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ABSTRACT

A METHODOLOGICAL FRAMEWORK FOR QUANTIFYING IMPACTS OF TRUCK TRAFFIC ON REGIONAL NETWORK WITH IMPLICATIONS TO TRANSPORT POLICY

**by
Chaitanya N Pathak**

Increased global trade has promoted the importance of shipping industry and the introduction of mega-ships has created an opportunity to be more cost-effective. Because of this, the expected change in freight transportation influences the operating regimes and schedules at the port terminals. Trucks being the predominant mode of transportation used to carry the freight transport, there is a growing concern about the impact of trucks in the region. The problems are further expected to grow as the improvements to resolve them are hindered by funding shortfalls. Public agencies are therefore involved in developing comprehensive state freight plans that outline immediate and long-range plans for freight-related transportation improvements. However, for states to develop and implement investment policies that can adequately address challenges, there is a need for a policy framework that can evaluate the impact of freight. The lack of the framework makes it difficult for state/metropolitan planning organizations to implement investment strategies in the best possible way.

The proposed framework in the dissertation tries to fill the gap by developing a methodological framework, which can help agencies to evaluate multiple policies and their impact on local communities. Additionally, the framework can ascertain the magnitude of impacts that the infrastructure or policy in conjunction with the change in truck traffic

might have on a regional level. The developed framework thus can help decision makers to prioritize policies that will benefit both public and freight transportation needs.

Three demand models are used in the framework, which is built on the principle of behavioral route choice and mode-choice assignment problem. The outputs from the demand models are further used to quantify the impact in terms of cost-benefit analysis. The dissertation includes a real-world case study demonstrating how the framework can be used to evaluate alternative policies and its impact on a regional level.

To this end, the developed framework in the dissertation addresses the research questions to present stakeholder's complex implications that policy can have on the region. It also 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.

**A METHODOLOGICAL FRAMEWORK FOR QUANTIFYING IMPACTS
OF TRUCK TRAFFIC ON REGIONAL NETWORK WITH
IMPLICATIONS TO TRANSPORT POLICY**

by
Chaitanya N Pathak

**A Dissertation
Submitted to the Faculty of
New Jersey Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy in Civil Engineering**

John A. Reif, Jr. Department of Civil and Environmental Engineering

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APPROVAL PAGE

**A METHODOLOGICAL FRAMEWORK FOR QUANTIFYING IMPACTS
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This dissertation is dedicated to my loving family. A special feeling of gratitude to my parents, Narendra and Vaijayanti whose words of encouragement and push for tenacity ring in my ears. I also dedicate this dissertation to my beloved wife, Renuka and daughter, Ariona who never left my side and have been my cheerleaders throughout the entire doctorate program. Special thanks to my sister, Shraddha and brother-in-law, Parag for believing in me.

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LIST OF ACRONYMS

MAP-21	The Moving Ahead for Progress in the 21st Century Act
DOT	Department of Transportation
FHWA	Federal Highway Administration
ITS	Intelligent Transportation System
IDAS	ITS Deployment Analysis System
AAPA	American Association of Port Authorities
GDP	Gross Domestic Product
NJDOT	New Jersey Department of Transportation
NS	Norfolk Southern
CSX	Class I Railroad Transportation Company
CP	Pacific Railway
NYS&W	The New York, Susquehanna, and Western
NCHRP	National Cooperative Highway Research Program
MPO	Metropolitan Planning Organization
NY/NJ	New York/New Jersey
PNE	Port of Newark/Elizabeth
PANYNJ	Port Authority of New York and New Jersey
AB	Assembly Bill
CTSW	Comprehensive Truck Size and Weight Limits
LCV	Long Combination Vehicles
GVWR	Gross Vehicle Weight Ratings
CREATE	The Chicago Region Environmental and Transportation Efficiency
RCI	Roadway Congestion Index
TCI	Travel Congestion Index

HPMS	Highway Performance Monitoring System
NO ₂	Nitrogen Dioxide
CO ₂	Carbon Dioxide
CO	Carbon Monoxide
NO _x	Nitrogen Dioxide
NO	Nitric Oxide
PM	Particulate Matter
ANOVA	Analysis of Variance
EPA	Environmental Protection Agency
VOC	Volatile Organic Compound
BC	Black Carbon
HCA	Highway Cost Allocation
PDC	Pavement Damage Costs
NAPCOM	National Pavement Cost Model
HERS	Highway Economic Requirement System
AASHTO	American Association of State Highway and Transportation Officials
ESAL	Equivalent Single Axle Load
MEPDG	Mechanistic Empirical Pavement Design Guide
EMS	Emergency Service Costs
FARS	Fatality Analysis Reporting System
GES	General Estimates Systems
KABCO	Severity Level (Killed [K], Disabling Injury [A], Evident Injury [B], Possible Injury [C], Property Damage [O])
VMT	Vehicle Miles Traveled
VHT	Vehicle Hour Travel

CHAPTER 1

INTRODUCTION

1.1 Research Objective

The Moving Ahead for Progress in the 21st Century Act (MAP-21), directs the US 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 that will effectively address challenges in statewide freight plan, there is a need for a policy framework that can evaluate the impact of truck traffic. The lack of structure which can be used to assess policy scenarios makes it difficult for states/metropolitan planning organizations (MPO) to implement investment strategies in the best possible way. The problem becomes more complicated mainly when multiple stakeholders with conflicting objectives are involved, having significant effects on the people in the region.

