chart of mode split assignment process for Scenario II

Model Parameters

Roadway characteristics including speed, capacity, and number of lanes are based on the North Jersey Model Development Report[33]. Socioeconomic data and freight volumes to and from the port area were obtained from the NJRTM-E.

For the case study auto and truck tolls were set at 10 and 60 cents per mile, respectively. Auto and truck operating costs were assumed to be 10 and 31 cents per mile, respectively. The toll costs were based on the existing toll structure for the New Jersey Turnpike. The E-ZPass penetration rates were assumed to be 67% for autos and 87% for trucks based on observed data at the Delaware Water Gap Toll Bridge[34]. The other parameters used in the route choice model: value of time, toll bias constants, and etc bias constants; are shown by trip purpose and vehicle type in Table 5.2 and are discussed below.

Table 5.2: Toll Diversion Model Parameters

	AUTO				
	HBW	HBS	HBO	NHB	TRUCK
Time Coefficient (per min)	0.1642	0.1182	0.0888	0.1468	0.1
Cost Coefficient ($/min)	0.4324	0.364	0.2971	0.361	0.068
Value of Time ($/hr)	22.78	19.48	17.93	24.40	88.24
Toll Bias Constant (c)	0	0	0	0	0
ETC Bias Constant (etc bias)	0	0	0	0	0

The relationship between the α and β coefficients represents the value of time and is represented in $/hr = [α/ β]*60. The value of time is lower for auto versus truck because of the greater sensitivity to goods movement and higher driver wages. The toll bias accounts for the reluctance of travelers to use toll roads. For the case study, the toll bias is assumed to be zero. The etc bias term implies toward selecting toll routes using ETC payment. These biases influence the route choice behavior and therefore need careful consideration.

The model parameters used in Scenario II are based on the utility function to choose between rail and truck modes. The coefficients are -0.009 for transport rate, -0.007 for transit time and the constant term is -2.1. Each mode (truck and rail) are assumed to have similar shipping rates ($100) and transit time for rail is assumed to be 120 minutes. The negative coefficients imply that increases in transport time or rates for a given mode decreases demand. The reference for these mode choices can be found in McCarthy (2001) and Levin (1978).

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[33] http://www.njtpa.org/getattachment/Data-Maps/Travel-Demand-Modeling/Model-Development-Report8G.pdf.aspx

[34] http://www.drjtbc.org/wp-content/uploads/March_Minutes_2017.pdf

Cost-Benefit Analysis of a Policy

The cost-benefit approach is used in this section to evaluate each scenario.

Travel Time Cost

Vehicle hours of travel were calculated from the demand model and the value of time was based on federal guidelines. The travel time cost calculations are described below:

Step 1: Determine the value of time for passenger cars and heavy trucks

The value of time for autos and trucks were obtained from the Bureau of Labor Statics (BLS)[35] and the American Transportation Research Institute (ATRI)[36] report, respectively.

Step 2: Determine the average vehicle occupancy for passenger cars and heavy trucks

Average vehicle occupancy rates vary by county and roadway type and were obtained from the New Jersey Congestion Management System (NJCMS) database.[37]

Step 3: Determine the annual vehicle hours of travel for passenger cars and heavy trucks

Annual vehicle hours of travel is calculated by multiplying the daily network flows obtained from the demand model by the number of workdays per year, assumed to be 250.

Step 4: Travel time cost is then calculated using **Equation 4.1**

Fuel Consumption Cost

Fuel consumption costs depend on vehicle type parameters. The fuel consumption cost calculations are described below:

Step 1: Determine the fuel consumption rate (in gallons/vehicle-mile)

The fuel consumption rate depends on two major components. vehicle type and speed, and were obtained from the Intelligent Transportation System Deployment Analysis System (IDAS) manual and is summarized in **Table 3.4**..

Step 2: Determine the percentage of vehicles by vehicle class

The vehicle and fuel types in New Jersey are classified using Mobile 6 data, and the percentages of each of the vehicle class are summarized in **Table 3.5**.

Step 3: Determine average fuel price ($ per gallon)

The most current average prices of gasoline and diesel in New Jersey were obtained from the U.S. Energy Information Administration (EIA)[38] and are summarized in **Table 3.6.**

Step 4: Fuel consumption costs are calculated using **Equation 4.2**

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[35] State Occupational Employment and wage estimate - http://www.bls.gov/oes/current/oes_nj.htm#00-0000

[36] American Transportation Research Institute report in September 2014

[37] For peak time period = 2.59 and off peak = 2.50

[38] http://www.eia.gov/dnav/pet/pet_pri_allmg_c_snj_epm0_dpgal_m.htm and http://www.eia.gov/dnav/pet/pet_pri_gnd_a_epd2d_pte_dpgal_m.htm

Emissions Cost

Primary pollutants, including carbon monoxide (CO), and secondary pollutants, including hydrocarbons (HC) and nitrogen oxides (NOx), are included because they are directly related to fossil fuel consumption, which is highly dependent on vehicle characteristics, travel speed and roadway characteristics. The emissions cost calculations are described below:

Step 1: Determine the emission rate for Carbon monoxide (CO), Hydrocarbons (HC) and Nitrogen oxides (NOx)

The IDAS manual provides emission rates based on the speed, vehicle class and fuel type are shown in **Table 3.7, Table 3.8** and **Table 3.9** for the three pollutants.

Step 2: Determine the percentage of vehicles by class

The percentage of each vehicle class and fuel type are based on NJCMS data and are summarized in **Table 3.5**.

Step 3: Determine the cost of mitigation for the pollutants (CO, NOx, and HC)

The cost of mitigation for contaminants varies by location so the default values from the IDAS manual were used and are shown in **Table 3.10**.

Step 4: Emissions cost are calculated using **Equation 4.3**

Pavement Cost

A major study conducted by the FHWA was used to calculate the cost of pavement reconstruction, rehabilitation and resurfacing. The study focused on highway agency expenses incurred in the provision and preservation of the road infrastructure. The pavement cost calculations are described below:

: **Step 1:** Determine the average pavement cost by vehicle class per mile

The cost for pavement impacts is based on a per mile basis by vehicle class and weight range as shown in **Table 3.11.**

Step 2: Pavement cost is calculated using **Equation 4.4**

Highway Safety Cost

Safety cost is calculated using the vehicle miles of travel, crash rates and monetized values of crash types. The highway safety cost calculations are described below:

Step 1: Determine the average crash rates based on facility type

The average crash rates per million vehicle miles of travel were used from the IDAS manual which provides rates based on volume/capacity (v/c) ratio, vehicle type, facility type and crash type and are shown in **Table 3.12**.

Step 2: Determine the recommended monetized value for crashes

The Highway Safety Improvement Program (HSIP) manual provides costs based on the KABCO scale and are shown in **Table 3.13**.

Step 3: Safety cost is calculated using **Equation 4.5**

Toll Revenue

Toll revenue was calculated by multiplying the toll rate by mode (auto/trucks) by the traffic volume. The toll revenue calculations are described below:

Step 1: Determine the toll rates by vehicle class (auto/trucks)

Toll rates can vary by vehicle class (auto/trucks), peak/non-peak and by E-ZPass/cash. Tolls were assumed to be 10 and 60 cents per mile for autos and trucks, respectively.

Step 2: Determine the volume traversing I-78

The volume traversing I-78 was obtained from the demand model and was used to calculate the revenue based on the vehicle miles of travel and the per mile toll cost.

Regional Impact of a Policy

As discussed, the impact of a scenario is being compared to the Baseline Case regarding the change in vehicle miles traveled (VMT), vehicle hour travel (VHT) and the cost associated with each scenario. The cost saving is accrued across the modeled network on an annual basis (250 weekdays) and is shown in the following chapter. The VMT and VHT metric plays an integral role in planning and thus can predict the amount of travel for all vehicles in a geographic region over a period. The cost analysis can help transportation agencies to consider the costs which are neither paid by freight haulers not by shippers as a result of policy change. At the same time the analysis can also help identify the disadvantaged population being impacted because of introduction of toll policy.

The toll policy initiation on interstates has been discussed by several state and local agencies to raise revenue for transportation infrastructure. For example, Beyond Traffic 2045 identifies tolling as one of the tolls that may result in more efficient use of transportation facility. The rationale behind this policy is that it can help tailor the demand for service to the available capacity and can represent true social cost of individual trips. However, the policy can negatively affect the current users which cannot afford the tolls and will therefore be tolled off. The situation can arise particularly in low income population affecting employment during working hours. This may lead to inequity in terms of accessibility when compared to higher income population. The inequity for the impacted population can be accounted by supporting the transportation improvement projects representing the affected communities. The statewide transportation improvement program (TIP) provides a list of state and local projects along with the proposed funds for each project. These projects within the affected communities can therefore be supported by the additional revenue generated by the toll policy to balance the inequity concern.

Chapter 6 - Results

The results of the analysis are presented in this chapter. The first section verifies the equilibrium condition by comparing the generalized cost for sample O-D pairs. The second section presents the changes in VMT and VHT compared to the baseline scenario to identify the areas being impacted by the policy change. The third section computes the user costs and revenue generated by each scenario. A comparison of truck travel patterns from a similar study are presented in the final section.