The primary objective of the dissertation is to develop a methodological 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. Transportation policies can have a significant effect on every aspect of life, as the travelers tend to choose their routes based on the lowest travel cost for a given origin-destination pair. The traveler preference can, therefore, be considerably affected as a result of increased congestion and availability of better mode of transport. It can further influence the distribution of trips among various possible destinations. To account for these traveler preferences as a result of policy change, three demand models have been used in the framework. The benefit of this approach is that the models consider the preferences of the travelers for not only choosing the routes but also

the modes for their trips given the availability of the mode. The models formulate these preferences in well-defined supply-demand functions to yield equilibrium solutions. The developed policy framework in this dissertation addresses key research questions such as:

- Can there be a framework that will present to the stakeholders complex implications that a policy can have on a region?
- Can the developed framework then be used to:
 - Quantify the impact of a policy implementation on the users of roadway networks with regards to their mobility and safety
 - Quantify the impact on infrastructure improvement and maintenance
- Can the quantification of the impacts be used to evaluate the implications of different transportation policies and planning decisions, with a goal to estimate the significant effect that a specific policy has on every aspect of life. Different transportation policies typically involve various compromises between conflicting socio-economic and environmental objectives that affect the performance of the transportation system.

To this end, the framework should be able to address the following:

- 1) The costs related to the increase in freight transport by trucks concerning:
 - a) Congestion on the roadway network
 - b) Crash cost due to unsafe driving conditions
 - c) Maintenance of roadway infrastructure
 - d) Mitigation of environmental impacts
- 2) The impact of mode choice on a road system (where two competing mode choices of rail and truck are available for freight transportation):
 - a) On a regional level
 - b) Corridor Level

The research presented in the dissertation is significant from both theoretical and practical perspective. It integrates demand and supply functions in a network equilibrium and formulates models that incorporate decision-making process. The impacts of these travel decisions can be quantified concerning safety and environmental benefits. The proposed

approach used to quantify these impacts is based on Federal Highway Administration (FHWA) methodology and ITS Deployment Analysis System (IDAS). The framework can, therefore, be used to evaluate different policy measures in the form of congestion, safety, emission, and pavement damage cost. Additionally, the framework can, therefore, be used to answer questions of interest to transportation planners and decision makers and help to investigate the tradeoffs as a result of policy changes. The simulation results from this research thus reveal valuable insights that will help policymakers design ideal policies or investment strategies. Ports being major freight generators, the study is focused on the movement of cargo to/from the harbor area. A macroscopic simulation modeling approach is adopted in the study to quantify the regional freight movement of trucks. This method was selected bearing in mind the time and budget constraints most states and MPOs face.

Although various studies have been developed using freight demand model, they lack a comprehensive approach that inculcates a wide variety of cost associated and mode choice with the change in demand. The research also integrates demand and supply functions in a network equilibrium context and formulates models, which incorporate the decision-making process. The research makes several practical contributions in the area of transportation planning by analyzing and evaluate freight policies and its regional impact. The research in this dissertation, therefore, tries to fill the knowledge gap by progressing modeling framework to enable long-term analysis of implemented policies.

1.2 Background

1.2.1 Global Trade and Role of Ports in International Trade

The United States' economy is the world's largest economy¹, and its market is among the top three global trading markets that rely on imports of raw materials, and the export of finished goods². U.S International Trade in goods and services also increased by 2.85% in exports, and 3.41% of assets in 2014 compared to previous years³. This increased growth in International Trade has promoted the importance of the maritime shipping industry, and port activities. Reports suggest that one in every eleven containers engaged in global commerce is either bound for or originating from the United States⁴.

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 handle more than 2 billion tons of domestic trade and import/export annually and is expected to double the volume by the end of 2020. The estimate suggests that ports also contribute more than \$3.15 trillion to the Gross Domestic Product (GDP) generating nearly 13.3 million jobs. Further, the completion of Panama Canal project in 2016, and the increasing international trade and movement of goods at 3.4 percent per year

¹ International Monetary Fund – World Economic Outlook (http://money.cnn.com/news/economy/world_economies_gdp/, accessed on January 9th, 2017).

² International Trade – Wikipedia, Largest countries by total international trade (http://en.wikipedia.org/wiki/International_trade, accessed on January 15th, 2017).

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>, accessed on January 20th, 2017).

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.

is placing pressure on ports to increase capacities of handling containerized cargo⁵. The projected container traffic growth at the East Coast and Gulf Coast ports will likely outpace container traffic at the West Coast ports after 2015⁶. Container terminal operators are embracing the challenges, and are investing in new infrastructure with a goal of being more competitive and cost-effective.