Verification of Equilibrium

The objective of the analysis was to develop an equilibrium solution to analyze future year traffic conditions under various policy scenarios. An example from Scenario I that satisfies the equilibrium condition for two O-D pairs is shown in Table 6.1. The first O-D pair is a local trip between Union County and the Port Area; the second O-D pair is a long-distance trip between Hunterdon County and the Port Area. Both O-D pairs use a portion of the proposed I-78 toll route as their preferred route. The generalized costs presented in Table 6.1 differ for autos and trucks because the operating and toll costs are different as discussed earlier. Based on the results, ten iterations were deemed sufficient to attain an equilibrium solution. At equilibrium, no traveler can improve their travel cost by unilaterally changing routes. A similar comparison for mode choice is shown in Table 6.2 for Scenario II. Ten iterations were assumed to be sufficient for the mode choice between truck and rail to reach equilibrium.

Table 6.1: Example of Equilibrium for O-D Pairs from Union and Hunterdon County – ($/auto or $/truck) – Scenario I

		Union County						Hunterdon County			
O-D Pair	Iteration	Generalized Cost [$]				O-D Pair	Iteration	Generalized Cost			
		Auto		Truck				Auto		Truck	
		I-78	Non I-	I-78	Non I-78			I-78	Non I-78	I-78	Non I-78
1776 – 1732	1	8.55	8.28	36.49	35.06	766 - 759	1	11.6	11.6	48.23	47.74
	2	8.73	9.16	37.35	38.8		2	11.89	11.62	49.55	47.82
	3	9.06	8.56	38.72	36.29		3	11.92	11.65	49.65	47.94
	4	9.05	9.21	38.72	38.97		4	11.93	11.67	49.71	48.06
	5	9.57	8.55	41	36.23		5	11.69	11.7	48.62	48.17
	6	9.37	9.24	40.13	39.12		6	12.06	11.72	50.28	48.27
	7	10.54	8.65	45.16	36.67		7	11.84	11.77	49.28	48.46
	8	9.7	9.3	41.58	39.37		8	12.2	11.78	50.84	48.52
	9	8.7	8.7	36.89	36.89		9	12.4	12.43	51.64	51.28
	10	9.08	9.42	38.85	39.9		10	11.91	11.92	49.63	49.02
1777 – 1750	1	12.85	11.92	54.47	50.3	768 - 761	1	11.62	11.12	48.92	46.16
	2	12.94	12.46	54.87	52.27		2	11.63	11.13	48.96	46.2
	3	13.07	12.62	55.45	52.98		3	11.63	11.15	48.96	46.3
	4	13.19	12.61	55.94	53.06		4	11.63	11.18	48.97	46.45
	5	13.17	13.12	55.86	55.34		5	11.63	11.22	48.97	46.6
	6	13.45	12.94	57.08	54.53		6	11.63	11.25	48.98	46.72

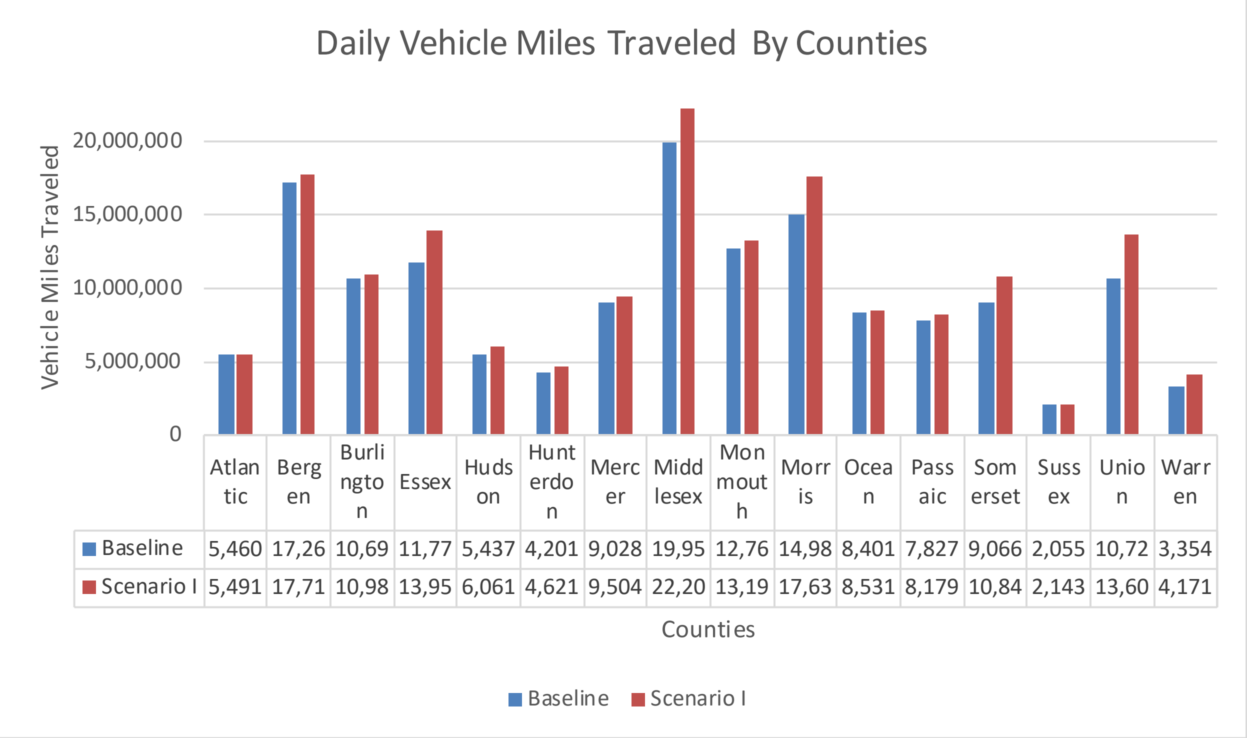
	7	14.14	13.34	60.06	56.14		7	11.63	11.31	48.97	47
	8	14.07	13.27	59.79	55.97		8	11.64	11.44	49	47.58
	9	16.46	13.52	70.12	56.87		9	11.64	11.36	48.99	47.24
	10	13.52	13.61	57.39	57.53		10	11.64	11.66	48.99	48.51

Table 6.2: Example of Equilibrium Condition for O-D Pairs – Scenario II

O-D Pair	Iteration	Truck	Rail	O-D Pair	Iteration	Truck	Rail
2517 - 1800	1	0.90	0.10	**2507 - 571**	1	0.92	0.08
	2	0.90	0.10		2	0.92	0.08
	3	0.89	0.11		3	0.92	0.08
	4	0.89	0.11		4	0.92	0.08
	5	0.90	0.10		5	0.92	0.08
	6	0.90	0.10		6	0.92	0.08
	7	0.89	0.11		7	0.91	0.09
	8	0.89	0.11		8	0.91	0.09
	9	0.89	0.11		9	0.90	0.10
	10	0.89	0.11		10	0.91	0.09

Network Wide Change in VMT and VHT

Changes in VMT and VHT are important to identify the communities impacted by the proposed policy and to help fund transportation improvements. A comparison of daily VMT by county is presented for the Baseline Scenario and Scenario I in **Figure 6.1**. As seen in the figure, the counties that I-78 passes through are generally affected the most as a result of Scenario I.



	Atlantic	Bergen	Burlington	Essex	Hudson	Hunterdon	Mercer	Middlesex	Monmouth	Morris	Ocean	Passaic	Somerset	Sussex	Union	Warren
🟦 Baseline	5,460	17,26	10,69	11,77	5,437	4,201	9,028	19,95	12,76	14,98	8,401	7,827	9,066	2,055	10,72	3,354
🟥 Scenario I	5,491	17,71	10,98	13,95	6,061	4,621	9,504	22,20	13,19	17,63	8,531	8,179	10,84	2,143	13,60	4,171

Figure 6.1: Daily vehicle miles traveled for Baseline Scenario and Scenario I

The total increase in regional VMT is 10.4%[39] The VMT changes are presented graphically on a percentage basis in Figure 6.2. Four of the top five counties affected by Scenario I are the counties that I-78 passes through: Union, Warren, Somerset, and Essex.

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[39] The total daily VMT is 168,843,489 and 152,987,128 for Scenario I and Baseline Scenario respectively.