1.2.2 States Role and Responsibility

According to the freight plans, the investments and strategies are targeted towards advancing policy changes, and pilot programs. Additionally, they also aim to establish a relationship with municipalities, and counties, as well as the logistics industry, to ensure that collaborative solutions are developed which target critical area impacting the freight industry. The annual proceeds from the taxes and fees dedicated to the Highway Trust Fund have apparently, fallen below annual expenditures in recent years⁷. 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 which provide nearly half of all surface transportation funding are facing a tough time. The primary source of financing which comes from vehicle fuel tax, vehicle registration fees, driver license fees, sales taxes on motor vehicles, heavy truck use taxes, traffic violation fines and similar taxes

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>, accessed on January 10th, 2017).

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

combined is insufficient. The fund has accumulated \$14.8 billion in debt and without significant policy reforms; the situation is going to worsen further⁸.

1.2.3 Freight System in New Jersey

According to the New Jersey Comprehensive Statewide Freight Plan, New Jersey moved nearly 621 million tons of freight worth \$860 billion into, out of, within, and through. The predominant mode of transportation used to carry freight in the state are trucks accounting for almost 75 percent of goods moved by weight (tons). This is followed by waterborne mode at 18 percent and rail at 7 percent. Statewide freight plan recognizes the trends in goods movement and presents strategies and actions geared towards improving the state's ability to provide efficient movement of goods. The identified infrastructure projects are selected to address safety and maintenance, expand support, as well as address some policy issues. Projects listed to address safety, maintenance, and expansions are all related to addressing issues related to roadway facilities. Policy problematic areas are related to supporting extensions of port operating hours, introducing delivery during non-business hours, supporting open road tolling, and encouraging statewide agencies to identify other issues related to the movement of goods by trucks.

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

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

in business income⁹. These investments with some additional investment such as the Goethals Bridge replacement are geared towards accommodating the arrival of mega-ships after the expansion of the Panama Canal.

The investment in the rail infrastructure and equipment close to \$300 million shows the State's intention of improving 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 railroads¹⁰. The New Jersey Department of Transportation (NJDOT) has a vital interest in preserving and improving the rail freight infrastructure. Eighteen freight railroads currently operate within the State of New Jersey. They are divided into three classes¹¹:

- 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).

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

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, accessed on February 2nd, 2017).

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>, accessed on January 5th, 2017).

¹¹ According to Surface Transportation Board, U.S. freight railroads are classified into three types: Class I refers to freight railroad with annual operating revenues above \$ 346.8 million in 2006 dollars, Class II refers to freight railroads with revenues between \$27.8 million and \$346.7 million and Class III for all other freights.

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 percent between 2007 and 2035, and rail freight by about 48% during the same period.

However, with limited resources to build new capacity, it is important to effectively utilize the existing multimodal transportation infrastructure and improve it to meet standards with a goal to accommodate freight growth. Statewide Freight Strategic Plan presents priority recommendations to address current shortcomings of the system. Some of them are discussed below:

- Upgrading secondary/light density lines to handle the current industry standard 286,000 lb. (286 K) rail cars;
- Identify and mitigate constraints inhibiting the movement of 286K rail cars on selected lines;
- Upgrading capacity and access to the rail yards;
- Upgrading tunnel and bridges height restrictions that prevent the movement of today's larger industry standard rail cars;
- Improving connectivity between northern and southern New Jersey;
- Enhancing connectivity between Class I and the short line railroads

1.2.4 Challenges Faced by State of New Jersey

The State of 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 by TRIP – A National Transportation Research Group, January 2015 estimates that traffic congestion costs New Jersey residents a total of \$5.2 billion annually in addition to \$3.7 billion in operating cost. Additionally, increased wear and tear, and another \$2.9 billion in traffic crashes in the form of lost household and workplace productivity, insurance costs, and other financial costs. A New Jersey driver thus loses \$1,951 annually as a result of driving on deficient roads.

The strategic location of New Jersey as a “Crossroads of East” creates a critical link 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 trucks¹². 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.

1.2.5 Summary

The logistic changes as a result of Panama Canal rebuilding may not only significant impact the New York/New Jersey metropolitan areas, but also in the United States as a whole. As a result of this, the expected change in freight transportation would impact the

¹² 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, accessed on January 5th, 2017).

operating regimes and schedules at the port terminals. Further, this may also affect highway and rail operations outside of the ports as well. Since trucks are being the predominant mode of freight transport, there is a growing concern about their impact on the environment, safety, congestion and roadway infrastructure. These issues are expected to grow, and funding shortfalls hinder the necessary improvements to resolve the issues.

1.3 Organization

The dissertation is organized into six chapters. Chapter 1 describes the background of the current issues related to U.S freight increase especially at ports and challenges faced by the agencies in providing sustainable infrastructure with limited funding availability. The chapter also presents the research objective and work scope of the research. 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 methodological framework being used to achieving the research objective by proposing three freight demand models which are used to identify the impacts of trucks on the region. Each of these demand models is being discussed in detail in this section along with its solution algorithm being used. Chapter 4 presents a case study that applies the proposed framework described in Chapter 3 in a real world. Port Newark/New York area forms a perfect test bed to implement the framework and analyze the regional highway network as a result of policy implications. Chapter 5 discusses the results of the case study and the regional implications of a policy. Chapter 6 includes a conclusion and the future research directions.

CHAPTER 2

LITERATURE REVIEW

This chapter of the dissertation presents a review of both academic literature and professional reports towards advancing the knowledge in the area of quantifying the truck impacts. In Section 2.1, an overview of policy directions is discussed to quantify the increasing truck traffic and strategies considered. The policy guidelines are further classified into three broad categories based on operational strategy, vehicle size and configurations and investment in alternative infrastructure. The next Section 2.2, discusses truck impacts based on congestion, environment, pavement, and safety.

2.1 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.

2.1.1 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%¹³ 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 extending terminal gate hours

¹³ <http://www.panynj.gov/port/trade-stats.html>, accessed on June 20th, 2016.

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 et 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.

2.1.2 Vehicle Size and Configurations

The Moving Ahead for Progress in the 21st Century Act (MAP-21) (P.L. 112-141) requires U.S. Department of Transportation (DOT) to conduct a comprehensive truck size and weight limits (CTSW) study. The study uses state-of-the-art analysis and modeling approach 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,” April 2016 focused on the magnitude of potential impacts if changes were implemented. The department of transportation concluded that no changes to federal policy on truck size and weight should be made at this time. The reason for this was the lack of necessary data to make the accurate assessment of the national impact of any adjustments. The study also found that the likely reduction in vehicle miles traveled that might have resulted from longer and heavier trucks were relatively small. It also concluded that, if federal vehicle weights were increased to 91,000 pounds, the added strengthening, and repair work would be needed to 4,800 bridges. This would cost \$1.1 billion which accounts for only 20% of the bridges considered in the analysis.

Another study conducted by DOT in 2000, claims that 80,000-pound five-axle combination trucks cover just 80 percent of the damage caused by highways and trucks weighing more than 100,000 pounds cover only 50 percent of their cost¹⁴. Further increase in size and weight would lead to even greater underpaid taxes and fees by heavy trucks. However, "grandfather" provision in the federal law allows states to permit to vehicles beyond legal limits and collect taxes to compensate for additional damage. However, it is

¹⁴ “Addendum to 1997 Federal Highway Cost Allocation Study Final Report” (2000).

believed that additional fees did not cover the cost of actual damage done to infrastructure. A study conducted by Dunning et al. (2016) reviewed state DOT's policies for overweight truck fees and pertinent stakeholders' perspectives. It found that often time's legislators and lobbyists, rather than engineering analysis govern the setting of overweight taxes and fines. These charges are logically not related to the damage inflicted on infrastructure and cost incurred to maintain pavement and bridges. The study also concluded that states had established exceptions, but the permitting rules are inconsistent from state to state and are problematic to interstate overweight trucking operations. The harmonization can not only resolve inconsistency but assist businesses to make appropriate mode choice, routing decisions and set business policies to account for damage fees.

A similar study by Dey et al. (2014) tried to estimate pavement and bridge damage cost caused by overweight trucks. The analysis revealed that damage increased significantly when vehicles exceeded the legal weight limits. The study further compared the fee types and its relative efficiency for each type. It estimated that in flat per trip damage cost recovery fee, would range from trucks paying 67% less to 293% more compared to an axle-based damage. Likewise, when weight-based per ton damage cost recovery fee type was compared, it ranged from trucks paying 67% less to 331% more compared with truck type. The study, therefore, concluded that careful analysis of market response is necessary before deciding to implement one fee type over another. 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 author found that the damage costs for loads exceeding highway standards were higher than the overweight fees recovered. To recover additional damage imparted, the study concluded that the permit fee would vary between \$24 and \$175 per trip for different overweight truck types, while in a

flat fee structure, all overweight trucks will pay \$65 per trip. A similar study conducted by Adams et al. (2013) at University of Wisconsin –Madison concluded that single trip permits for oversize/overweight fees do not capture the ongoing operational or infrastructural damage caused by overweight loadings. This is further magnified in the multi-trip process which is available in most states as more damage is caused by the high number of loads carried. A report to Congress in 2012 following the enactment of Public Law 111-117 allowed conducting a pilot program in Vermont. The study raised size and weight on its interstate highways for one year beginning December 2009 and estimated traffic, infrastructure impacts, and energy consumption compared to the pre-pilot case. The results concluded that the pavement damage on Vermont Interstate system increased by 12% which translated into the significant increase in pavement maintenance costs and more frequent work zones. To better understand the influence of overloading on operational life of the flexible pavement, Sadeghi et al. (2007) conducted a study which developed a deterioration model for pavement and ticketing formulation for overweight vehicles. The results indicated that the revenue collected from fines by the road authorities were inadequate compared to the pavement damage predicted by the model, particularly if the magnitude of the excess load is more than 20% of the vehicle allowable loads.