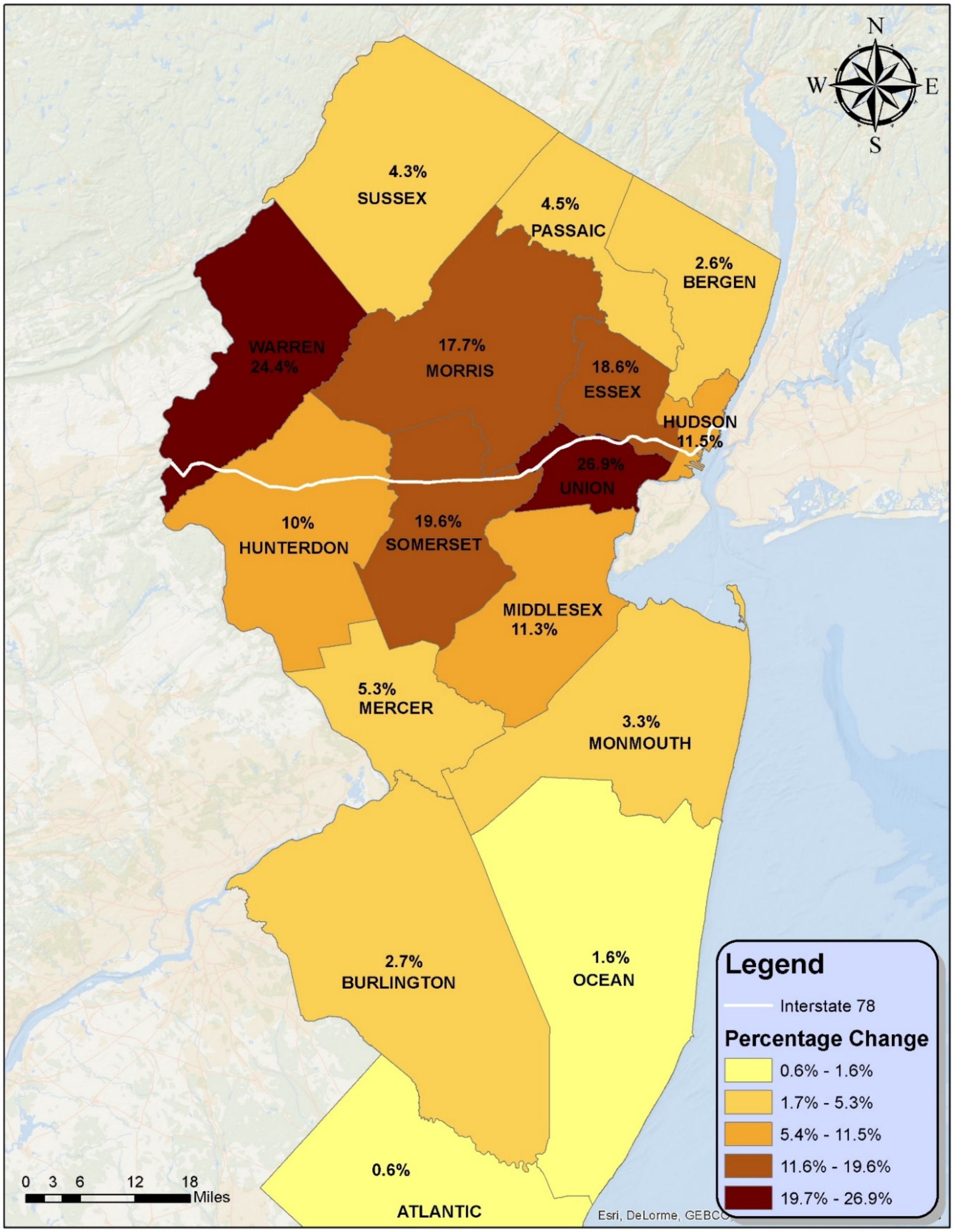

Figure 6.2: Percentage change in vehicle miles traveled by county

A similar VMT comparison can be made between the Baseline Scenario and Scenario II however Scenario II affects both mode and route preference. For the selected O-D pairs to and from the port area, as shown in Figure 5.5, 10.2% of shippers, or 488 trips, would prefer to use rail while the remaining 89.8%, or 4304, trips, would prefer truck. Of these truck trips, 63.6%, or 3048 trips, would use a non I-78 route, while 26.2%, or 1257 trips, would use a the tolled I-78 route. The small number of truck trips diverted is based on the selected zones only.

The comparison of vehicle miles traveled between Baseline Scenario, and Scenario II is shown in Figure 6.3. The comparison of Scenario II and Scenario I do not yield significant differences because only 10.2% of port trucks are expected to shift to the alternate rail mode.

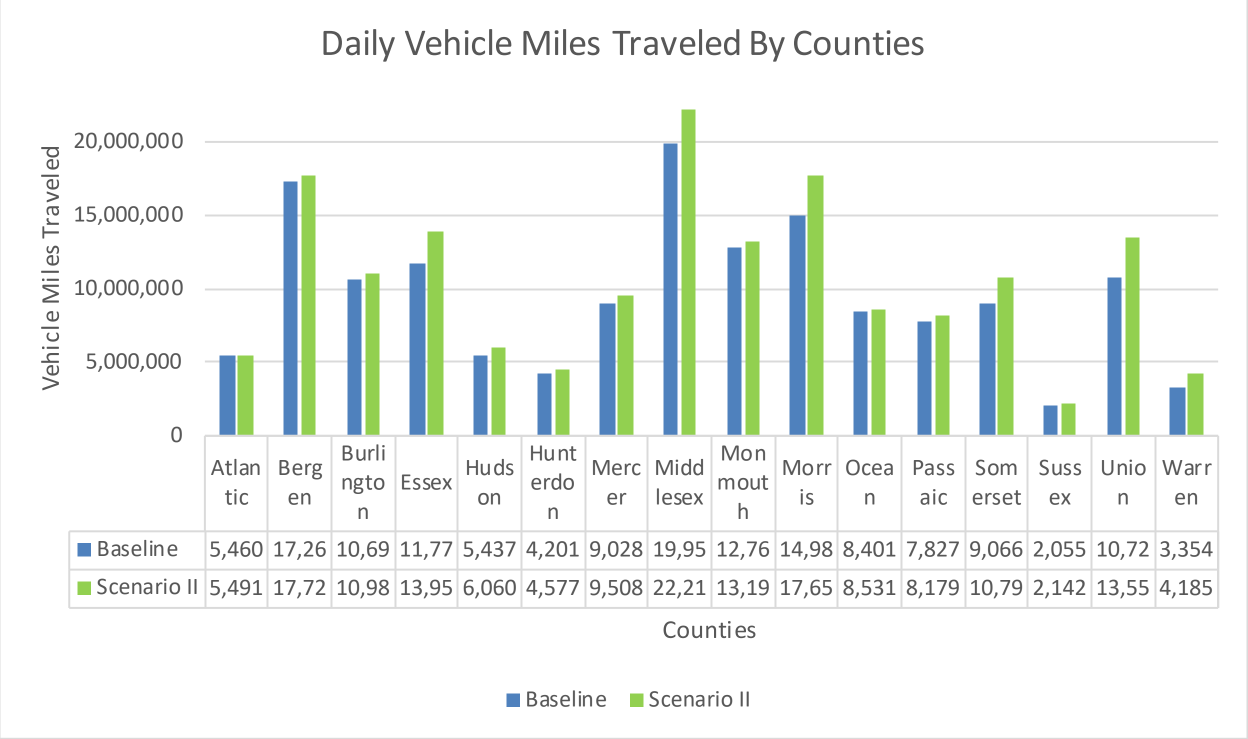

Figure 6.3: Daily vehicle miles traveled for Baseline Scenario and Scenario II

Corridor Analysis

The I-78 corridor passes through five counties in New Jersey: Essex, Union, Somerset, Hunterdon, and Warren. The change in VMT on I-78 between the Baseline Scenario and Scenario I on I-78 in these five counties is presented in **Table 6.3**. The VMT on I-78 in the western counties: Hunterdon and Warren, are significantly reduced because the alternate routes are not congested enough for travelers to pay tolls on I-78. However, as the congestion increases in the more densely populated eastern counties: Essex and Union, the vehicle miles traveled on I-78 increases, suggesting that travelers prefer I-78 over the alternate more congested routes and are willing to bear the additional cost of tolls on I-78. The results from Somerset County also suggest that trucks are more sensitive to tolls than autos.

Table 6.3: Comparison of VMT on I-78 Corridor between Baseline Scenario and Scenario

	Baseline Scenario [000]			Scenario I [000]			Percent Difference		
County	Auto	Truck	Total	Auto	Truck	Total	Auto	Truck	Total
Essex	455.9	39.7	495.6	544.7	49.8	594.6	19.5%	25.6%	20.0%
Hunterdon	1,280.8	353.6	1,634.5	916.0	180.3	1,096.3	-28.5%	-49.0%	-32.9%
Somerset	1,163.8	207.2	1,371.0	1,163.0	185.8	1,348.8	-0.1%	-10.4%	-1.6%
Union	1,433.5	138.5	1,572.0	1,763.5	166.3	1,929.8	23.0%	20.1%	22.8%
Warren	374.5	118.0	492.5	263.5	60.0	323.5	-29.6%	-49.2%	-34.3%
Total	4,708.6	857.0	5,565.6	4,650.7	642.2	5,292.9	-1.2%	-25.1%	-4.9%

Cost-Benefit Analysis of Scenarios

The cost-benefit analysis focuses on the evaluation of economic benefits, toll revenue, versus disbenefits, user costs, for each scenario. User costs, previously discussed, include travel time, emissions, pavement damage, and safety. The analysis evaluates the differences in benefits and costs between the baseline scenarios and scenarios I and II on a regional basis.