However, some research suggests that increasing the truck size and weight on highways can accommodate greater volumes of freight with the same number of trucks and thus can increase productivity. Woodrooffe (2016) discussed the truck size and weight policy in the United States and compared it internationally regarding freight efficiency. The data showed that U.S federal size and weight limits are the lowest and restrictive compared to Australia, Canada, Mexico, New Zealand and the European Union. A similar study conducted by Bereni et al. (2010) projects a stagnant policy resulting in the U.S

trailing all developed nation concerning mass freight efficiency per unit. The study claims both Canadian and Mexican tractor semi-trailers by mass are more efficient than the 80,000 lb U.S vehicle by 44% and 53% respectively. To understand the potential impact of U.S size and weight reform on truck transport efficiency regarding truck travel and fuel use, Woodroffe et al. (2009) conducted a study. The results of the research concluded that not all transport companies could make use of heavier and longer trucks, however in aggregate 10% reduction in fuel consumption for the same freight task could be achieved. In 2006, Minnesota Department of Transportation led a project to assess changes in Minnesota's 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. It identified that based on the proposed vehicle configuration fewer truck trips would be needed leading to significantly lower transport cost. Also, additional axle would result in less pavement wear, and the surplus brake capacity would be better than a five-axle tractor-trailer. The proposed vehicle configuration would, however, increase bridge postings and future design cost modestly. The body of research related to truck size and weight extends beyond the impact of pavements and bridges. It includes large truck size and weight related to modal share, highway safety, highway geometrics, congestion and environmental factors.

A special report 227, published by Transportation Research Board (1990) discussed new trucks for greater productivity and less road wear. The evaluation report called "Tuner" proposal anticipated that the most attractive configuration would be nine axles double trailer and estimated that lower truck freight costs would attract about 4 percent of rail ton-miles. As a result, rail would lose 5 percent of its gross revenue. A similar study by Hymson (1978) discussed that the size and weight of trucks has a significant influence

on the modal share. The author concluded that if the capacity of truck increases to 90,000 lbs, the cost of operation and rates for trucks will decline by 16.8 percent. This potential would force the railroad to make a competitive adjustment that would cost up to \$2 billion. Size and weight regulations have triggered safety concern and to study its effect 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 the likelihood of fatalities and severe injury is estimated to rise with the number of trailers but fall with the truck length and gross vehicle weight ratings (GVWR). Another study conducted by Adams et al. (2009) considered the impacts of various vehicle configurations including 6-axle, 7-axle and 8-axle combinations with increased weight on highway safety. These were compared to the base case of 5-axle tractor-semitrailer, and the greatest saving was projected for 6-axle 98,000 lb tractor-semitrailer, 7-axle 97,000 lb tractor-semitrailer, and 6-axle 90,000 lb tractor-semitrailer. Historically research related to effects of size and weight on geometrics has focused on horizontal curvature and ramp/interchange design.

A study conducted by Harkey et al. (1992) determined differences in performance based on truck width (102 and 96 inches) and its impact on other traffic. The data was collected mostly on rural two-lane and multi-lane roads that include curve and tangent sections along with different traffic conditions. The measure of effectiveness was estimated based on 100 hr of videotape and actions include lateral placement, edge line encroachments, and lane encroachment of trucks/vehicles. The results revealed that wider trucks had significantly higher rate of edge line encroachment and tended to drive closer to centerline than narrow trucks. A similar study conducted by Zegeer et al. (1990) examines the ability of multiple vehicle configurations assigned to the rural road with

restrictive geometry. The trailer lengths of 40, 45, and 48-ft and twin trailer combinations with 28-ft trailers were used on rural two-lane roads in California and New Jersey in the mix of lane widths, shoulder widths, horizontal and vertical alignment. Radar and photographic equipment were used to measure the change in speed, and lateral placements and operational differences were compared using statistical testing. 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, therefore, recommended restricting these vehicles to wide, well-maintained roads.

To study the impact of size and weight on congestion, Adams et al. (2009) tested various vehicle configurations and estimated the cost of congestion on non-interstate and interstate highways combined. Researchers argued that cost savings can be achieved as a result of fewer trucks on the road because of increased size and weight. This, in turn, reduces delays, generating time savings, especially urban roads. The study estimated that 6-axle 98,000lb, 7-axle 97,000 lb and 6-axle 90,000 lb, combinations would have greatest congestion cost savings. Similarly, a case study conducted by Cambridge Systematics (2006) for Minnesota Department of Transportation assessed proposes changes to the size and weight concerning congestion. The study concluded that cost savings ranged from \$0.05 million per year for the single unit truck up to 80,000 lb to \$0.23 million per year for the 97,000 lbs 7-axle tractor-semitrailer. Another combination of 6-axle and 80axle twin configuration was estimated to be \$0.18 and \$0.08 million per year respectively. On the contrary, a special report 267: Regulation of Weights, Lengths, and Widths of Commercial Motor Vehicles (2002) presents previous study findings of congestion costs. According to an expert panel, prior studies have oversimplified the complex interaction between trucks

and other vehicles in the traffic stream. It claims that changing traffic volume, dimensions and acceleration abilities of trucks will change how motorists drive around them affecting other vehicle acceleration and braking pattern.

2.1.3 Investment in Alternative Infrastructure

The increasing truck traffic has led public agencies to explore alternative strategies which can be used for efficient movement of freight. Three types of options (waterborne, air freight, and rail) have been discussed instead of trucks. The most common alternative being discussed is rail. For example, Port of Long Beach recently in April 2016 commissioned a study to check the feasibility of shipping more incoming cargo to the Inland Empire by using short-haul rail rather than trucks. It was estimated that about 750 truck trips could be reduced by using the short-haul rail¹⁵. One of the major reasons to look into alternative strategy was the congestion in the region which ranked nationally and estimated average time wasted to be 81 hours per commuter per year¹⁶.

By investing in alternative infrastructure such as rail, the freight can be moved efficiently thus increasing the overall productivity. Kawamura et al. (2016) studied the economic benefits of productivity increase through truck-to-rail mode shift in freight transportation. The research applied computable general equilibrium model for the Chicago region to analyze the impacts of productivity increase in the trucking sector as a result of reduced congestion from the modal shift. The results of the study found that the productivity of trucking sector grew by 20 percent and the capital cost and labor cost of

¹⁵ <http://www.polb.com/news/displaynews.asp?NewsID=1542>, accessed on July 5th, 2016.

¹⁶ http://inrix.com/wp-content/uploads/2016/03/INRIX_2015_US_Scorecard_Infographic.pdf, accessed on May 5th, 2016.

rail reduced due to larger mode share. It is a well-known fact that freight railway infrastructure is privately financed however significant public benefits (reduced congestion, environmental impacts, and reduced fuel consumption) can be achieved by investing into rail network. An example “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 between the Port of Virginia and Columbus, Ohio. The benefits of the project included increased corridor capacity, reduced distance traveled by 250 miles, improved safety on highways and reduced commercial truck traffic. It also made Port of Virginia attractive to international shippers and inland terminals. Similarly, another program called "The Chicago Region Environmental and Transportation Efficiency (CREATE)" also involved significant cooperation between private railroad industry and public agencies. The program was formed in 2003 and involved multi-modal infrastructure improvements to handle the congestion choke points in Chicago region. It involved 70 projects at an estimated cost of \$3.2 billion which included upgrading tracks, grade separations, operation visibility improvement, and safety enhancements. The benefits from improvements involved reduced traffic congestion on highways reduced fuel consumption and emissions from locomotives and trucks and improved pavement conditions of roadways. Another case study in Fort Worth, Texas addressed rail congestion issue by investing in adding tracks and improved rail geometry. It was estimated that around 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, enhanced signal arrangement, improved track alignment and faster train movements.

In addition to addressing the congestion, most of the case studies discussed here achieved more than what their primary objective was. Pennsylvania department of transportation in coordination with Conrail in the 1980s took a bold initiative to modernize port and regional transportation facilities. 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 Port of Philadelphia. The project not only benefited from reduced shipping costs and improved service but it also provided new competitive rail alternatives besides improved economic development opportunities. In addition to Port of Philadelphia, Port of Norfolk also uses these double stack rail lines with some trains to Midwest moving across Pennsylvania. Similarly, ports in Wilmington and Baltimore are also seeking to obtain access to the network. The program continues to provide benefits far beyond its anticipated results. International experience such as "Betuweroute Freight Line" developed a 160-km of freight-only rail lines work U.S \$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 supported by European Commission was intended to discourage road haulage for rail freight across Europe.

The case studies indicated provide an overview of rail investment strategies being adopted as an alternative to trucks. Congestion in urban areas caused by truck traffic has become a significant contributor, and public investment in rail freight can help mitigate the issue. However, government funding for these projects is not easy even though the benefits are worth the cost. NCHRP 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. Similar evaluation methods have been discussed in literature throughout the world. Tsamboulas (2016) published a paper which discussed the assessment of rail infrastructure investments and defined socioeconomic viability of these projects. The innovative part of the proposed study was it applied two approaches for evaluation (Economic and Financial). The economic evaluation demonstrated whether a specific project is beneficial to the society and financial analysis is carried out to demonstrate financial viability. Financial analysis is performed only if socioeconomic evaluations are positive because society would not accept if there are no social benefits. The proposed study provided useful guidance for governments and policy makers for transparency, validity, reliability, and precision in decision making. It has been recognized that public investment in freight rail infrastructure is mutually beneficial if it benefits the public. To evaluate this, Protopapas et al. (2012) conducted a study to evaluate two major methodologies (benefit-cost analysis and economic impact analysis) for rail projects. The authors tried to analyze, evaluate, synthesize and mildly critique the state of the practice in conducting benefit-cost analysis and economic impact analysis that estimated the benefits generated by freight rail projects. The study recommends that for the clear relationship between rail projects and expected public benefits, further research is needed. The areas include modal share and diversion potential for change in transportation pricing, performance monitoring for short term/long term benefits and development of methodologies to quantify externalities. Addressing these would boost the confidence in investing in rail infrastructure projects.