The annual estimates are calculated for year 2015 and 2040 for each of the three scenarios. It is assumed that traffic growth for the intermediate years and constant and that benefits and costs are proportional to traffic growth. The following formula is used to calculate benefits and costs for any given analysis year between 2015 and 2040 using geometric extrapolation:

$$C_{t,s} = C_{t_o,s} * (1 + j_s)^{(t - t_o)}$$

Where:

$C_{t,s}$ = cost in year t and for scenario S;

t_o = initial year of analysis, 2015;

t = year of analysis

j_s = annual rate of change in cost in scenario S between the year 2015 and 2040

which is given by

$$= \left(\frac{C2040,S}{C2015,S}\right)^{\frac{1}{(2040-2015)}} - 1$$

The change in annual regional VMT and VHT as a result of the proposed policy changes, along with a calculation of benefits and costs, is presented in the following tables. Net gap is computed as the difference between benefits and costs. If costs exceed benefits, than the net gap would be negative. A comparison of the Baseline Scenario with Scenario I for years 2015 and 2040 is presented in Table 6.4. The results indicate that the additional revenue generated by Scenario I are insufficient compared to its cost and account for only 3.5%[40] of the additional user costs for year 2015. Using the geometric extrapolation discussed earlier, a comparison of the Baseline Scenario with Scenario I for year 2020 is presented in Table 6.5. The results suggest that travel time costs account for approximately 72% of total costs[41] followed by fuel consumption, safety, environmental and pavement costs. The increased costs of Scenario I can be attributed towards travelers changing routes to avoid the proposed tolls on I-78 leading to increased congestion on local roads. The gross revenue generated was $860,230 per day[42]. The net gap is estimated be to approximately $24 million/day[43] for the year 2020.

A similar analysis was done by comparing the Baseline Scenario with Scenario II as shown in Table 6.6 and Table 6.7. The results from the analysis for year 2020 suggests that the revenue generated in this case I slower than Scenario I at $845,351[44]. However the net gap also reduces by $150,271 per day suggesting that Scenario II would be better than Scenario I. The comparison of net gap for year 2020 between Scenario II and Scenario I suggests that availability of alternate mode can help reduce the overall cost of truck trips by $308/day[45].

This analysis is based on the assumption that the value of time used for the multiclass assignment problem remains the same for the future year 2040 analysis. The use of a higher value of time during the assignment process would result in more traffic on I-78 during the future year. If the value of travel time is higher, than an alternate congested route would be less desirable than paying additional tolls for an uncongested I-78. The analysis is based on the assumption that tolls are constant throughout the day. Time of day pricing may increase revenue and reduce the net gap.

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[40] Refer Table 6.4 – Total Revenue/Total Cost [$208,326,451/$5,928,672,185 = 0.035 (3.5%)]

[41] Refer Table 6.5 – Travel Time Cost/Total Cost [$4,449,711,453/$6,177,139,401 = 0.720 (72%)]

[42] Refer Table 6.5 – Total Revenue/Number of Weekdays [$215,057,625/250 = $860,230 per day]

[43] Refer Table 6.5 – Net Gap/Number of Weekdays [$6,003,369,289/250 = $24,013,477 per day]

[44] Refer Table 6.7 – Total Revenue/Number of Weekdays [$211,337,778/250 = $845, 351 per day]

[45] Refer Table 6.5 and 6.7 - $6,003,369,289 - $5,965,801,624 = $37,567,665/488 trips diverted to rail = $76,983 per day. The value can be further divided to represent truck trip per day = $76,983/250 (number of weekdays) = $308 per day.

Table 6.4: Comparison of Annual Vehicle Miles Traveled, Vehicle Hour Traveled, Costs and Revenue for Year 2015 and 2040 between Baseline Scenario and Scenario I

		Year 2015			**Year 2040**		
		Baseline Scenario	**Scenario I**	**Difference**	**Baseline Scenario**	**Scenario I**	**Difference**
Annual VMT [000]	**Autos**	35,831,964	39,204,308	(3,372,344)	41,371,250	45,412,563	(4,041,313)
	Trucks	1,602,887	3,006,564	(1,403,677)	2,587,334	3,230,756	(643,421)
	Total	***37,434,850***	***42,210,872***	***(4,776,022)***	***43,958,585***	***48,643,319***	***(4,684,734)***
Annual VHT [000]	**Autos**	804,388	1,052,960	(248,572)	970,781	1,323,607	(352,826)
	Trucks	45,136	63,645	(18,509)	49,762	72,855	(23,092)
	Total	***849,524***	***1,116,605***	***(267,081)***	***1,020,543***	***1,396,461***	***(375,919)***
Annual Costs [$000]							
Travel Time		**$12,772,588**	**$16,936,478**	($4,163,891)	**$15,190,631**	**$20,949,711**	($5,759,080)
Environmental		**$1,433,036**	**$1,639,275**	($206,238)	**$1,719,274**	**$1,907,976**	($188,701)
Fuel		**$4,771,772**	**$5,999,109**	($1,227,337)	**$6,041,478**	**$6,859,582**	($818,104)
Safety		**$3,294,285**	**$3,631,198**	($336,912)	**$3,848,257**	**$4,250,671**	($402,414)
Pavement		**$69,348**	**$110,754**	($41,405)	**$100,578**	**$121,279**	($20,701)
Total Cost		***$22,341,030***	***$28,316,814***	***($5,975,783)***	***$26,900,218***	***$34,089,218***	*($7,189,001)*
Revenue		**$0**	**$212,599**	**$212,599**	**$0**	**$224,892**	**$224,892**
		Net Gap		***($5,763,185)***	**Net Gap**		***($6,964,108)***

Table 6.5: Projected Costs and Revenue for Year 2020 Based on the Geometric Extrapolation for Baseline Scenario and Scenario I

Cost Type		**Baseline Scenario**	**Scenario I**	**Difference**
Travel Time Cost [$000]		$13,256,196	$17,739,125	($4,482,929)
Environmental Cost [$000]		$1,490,284	$1,693,015	($202,731)
Fuel Cost [$000]		$5,025,714	$6,171,204	($1,145,490)
Safety Cost [$000]		$3,405,080	$3,755,093	($350,013)
Pavement Cost [$000]		$75,594	$112,859	($37,265)
***Total Cost* [$000]**		***$23,252,868***	***$29,471,295***	***($6,218,427)***
Revenue [$000]		**$0**	**$215,058**	**$215,058**
		Net Gap		***($6,003,369)***

Table 6.6: Comparison of Annual Vehicle Miles Traveled, Vehicle Hour Traveled, Costs and Revenue for Year 2015 and 2040 between Baseline Scenario and Scenario II

		Year 2015			**Year 2040**		
		Baseline Scenario	Scenario II	Difference	Baseline Scenario	Scenario Ii	Difference
Annual VMT [000]	**Autos**	35,831,964	39,189,610	(3,357,646)	41,371,250	45,413,398	(4,042,147)
	Trucks	1,602,887	2,997,240	(1,394,353)	2,587,334	3,222,120	(634,785)
	Total	***37,434,850***	***42,186,850***	***(4,752,000)***	***43,958,585***	***48,635,517***	***(4,676,932)***
Annual VHT [000]	**Autos**	804,388	1,051,743	(247,355)	970,781	1,323,610	(352,829)
	Trucks	45,136	63,168	(18,032)	49,762	72,623	(22,861)
	Total	***849,524***	***1,114,911***	***(265,387)***	***1,020,543***	***1,396,233***	***(375,690)***
Annual Costs [$000]							
Travel Time		**$12,772,588**	**$16,897,704**	**($4,125,116)**	**$15,190,631**	**$20,938,723**	**($5,748,092)**
Environmental		**$1,433,036**	**$1,638,518**	**($205,482)**	**$1,719,274**	**$1,907,483**	**($188,209)**
Fuel		**$4,771,772**	**$5,993,080**	**($1,221,308)**	**$6,041,478**	**$6,854,020**	**($812,542)**
Safety		**$3,294,285**	**$3,629,916**	**($335,631)**	**$3,848,257**	**$4,249,961**	**($401,704)**
Pavement		**$69,348**	**$110,484**	**($41,136)**	**$100,578**	**$121,039**	**($20,462)**
Total Cost		***$22,341,030***	***$28,269,702***	***($5,928,672)***	***$26,900,218***	***$34,071,226***	***($7,171,008)***
Revenue		**$0**	**$208,326**	**$208,326**	**$0**	**$223,383**	**$223,383**
		Net Gap		***($5,720,346)***	**Net Gap**		***($6,947,625)***

Table 6.7: Projected Costs and Revenue for Year 2020 Based on the Geometric Extrapolation for Baseline Scenario and Scenario II

Cost Type	**Baseline Scenario**	**Scenario II**	**Difference**
Travel Time Cost [$000]	$13,256,196	$17,705,908	($4,449,711)
Environmental Cost [$000]	$1,490,284	$1,692,311	($202,027)
Fuel Cost [$000]	$5,025,714	$6,165,268	($1,139,555)
Safety Cost [$000]	$3,405,080	$3,753,925	($348,845)
Pavement Cost [$000]	$75,594	$112,595	($37,001)
***Total Cost* [$000]**	***$23,252,868***	***$29,430,007***	***($6,177,139)***
Revenue [$000]	**$0**	**$211,338**	**$211,338**
	Net Gap		***($5,965,802)***

Similar Origin–Destination Studies within Region

The Port Authority of New York and New Jersey conducted a maritime container terminal survey of truck origins and destinations in 2005. The objective of the study was to identify major characteristics of truck movement and determine the routes being accessed by the container terminals served by Port of New York and New Jersey. The study included seven terminals; five in Port Newark and Elizabeth, one in Jersey City and one in Staten Island, New York. The New York ports were surveyed for two days and the ports in New Jersey were surveyed for one day. The data was collected at the city/state or zip code level and was then aggregated to the county level.

The Port Authority study was compared to the origin-destination data from the NJTPA which was used in this study and is presented in Figure 6.4. The comparison of the truck trip percentages by county showed significant differences. One possible reason would be a major change in traffic since 2005. Another reason could be the difference in the pool of data collected. For example, the results from 2005 study were based on the surveys conducted at ports whereas the NJTPA data represents data generated outside of New Jersey in the form of external zones.