2.2 Freight Demand Modelling

For efficient and reliable transportation planning process, freight demand models have been used to predict short and long-term impact on transportation network and its interaction with passenger travel. However, several research studies have confirmed the freight demand methods lack behind when compared to passenger forecasting (Jansuwan et al. 2016, Knudson et al. 2011, Samimi et al. 2010, Giuliano et al. 2010). One of the reason is freight demand is considered as a complex process and depends on many factors affecting the performance of the system. Moreover, as the freight demand continues to grow, agencies face greater pressure to develop improved approaches to tracking and analyzing the freight flows (Greaves et al. 2008, Chow et al. 2010). The estimation of the freight flow is based on the routing of shipment across highway or alternate mode available and falls under the category of assignment problem. The network flows are determined with an objective to minimize the travel time for each mode available between given origin and destination. The process is also sometimes called as equilibrium assignment, and the models have been studied and represented in mathematical form. Methodologies used to solve the network equilibrium assignment problem have been discussed in this section. For example, 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).

The studies which considered the assignment formulation in freight transportation have been discussed by Winebrake et al. (2008). The study proposed a geospatial intermodal freight transportation model in GIS platform and combined modes (road, rail, and waterways) into one network with modal transfer points. The links were then associated with travel time, cost and emissions to find the least delivery time and least cost for the network for given O/D pair. Similarly, Comer et al. (2010) investigated the use of marine vessels instead of heavy duty trucks and suggested the opportunities to improve the performance of freight through infrastructure and economic incentives. The algorithmic development is briefly described in this section and is not further analyzed since the dissertation deals with the formulation of the network equilibrium problem and not with algorithmic approaches. Also, the network equilibrium models focused in the literature are based on the combine mode choice and route selection in an intermodal network equilibrium context.

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

relevant to this dissertation because they deal with the equilibrium between the demand and supply over transportation networks that are served by more than one mode. The basic difference between the studies discussed is that the former considers autos and their selection of mode and does not discuss freight trucks.

The proposed research work focuses on the truck demand models to analyze the shifts between modes. The work improvises the existing models to include freight mode choice based on user equilibrium principle. It allows for the analysis of the case when two competing mode choices of rail and truck are available for freight transportation, this aids in the evaluation of the impact of the change in demand on a roadway network.

2.3 Externalities Associated with Truck Movement

A 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. The impact of these trucks includes traffic congestion (increased travel time and fuel consumption), environmental impacts, increased infrastructure deterioration, decreased road safety, loss of productivity and decreased the quality of life. To quantify these impacts, the literature review further looks into these parameters in detail.

2.3.1 Congestion

The cost of congestion is a function of two variables: delay cost and fuel cost. Delay cost is defined as hours of extra travel time due to congestion. It is calculated using an average value of each hour of travel time. The fuel cost is defined as the additional cost of fuel

spend while vehicles are traveling under congested conditions. It can be estimated as average cost per gallon of fuel consumption¹⁷.

The growth of the freight sector is a major contributor to congestion, especially in urban areas. Not only it affects the timeliness but also impacts the reliability of cargo transportation. Urban Mobility Report 2015 estimated truck congestion cost of \$28 billion (2014 dollars) which includes the yearly value of operating time and wasted fuel for commercial trucks. It is also estimated that even though trucks constitute only 7 percent of urban travel, they account for 18 percent of urban congestion cost. The cost represented, however, does not include additional cost for distribution centers, investing in more trucks and office centers to overcome the congestion. The report ranks the tristate area of New York-New Jersey-Connecticut as number one in the country with total congestion cost of approximately \$15 billion. To study the economic impact of increased congestion for freight dependent business, Taylor et al. (2012) conducted a study to estimate the cost of congestion in the state of Washington. Surveys of freight-dependent businesses and seven IMPLAN models were used to calculate the costs of congestion and estimate the annual economic impact of increased congestion. The cost increased due to congestion was due to additional trucking cost and inventory costs. The results from the study concluded that the consumers were likely to pay 60 to 80% of the increased cost of congestion. A similar study conducted by Chicago Metropolitan Area in 2008 estimated \$7.3 billion a year in wasted time and fuel because of traffic congestion on its express and arterials. Out of which, \$1 billion a year can be accounted for losses in freight section alone. The study used

¹⁷ <http://ntl.bts.gov/lib/8000/8700/8729/congestion.pdf>, accessed on May 8th, 2016.

Texas Transportation Institute's 2005 data and Chicago Metropolitan Agency for Planning figures to estimate heavy truck vehicle hours of delay of 60,000 hours per day at an estimated cost per truck-hour delay of \$66.83 to estimate the congestion cost. To estimate the impact of congestion at the individual level as well as county level, Spasovic et al. (2000) conducted a study to estimate the mobility and the cost of congestion in New Jersey. The methodology used in the research was based on the improvements to the Texas Transportation Institute study which used Highway Performance Monitoring System database. To quantify how congestion affects productivity and quality of life, performance measures including Roadway Congestion Index (RCI), Travel Congestion Index (TCI), Travel Delay, Congestion Cost and Congestion Cost per Licensed Driver were used in the study. Based on the results, the study concluded that traffic congestion in New Jersey resulted in approximately \$4.9 billion out of which 75 % was attributed towards auto and bus users and 25% for trucks. On an individual basis, it was estimated that congestion cost was \$880 per licensed driver.