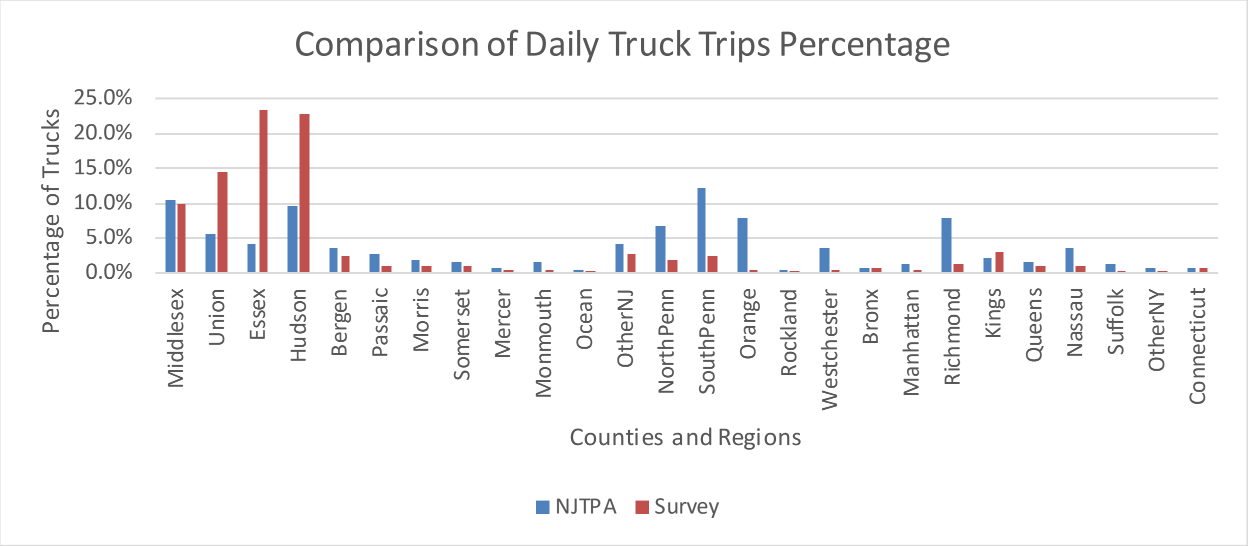

Figure 6.4: Comparison of daily truck trips percentage between NJTPA and survey by county

The truck trip tables, therefore, could be obtained by either actual measurement via O-D surveys as was done in the 2005 study or through the synthesis of the demand models as in the case of the NJTPA. Although the models are estimated and calibrated using O-D surveys, it may not be possible to obtain a statistically significant trip table from the survey data. Also, the demand models represent comprehensive data within the region and are more suitable for macroscopic analysis.

Chapter 7 - Summary

The proposed objective of the research was to develop a policy framework which can be used as a tool to determine the impacts of change in truck traffic on a regional level as a result of policy change. To achieve the objective three demand models were used in the framework which is built on the principle of behavioral route choice and mode-choice assignment problem. The problem is represented in more realistic context by using stochastic route-choice behavior for multi-user groups and uses logit model to describe their behavior. In first two models, the demand is assumed to be fixed, whereas the third model considers variable demand. The complexity of the models is increased as they account for traveler's preference towards mode and represent the demand as a function of congestion on the network. The models have been formulated as mathematical programs with non-linear objective functions with linear constraints.

The proposed models in the framework are used to analyze and evaluate the effects of policy on the flow pattern at a regional level. The predicted flow patterns as a result of policy change are then used to compute the associated costs and benefits. The developed framework can thus be used to answer questions of interest to transportation policy makers and planners. It can further help them to better understand the trade-offs between the economic advantages (benefit concerning revenue) and disadvantages (regarding costs) of policy. The framework can, therefore, be used as a tool that provides the ability to public agencies to evaluate the freight issues in the region and its effect on communities.

The framework was applied to the real-world case study in New Jersey area. The strategic location of the New Jersey as a "Crossroads of East" creates a critical link in shipping routes and is served by Port of Newark/New York. Trucks being the major mode of transportation for freight movement through ports, the region served a perfect test-bed for application of the framework. The socioeconomic data, complete highway network and the demand representing the region were based on the latest available data. Scenarios describing policy changes were built within Citilabs Cube platform to reflect the regional changes. The analysis of the results from the case study suggested that the costs associated with scenarios are much higher than the benefit generated by them.

To this end, the developed framework addresses the research questions to present stakeholder's complex implications that a policy can have on the region. It also to answers the question of how much the change in truck demand affects the region regarding monetary costs such as safety, congestion, environment, and pavement damage. The research further provides an insight of the change in travel behavior as a result of policy decision and its effect on communities. The study is built on the data that is readily available to planning agencies and can be further enhanced with improved data availability.

References

Adams, T., Perry, E., Schwartz, A., Gollnik, B., Kang, M., Bittner, J., & Wagner, S. (2013). Aligning oversize/overweight fees with agency costs: Critical issues. Wisconsin Dept. of Transportation, WI.

Adams, T. M., Bittner, J., & Wittwer, E. (2009). Wisconsin Truck Size and Weight Study (No. CFIRE 02-01). University of Wisconsin, Madison and Wisconsin Department of Transportation.

Agbelie, B. R., Volovski, M., Zhang, Z., Bardaka, E., Labi, S., & Sinha, K. C. (2016). Updating State and Local Highway Cost Allocation and Revenue Attribution: A Case Study for Indiana. Transportation Research Record: Journal of the Transportation Research Board, (2597), 1-10.

Ahmed, A., Bai, Q., Lavrenz, S., & Labi, S. (2015). Estimating the marginal cost of pavement damage by highway users on the basis of practical schedules for pavement maintenance, rehabilitation and reconstruction. Structure and Infrastructure Engineering, 11(8), 1069-1082.

Bai, Y., Schrock, S. D., Mulinazzi, T. E., Hou, W., Liu, C., & Firman, U. (2010). Estimating highway pavement damage costs attributed to truck traffic.

Balducci, P., & Stowers, J. (2008). NCHRP Synthesis 378: State Highway Cost Allocation Studies. Transportation Research Board of the National Academies, Washington, DC.

Bell, M. L. (2012). Assessment of the health impacts of particulate matter characteristics. Research Report (Health Effects Institute), (161), 5-38.

Bigazzi, A., & Figliozzi, M. (2013). Role of heavy-duty freight vehicles in reducing emissions on congested freeways with elastic travel demand functions. Transportation Research Record: Journal of the Transportation Research Board, (2340), 84-94.

Boardman, B. S., Malstrom, E. M., & Trusty, K. (1999). Intermodal transportation cost analysis tables (No. MBTC FR-1100-3). University of Arkansas, Mack-Blackwell National Rural Transportation Study Center.

Boile, M., Ozbay, K., & Narayanan, P. (2001). Infrastructure Costs Attributable to Commercial Vehicles (No. FHWA-NJ-2001-030,).

Brodrick, C. J., Laca, E., Burke, A., Farshchi, M., Li, L., & Deaton, M. (2004). Effect of vehicle operation, weight, and accessory use on emissions from a modern heavy-duty diesel truck. Transportation Research Record: Journal of the Transportation Research Board, (1880), 119-125.

Brogan, J. J., Aeppli, A. E., Bagan, D. F., Brown, A., Fischer, M. J., Grenzeback, L. R., ... & Witzke, E. (2013). Freight transportation modal shares: scenarios for a low-carbon future (No. DOE/GO-102013-3705).

Bruzelius, N. (2004). Measuring the marginal cost of road use: An international survey (Vol. 963). Swedish National Road and Transport Research Institute.

BTS, U. Transportation statistics annual report 2012. 2013.

Chowdhury, M., Putman, B., Pang, W., Dunning, A., Dey, K., & Chen, L. (2013). Rate of Deterioration of Bridges and Pavements as Affected by Trucks (No. FHWA-SC-13-05). FHWA-SC-13-05, Clemson University, Clemson, SC.

Commodity Flow Survey Preliminary Report – Shipment Characteristics by Mode of Transportation 2012, Bureau of Transportation Statistics, U.S. Department of Transportation. http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/commodity_flow_survey/2012/united_states/table1.html

Comprehensive Truck Size and Weight Limits Study Report to Congress, 2016. (http://ops.fhwa.dot.gov/freight/sw/map21tswstudy/index.htm)

Council, M. P. (2008). Moving at the Speed of Congestion. Chicago: MPC.

Dey, K., Chowdhury, M., Pang, W., Putman, B., & Chen, L. (2014). Estimation of pavement and bridge damage costs caused by overweight trucks. Transportation Research Record: Journal of the Transportation Research Board, (2411), 62-71.

Dougherty, P. S. (2010). Evaluating the impact of gate strategies on a container terminal's roadside network using microsimulation: the Port Newark/Elizabeth case study (Doctoral dissertation, Rutgers University-Graduate School-New Brunswick).

Dunning, A., Dey, K. C., & Chowdhury, M. (2016). Review of State DOTs Policies for Overweight Truck Fees and Relevant Stakeholders' Perspectives. Journal of Infrastructure Systems, 22(3), 05016002.

Eisele, W. L., Schrank, D. L., Schuman, R., & Lomax, T. J. (2013). Estimating urban freight congestion costs: Methodologies, measures, and applications. In Transportation Research Board 92nd Annual Meeting (No. 13-1344).

FHWA, U. (2000). Addendum to the 1997 Federal Highway Cost Allocation Study Final Report.

Figliozzi, M. A. (2011). The impacts of congestion on time-definitive urban freight distribution networks CO 2 emission levels: Results from a case study in Portland, Oregon. Transportation Research Part C: Emerging Technologies, 19(5), 766-778.

Forkenbrock, D. J. (1999). External costs of intercity truck freight transportation. Transportation Research Part A: Policy and Practice, 33(7), 505-526.

Freight Transportation and Economic Development: Planning for the Panama Canal Expansion, National Association of Development Organization (NADO) Research Foundation Center for Transportation Advancement and Regional Development with support from the Federal Highway Administration, February 2012.

Giuliano, G., O'Brien, T., Hayden, S., & Dell'aquila, P. (2006, September). The Terminal Gate Appointment System at the Ports of Los Angeles and Long Beach: An Assessment. In Transportation Research Board 85th Annual Meeting.

Hagemann, G., Hymel, K., Klauber, A., Lee, D. B., Noel, G., Pace, D., & Taylor, C. (2013). Delay and Environmental Costs of Truck Crashes (No. FMCSA-RRA-13-043).

Harkey, D. L., Zegeer, C. V., Stewart, J. R., & Reinfurt, D. W. (1992). Operational Impacts of Wider Trucks on Narrow Roadways. Transportation Research Record, 56-56.

Hatzopoulou, M., & Miller, E. J. (2010). Linking an activity-based travel demand model with traffic emission and dispersion models: transport's contribution to air pollution in Toronto. Transportation Research Part D: Transport and Environment, 15(6), 315-325.

Haveman, J. D., & Hummels, D. (2004). California's global gateways: trends and issues. San Francisco: Public Policy Institute of California.

Holguín-Veras, J., Silas, M., Polimeni, J., & Cruz, B. (2008). An investigation on the effectiveness of joint receiver–carrier policies to increase truck traffic in the off-peak hours. Networks and Spatial Economics, 8(4), 327-354.

https://www.nado.org/wp-content/uploads/2012/03/panama.pdf

Hymson, E. B. (1978). EFFECT OF INCREASED MOTOR-CARRIER SIZES AND WEIGHTS ON RAILROAD REVENUES. Transportation Research Record, (668).

Karafa, J. (2012). Simulating gate strategies at intermodal marine container terminals (Doctoral dissertation, The University of Memphis).

Kawamura, K. (2016). Economic Benefits of Productivity Increases through Truck-to-Rail Mode Shift in Freight Transport (Doctoral dissertation, University of Illinois, Chicago).

Kozawa, K. H., Fruin, S. A., & Winer, A. M. (2009). Near-road air pollution impacts of goods movement in communities adjacent to the Ports of Los Angeles and Long Beach. Atmospheric Environment, 43(18), 2960-2970.

Lawrence, J., Blincoe, J., & Barbara, M. F. (1992). The economic cost of motor vehicle crashes. DOT HS, 807, 876.

Lemp, J. D., Kockelman, K. M., & Unnikrishnan, A. (2011). Analysis of large truck crash severity using heteroskedastic ordered probit models. Accident Analysis & Prevention, 43(1), 370-380.

Levin, R. C. (1978). Allocation in surface freight transportation: does rate regulation matter?. The Bell Journal of Economics, 18-45.

Lena, T. S., Ochieng, V., Carter, M., Holguín-Veras, J., & Kinney, P. L. (2002). Elemental carbon and PM (2.5) levels in an urban community heavily impacted by truck traffic. Environmental Health Perspectives, 110(10), 1009.

Liao, C. H., Tseng, P. H., Cullinane, K., & Lu, C. S. (2010). The impact of an emerging port on the carbon dioxide emissions of inland container transport: an empirical study of Taipei port. Energy Policy, 38(9), 5251-5257.

Lyman, S., & Braver, E. R. (2003). Occupant deaths in large truck crashes in the United States: 25 years of experience. Accident Analysis & Prevention, 35(5), 731-739.

McCarthy, P. S. (2001). Transportation economics: theory and practice: a case study approach. Wiley-Blackwell.

Miller, T., Levy, D., Spicer, R., & Lestina, D. (1998). Allocating the costs of motor vehicle crashes between vehicle types. Transportation Research Record: Journal of the Transportation Research Board, (1635), 81-87.

Miller, T., Viner, J., Rossman, S., Pindus, N., Gellert, W., Douglass, J., ... & Blomquist, G. (1991). The costs of highway crashes.

Miller, T. R., Spicer, R. S., Lestina, D. C., & Levy, D. T. (1999). Safest to travel by bicycle, car, or big truck?. Traffic Injury Prevention, 1(1), 25-34.

Model Development Report, North Jersey Regional Transportation Model-Enhanced, November 2008

Moini, N. (2010). Modelling the interrelationship between vessel and truck traffic at marine container terminals (Doctoral dissertation, Rutgers University-Graduate School-New Brunswick).

Murillo-Hoyos, J., Ahmed, A., & Labi, S. (2014). Using Regional Freight Traffic Assignment Modeling to Quantify the Variability of Pavement Damage for Highway Cost Allocation and Revenue Analysis (No. 083PY04).

National Research Council (US). Committee for the Study of Relationships between Vehicle Configurations, & Highway Design. (1990). New Trucks for Greater Productivity and Less Road Wear: An Evaluation of the Turner Proposal (No. 227). Transportation Research Board.

Perugu, H., Wei, H., & Yao, Z. (2016). Integrated data-driven modeling to estimate PM 2.5 pollution from heavy-duty truck transportation activity over metropolitan area. Transportation Research Part D: Transport and Environment, 46, 114-127.

Protopapas, A., Warner, J., & Morgan, C. (2012). Evaluation of methodologies in benefit-cost and economic impact analyses for freight rail projects. Transportation Research Record: Journal of the Transportation Research Board, (2288), 83-90.

Przybocki M., Iseman M. (2014). U.S. Bureau of Ecnonomic Analaysis, U.S. Census Bureau, U.S. Department of Commerce, Washington, DC.

Puglisi, C. M. (2008). Issues and Challenges of Federating Between Different Transportation Simulators (Doctoral dissertation, Georgia Institute of Technology).

Robinson, J., & Vadali, S. (2011). FEASIBILITY OF CONTAINERIZED TRANSPORT IN RURAL AREAS AND ITS EFFECT ON ROADWAYS AND ENVIRONMENT: A CASE STUDY.

Saber, A., Morvant, M. J., & Zhang, Z. (2009). Effects of Heavy Truck Operations on Repair Costs of Low-Volume Highways. In Transportation Research Board 88th Annual Meeting (No. 09-0228).

Sadeghi, J. M., & Fathali, M. (2007). Deterioration analysis of flexible pavements under overweight vehicles. Journal of Transportation Engineering, 133(11), 625-633.

Santos, G., Behrendt, H., Maconi, L., Shirvani, T., & Teytelboym, A. (2010). Part I: Externalities and economic policies in road transport. Research in Transportation Economics, 28(1), 2-45.

Shirley, C. (2011). Spending and Funding for Highways.

Spasovic, L. N., Dimitrijevic, B., & Rowinski, J. (2009). Extended Hours of Operation at the Port Facilities in New Jersey: A Feasibility Analysis. New Jersey Institute of Technology, Prepared for New Jersey Department of Transportation, Bureau of Freight Services.

Spasovic, L. N., Hausman, K. J., Daniel, J., Bladikas, A. K., Sideris, A., & Rowinski, J. (2000). Mobility and the Costs of Congestion in New Jersey (No. Final Report).

Spasovic, L. N., He, Y., Besenski, D., Rowinski, J., & Authority, N. J. T. P. (2015). Quantifying Impact of Port Truck Traffic on Highway Operations Using GPS-Based Speed Data (No. CAIT-UTC-023).

Systematics, C. (2006). Inc. Minnesota Truck Size and Weight Project.

Taylor, J., Casavant, K., Sage, J., Moore, D. L., & Ivanov, B. (2013). The Economic Impact of Increased Congestion for Freight-Dependent Businesses in Washington State. In Journal of the Transportation Research Forum (Vol. 52, No. 3, pp. 25-39). Transportation Research Forum.

Timm, D. H., Turochy, R. E., & Peters, K. D. (2007). Correlation Between Truck Weight, Highway Infrastructure Damage and Cost. Auburn University Highway Research Center, FHWA Contract DTFH61-05-Q-00317, 70, 71-5048.

Tsamboulas, D. (2014). Evaluation of rail infrastructure investments related to the new rail regulatory environment in some countries. Transportation Research Record: Journal of the Transportation Research Board, (2411), 1-9.

U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics, America's Container Ports: Linking Markets at Home and Abroad. Washington, DC: 2011.

United States. Maritime Administration. (2007). US Water Transportation Statistical Snapshot. US Department of Transportation, Maritime Administration.

US Environmental Protection Agency. (2004). User's Guide for the AMS/EPA Regulatory Model—AERMOD.

Weisbrod, G., Vary, D., & Treyz, G. (2003). Measuring economic costs of urban traffic congestion to business. Transportation Research Record: Journal of the Transportation Research Board, (1839), 98-106.

Woodrooffe, J., Belzowski, B. M., Reece, J., & Sweatman, P. (2009). Analysis of the potential benefits of larger trucks for US businesses operating private fleets.

Woodrooffe, J., Bereni, M., Germanchev, A., Eady, P., Glaeser, K. P., Jacob, B., & Nordengen, P. (2010, August). Safety, Productivity, Infrastructure Wear, Fuel Use and Emissions Assessment of the International Truck Fleet: a Comparative Analysis. In Publication of the Joint Transport Research Centre of the OECD and the International Transport Forum, Paris.

Woodrooffe, J. (2016). Opportunity Cost for Society Related to US Truck Size and Weight Regulation: Freight Efficiency. Transportation Research Record: Journal of the Transportation Research Board, (2547), 25-31.

Zaloshnja, E., & Miller, T. (2007). Unit costs of medium and heavy truck crashes (No. FMCSA-RRA-07-034). Washington DC: Federal Motor Carrier Safety Administration.

Zaloshnja, E., & Miller, T. R. (2004). Costs of large truck-involved crashes in the United States. Accident Analysis & Prevention, 36(5), 801-808.

Spasovic, L. N., He, Y., Besenski, D., Rowinski, J., & Authority, N. J. T. P. (2015). Quantifying Impact of Port Truck Traffic on Highway Operations Using GPS-Based Speed Data (No. CAIT-UTC-023).

Karafa, J. (2012). Simulating gate strategies at intermodal marine container terminals (Doctoral dissertation, The University of Memphis).

Dougherty, P. S. (2010). Evaluating the impact of gate strategies on a container terminal's roadside network using microsimulation: the Port Newark/Elizabeth case study (Doctoral dissertation, Rutgers University-Graduate School-New Brunswick).

Moini, N. (2010). Modelling the interrelationship between vessel and truck traffic at marine container terminals (Doctoral dissertation, Rutgers University-Graduate School-New Brunswick).

Spasovic, L. N., Dimitrijevic, B., & Rowinski, J. (2009). Extended Hours of Operation at the Port Facilities in New Jersey: A Feasibility Analysis. New Jersey Institute of Technology, Prepared for New Jersey Department of Transportation, Bureau of Freight Services.

Holguín-Veras, J., Silas, M., Polimeni, J., & Cruz, B. (2008). An investigation on the effectiveness of joint receiver–carrier policies to increase truck traffic in the off-peak hours. Networks and Spatial Economics, 8(4), 327-354.

Puglisi, C. M. (2008). Issues and Challenges of Federating Between Different Transportation Simulators (Doctoral dissertation, Georgia Institute of Technology).

Giuliano, G., O'Brien, T., Hayden, S., & Dell'aquila, P. (2006, September). The Terminal Gate Appointment System at the Ports of Los Angeles and Long Beach: An Assessment. In Transportation Research Board 85th Annual Meeting.

Haveman, J. D., & Hummels, D. (2004). California's global gateways: trends and issues. San Francisco: Public Policy Institute of California.

Comprehensive Truck Size and Weight Limits Study Report to Congress, 2016. (http://ops.fhwa.dot.gov/freight/sw/map21tswstudy/index.htm)

FHWA, U. (2000). Addendum to the 1997 Federal Highway Cost Allocation Study Final Report.

Dunning, A., Dey, K. C., & Chowdhury, M. (2016). Review of State DOTs Policies for Overweight Truck Fees and Relevant Stakeholders' Perspectives. Journal of Infrastructure Systems, 22(3), 05016002.

Dey, K., Chowdhury, M., Pang, W., Putman, B., & Chen, L. (2014). Estimation of pavement and bridge damage costs caused by overweight trucks. Transportation Research Record: Journal of the Transportation Research Board, (2411), 62-71.

Chowdhury, M., Putman, B., Pang, W., Dunning, A., Dey, K., & Chen, L. (2013). Rate of Deterioration of Bridges and Pavements as Affected by Trucks (No. FHWA-SC-13-05). FHWA-SC-13-05, Clemson University, Clemson, SC.

Adams, T., Perry, E., Schwartz, A., Gollnik, B., Kang, M., Bittner, J., & Wagner, S. (2013). Aligning oversize/overweight fees with agency costs: Critical issues. Wisconsin Dept. of Transportation, WI.

Sadeghi, J. M., & Fathali, M. (2007). Deterioration analysis of flexible pavements under overweight vehicles. Journal of Transportation Engineering, 133(11), 625-633.

Hymson, E. B. (1978). EFFECT OF INCREASED MOTOR-CARRIER SIZES AND WEIGHTS ON RAILROAD REVENUES. Transportation Research Record, (668).

Woodrooffe, J. (2016). Opportunity Cost for Society Related to US Truck Size and Weight Regulation: Freight Efficiency. Transportation Research Record: Journal of the Transportation Research Board, (2547), 25-31.

Woodrooffe, J., Bereni, M., Germanchev, A., Eady, P., Glaeser, K. P., Jacob, B., & Nordengen, P. (2010, August). Safety, Productivity, Infrastructure Wear, Fuel Use and Emissions Assessment of the International Truck Fleet: a Comparative Analysis. In Publication of the Joint Transport Research Centre of the OECD and the International Transport Forum, Paris.

Woodrooffe, J., Belzowski, B. M., Reece, J., & Sweatman, P. (2009). Analysis of the potential benefits of larger trucks for US businesses operating private fleets.

Systematics, C. (2006). Inc. Minnesota Truck Size and Weight Project.

National Research Council (US). Committee for the Study of Relationships between Vehicle Configurations, & Highway Design. (1990). New Trucks for Greater Productivity and

Less Road Wear: An Evaluation of the Turner Proposal (No. 227). Transportation Research Board.

Przybocki M., Iseman M. (2014). U.S. Bureau of Ecnonomic Analaysis, U.S. Census Bureau, U.S. Department of Commerce, Washington, DC.

Lemp, J. D., Kockelman, K. M., & Unnikrishnan, A. (2011). Analysis of large truck crash severity using heteroskedastic ordered probit models. Accident Analysis & Prevention, 43(1), 370-380.

Adams, T. M., Bittner, J., & Wittwer, E. (2009). Wisconsin Truck Size and Weight Study (No. CFIRE 02-01). University of Wisconsin, Madison and Wisconsin Department of Transportation.

Harkey, D. L., Zegeer, C. V., Stewart, J. R., & Reinfurt, D. W. (1992). Operational Impacts of Wider Trucks on Narrow Roadways. Transportation Research Record, 56-56.

BTS, U. Transportation statistics annual report 2012. 2013.

Kawamura, K. (2016). Economic Benefits of Productivity Increases through Truck-to-Rail Mode Shift in Freight Transport (Doctoral dissertation, University of Illinois, Chicago).

Tsamboulas, D. (2014). Evaluation of rail infrastructure investments related to the new rail regulatory environment in some countries. Transportation Research Record: Journal of the Transportation Research Board, (2411), 1-9.

Protopapas, A., Warner, J., & Morgan, C. (2012). Evaluation of methodologies in benefit-cost and economic impact analyses for freight rail projects. Transportation Research Record: Journal of the Transportation Research Board, (2288), 83-90.

Taylor, J., Casavant, K., Sage, J., Moore, D. L., & Ivanov, B. (2013). The Economic Impact of Increased Congestion for Freight-Dependent Businesses in Washington State. In Journal of the Transportation Research Forum (Vol. 52, No. 3, pp. 25-39). Transportation Research Forum.

Council, M. P. (2008). Moving at the Speed of Congestion. Chicago: MPC.

Spasovic, L. N., Hausman, K. J., Daniel, J., Bladikas, A. K., Sideris, A., & Rowinski, J. (2000). Mobility and the Costs of Congestion in New Jersey (No. Final Report).

Weisbrod, G., Vary, D., & Treyz, G. (2003). Measuring economic costs of urban traffic congestion to business. Transportation Research Record: Journal of the Transportation Research Board, (1839), 98-106.

Eisele, W. L., Schrank, D. L., Schuman, R., & Lomax, T. J. (2013). Estimating urban freight congestion costs: Methodologies, measures, and applications. In Transportation Research Board 92nd Annual Meeting (No. 13-1344).

Bigazzi, A., & Figliozzi, M. (2013). Role of heavy-duty freight vehicles in reducing emissions on congested freeways with elastic travel demand functions. Transportation Research Record: Journal of the Transportation Research Board, (2340), 84-94.

Brodrick, C. J., Laca, E., Burke, A., Farshchi, M., Li, L., & Deaton, M. (2004). Effect of vehicle operation, weight, and accessory use on emissions from a modern heavy-duty diesel truck. Transportation Research Record: Journal of the Transportation Research Board, (1880), 119-125.

Figliozzi, M. A. (2011). The impacts of congestion on time-definitive urban freight distribution networks CO 2 emission levels: Results from a case study in Portland, Oregon. Transportation Research Part C: Emerging Technologies, 19(5), 766-778.

Bell, M. L. (2012). Assessment of the health impacts of particulate matter characteristics. Research Report (Health Effects Institute), (161), 5-38.

Lena, T. S., Ochieng, V., Carter, M., Holguín-Veras, J., & Kinney, P. L. (2002). Elemental carbon and PM (2.5) levels in an urban community heavily impacted by truck traffic. Environmental Health Perspectives, 110(10), 1009.

Perugu, H., Wei, H., & Yao, Z. (2016). Integrated data-driven modeling to estimate PM 2.5 pollution from heavy-duty truck transportation activity over metropolitan area. Transportation Research Part D: Transport and Environment, 46, 114-127.

US Environmental Protection Agency. (2004). User's Guide for the AMS/EPA Regulatory Model—AERMOD.

Hatzopoulou, M., & Miller, E. J. (2010). Linking an activity-based travel demand model with traffic emission and dispersion models: transport’s contribution to air pollution in Toronto. Transportation Research Part D: Transport and Environment, 15(6), 315-325.

Liao, C. H., Tseng, P. H., Cullinane, K., & Lu, C. S. (2010). The impact of an emerging port on the carbon dioxide emissions of inland container transport: an empirical study of Taipei port. Energy Policy, 38(9), 5251-5257.

Kozawa, K. H., Fruin, S. A., & Winer, A. M. (2009). Near-road air pollution impacts of goods movement in communities adjacent to the Ports of Los Angeles and Long Beach. Atmospheric Environment, 43(18), 2960-2970.

Shirley, C. (2011). Spending and Funding for Highways.

Balducci, P., & Stowers, J. (2008). NCHRP Synthesis 378: State Highway Cost Allocation Studies. Transportation Research Board of the National Academies, Washington, DC.

Bruzelius, N. (2004). Measuring the marginal cost of road use: An international survey (Vol. 963). Swedish National Road and Transport Research Institute.

Agbelie, B. R., Volovski, M., Zhang, Z., Bardaka, E., Labi, S., & Sinha, K. C. (2016). Updating State and Local Highway Cost Allocation and Revenue Attribution: A Case Study for Indiana. Transportation Research Record: Journal of the Transportation Research Board, (2597), 1-10.

Murillo-Hoyos, J., Ahmed, A., & Labi, S. (2014). Using Regional Freight Traffic Assignment Modeling to Quantify the Variability of Pavement Damage for Highway Cost Allocation and Revenue Analysis (No. 083PY04).

Ahmed, A., Bai, Q., Lavrenz, S., & Labi, S. (2015). Estimating the marginal cost of pavement damage by highway users on the basis of practical schedules for pavement maintenance, rehabilitation and reconstruction. Structure and Infrastructure Engineering, 11(8), 1069-1082.

Bai, Y., Schrock, S. D., Mulinazzi, T. E., Hou, W., Liu, C., & Firman, U. (2010). Estimating highway pavement damage costs attributed to truck traffic.

Robinson, J., & Vadali, S. (2011). Feasibility of Containerized Transport in Rural Areas and its effect on Roadways and Environment: A Case Study.

Saber, A., Morvant, M. J., & Zhang, Z. (2009). Effects of Heavy Truck Operations on Repair Costs of Low-Volume Highways. In Transportation Research Board 88th Annual Meeting (No. 09-0228).

Dey, K., Chowdhury, M., Pang, W., Putman, B., & Chen, L. (2014). Estimation of pavement and bridge damage costs caused by overweight trucks. Transportation Research Record: Journal of the Transportation Research Board, (2411), 62-71.

Timm, D. H., Turochy, R. E., & Peters, K. D. (2007). Correlation Between Truck Weight, Highway Infrastructure Damage and Cost. Auburn University Highway Research Center, FHWA Contract DTFH61-05-Q-00317, 70, 71-5048.

Boile, M., Ozbay, K., & Narayanan, P. (2001). Infrastructure Costs Attributable to Commercial Vehicles (No. FHWA-NJ-2001-030,).

Miller, T., Viner, J., Rossman, S., Pindus, N., Gellert, W., Douglass, J., ... & Blomquist, G. (1991). The costs of highway crashes.

Miller, T., Levy, D., Spicer, R., & Lestina, D. (1998). Allocating the costs of motor vehicle crashes between vehicle types. Transportation Research Record: Journal of the Transportation Research Board, (1635), 81-87.

Miller, T. R., Spicer, R. S., Lestina, D. C., & Levy, D. T. (1999). Safest to travel by bicycle, car, or big truck?. Traffic Injury Prevention, 1(1), 25-34.

Zaloshnja, E., & Miller, T. R. (2004). Costs of large truck-involved crashes in the United States. Accident Analysis & Prevention, 36(5), 801-808.

Lawrence, J., Blincoe, J., & Barbara, M. F. (1992). The economic cost of motor vehicle crashes. DOT HS, 807, 876.

Zaloshnja, E., & Miller, T. (2007). Unit costs of medium and heavy truck crashes (No. FMCSA-RRA-07-034). Washington DC: Federal Motor Carrier Safety Administration.

Lyman, S., & Braver, E. R. (2003). Occupant deaths in large truck crashes in the United States: 25 years of experience. Accident Analysis & Prevention, 35(5), 731-739.

Forkenbrock, D. J. (1999). External costs of intercity truck freight transportation. Transportation Research Part A: Policy and Practice, 33(7), 505-526.

Hagemann, G., Hymel, K., Klauber, A., Lee, D. B., Noel, G., Pace, D., & Taylor, C. (2013). Delay and Environmental Costs of Truck Crashes (No. FMCSA-RRA-13-043).

Santos, G., Behrendt, H., Maconi, L., Shirvani, T., & Teytelboym, A. (2010). Part I: Externalities and economic policies in road transport. Research in Transportation Economics, 28(1), 2-45.

Brogan, J. J., Aeppli, A. E., Bagan, D. F., Brown, A., Fischer, M. J., Grenzeback, L. R., ... & Witzke, E. (2013). Freight transportation modal shares: scenarios for a low-carbon future (No. DOE/GO-102013-3705).

United States. Maritime Administration. (2007). US Water Transportation Statistical Snapshot. US Department of Transportation, Maritime Administration.

U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics, America's Container Ports: Linking Markets at Home and Abroad. Washington, DC: 2011.

Freight Transportation and Economic Development: Planning for the Panama Canal Expansion, National Association of Development Organization (NADO) Research Foundation Center for Transportation Advancement and Regional Development with support from the Federal Highway Administration, February 2012.

https://www.nado.org/wp-content/uploads/2012/03/panama.pdf

Commodity Flow Survey Preliminary Report – Shipment Characteristics by Mode of Transportation 2012, Bureau of Transportation Statistics, U.S. Department of Transportation. http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/commodity_flow_survey/2012/united_states/table1.html

Boardman, B. S., Malstrom, E. M., & Trusty, K. (1999). Intermodal transportation cost analysis tables (No. MBTC FR-1100-3). University of Arkansas, Mack-Blackwell National Rural Transportation Study Center.

Spasovic, L. N., He, Y., Besenski, D., Rowinski, J., & Authority, N. J. T. P. (2015). Quantifying Impact of Port Truck Traffic on Highway Operations Using GPS-Based Speed Data (No. CAIT-UTC-023).

Giuliano, G., O'Brien, T., Hayden, S., & Dell'aquila, P. (2006, September). The Terminal Gate Appointment System at the Ports of Los Angeles and Long Beach: An Assessment. In Transportation Research Board 85th Annual Meeting.

Karafa, J. (2012). Simulating gate strategies at intermodal marine container terminals (Doctoral dissertation, The University of Memphis).

Model Development Report, North Jersey Regional Transportation Model-Enhanced, November 2008

Jansuwan, S., Ryu, S., & Chen, A. (2016). A two-stage approach for estimating a statewide truck trip table. Transportation Research Part A: Policy and Practice.

Samimi, A., MOHAMMADIAN, K., & Kawamura, K. (2010). Behavioral Paradigms for Modeling Freight Travel Decision-Making. In The 12th International Conference on Travel Behaviour Research.

Giuliano, G., Gordon, P., Pan, Q., Park, J., & Wang, L. (2010). Estimating freight flows for metropolitan area highway networks using secondary data sources. Networks and Spatial Economics, 10(1), 73-91.

Knudson, B., Hunt, J. D., Weidner, T., Bettinardi, A., & Wardell, E. (2011). Effective Modeling Analysis: A Case Study Using the Oregon Statewide Integrated Model for the Oregon Freight Plan.

Wang, X. C., & Zhang, D. (2017). Truck freight demand elasticity with respect to tolls in New York State. Transportation Research Part A: Policy and Practice, 101, 51-60.

Tsekeris, T., & Tsekeris, C. (2011). Demand forecasting in transport: Overview and modeling advances. Economic Research-Ekonomska Istraživanja, 24(1), 82-94.

Litman, T. (2013). Understanding transport demands and elasticities. How prices and other factors affect travel behavior.(Victoria Transport Policy Institute: Litman) Available at http://www. vtpi. org/elasticities. pdf [Verified 22 November 2013].

Sheffi, Y. (1985). Urban transportation networks.

Chow, J. Y., Yang, C. H., & Regan, A. C. (2010). State-of-the art of freight forecast modeling: lessons learned and the road ahead. Transportation, 37(6), 1011-1030.

Bari, M. E., Burris, M. W., & Huang, C. (2015). The impact of a toll reduction for truck traffic using SH 130. Case Studies on Transport Policy, 3(2), 222-228.

Arentze, T., Feng, T., Timmermans, H., & Robroeks, J. (2012). Context-dependent influence of road attributes and pricing policies on route choice behavior of truck drivers: results of a conjoint choice experiment. Tran