From the above research, it is evident that traffic congestion imposes a cost upon travelers and affects business operations. To study this economic cost of congestion to businesses, Weisbrod et 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, Illinois, and Philadelphia, Pennsylvania 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. A similar study conducted by Eisele et al. (2013) estimated

urban freight congestion costs by developing methodologies and measures which can help to quantify the impact of congestion. The method adopted in the study used data from Highway Performance Monitoring System (HPMS) and historical speed data from INRIX to estimate wasted time (delay in person-hours) and diesel fuel (gallons wasted). The study documented the development and application of methodologies to help inform trucking stakeholders by quantifying the congestion impact to the trucking industry.

2.3.2 Environment

Increased congestion in urban areas not only increases logistic cost but also impacts the environment. Air pollutant such as nitrogen dioxide (NO₂), particulate matter (PM), carbon dioxide (CO₂), carbon monoxide (CO) is some of the major source of pollutants from motorized traffic. Previous studies (Scora et al. 2010, Brodrick et al. 2004) have shown that freight vehicles, particularly heavy duty trucks have higher emission rates than other vehicles. To study the role of heavy duty freight 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 emission. 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 increases proportionally (4 to 8 times) more in congested condition compared to light duty. This was because heavy duty emission rates were more sensitive to average speed than light duty trucks and congestion mitigation of heavy duty vehicle fleet can substantially reduce the pollutants in the air. A similar study conducted by Brodrick et al. (2004) tried to evaluate

the effects of vehicle operation, weight and use of accessory (air conditioner on/off) on pollutants by heavy duty truck. The study measured pollutants such as nitrogen dioxide (NO_x), hydrocarbons and carbon monoxide from an on-road test of heavy duty truck 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 nitrogen dioxide by approximately 40% (grams per mile) during accelerations. These results were found to be consistent with the simulation model results from National Renewable Energy Laboratory's ADVISOR model. Additionally, a statistical test of ANOVA and regression analysis were conducted by the author to identify the relationship between variables and emission. Air pollutants caused by heavy duty trucks are more prominent in urban areas and vary depending on peak/non-peak time periods.

To study these time-definitive urban freight effects on emission, Figliozzi (2011) conducted a study which focused on the analysis of CO₂ 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 Portland area as a case study. The study focused on approximating carrier's route planning as well as capturing the trade-off between congestion, depot locations, customer characteristics and CO₂ emission in the study area. The experiment results were based on three developed scenarios – uncongested or base case, congested and uncongested case but with limiting speed (44 mph on freeways and 30 mph on local). Comparing scenarios on depot location and change in travel speed impacted CO₂ emission. The study concluded that congestion impacts on emissions are significant for commercial vehicle and it is possible that emission decreases with total route distance increase as a result of an increased proportion of freeway travel.

Another major pollutant ($PM_{2.5}$), which is leading cause of a cardiovascular/respiratory disease, is reported (Bell 2012, Lena et al. 2012) to be highest on-road emitter from heavy duty trucks. To understand the impact of overall $PM_{2.5}$ pollutions in urban areas, Perugu et al. (2016) conducted a study which 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 the training data which creates spatial regression model and the second stage optimizes the truck demand using model outputs and trip distribution matrices. The results are further used in emission, model which used bottom-up method approach to calculating link-specific emissions using link level activity and emission rates. In the end, the study applied dispersion model which estimates downwind concentration of air pollutants emitted from traffic using mathematical simulation (U. S. EPA, 2004). The methodology was validated on Cincinnati urban area, and the results found that 71 percent of urban overall mobile-source $PM_{2.5}$ was caused by trucks.

A similar study was conducted by Hatzopoulou et al. (2010) which tried to integrate activity-based demand models with traffic emission and dispersion models. The study used microsimulation activity-based travel demand model for Greater Toronto Area to calculate vehicle emissions. These emissions were then used as input to 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. Based on the results, the study concludes 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.

Another study conducted by Liao et al. (2010) tried to analyze the change in carbon dioxide emissions from established ports to emerging ports. The study applied an activity-based method for estimating CO₂ emissions and developed four scenarios with 30%, 50%, 80% and 100% change in market share for emerging port of Taipei. Carbon dioxide was estimated by multiplying activity intensity (ton-km) by the truck emission factor (155 g/ton-km). The results from the study concluded that changing inland container shipment routes by shifting the port of call can reduce the carbon dioxide emission.

The increasing concentration of pollutants in an urban area is a major concern, especially those who serve as primary nodes with international trade. Leena et al. (2002) documented the high volume of truck traffic in Port of New York and New Jersey area and concluded that low-income residents experience higher exposure to pollutants. A similar study conducted by Kozawa et al. (2009) tried to evaluate air pollution impacts of goods movement in communities adjacent to Port of Los Angeles and Long Beach. Mobile platforms outfitted with real-time monitoring instruments were used in the study to monitor temporal and spatial resolution at normal speeds. The monitoring tools/equipment could measure 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 impact of heavy duty diesel trucks respectively. The results of the study conclude that the concentration of pollutants (BC, NO, UFP) are two to five times elevated within 150 m of freeways and arterial roads which carried a significant amount of diesel trucks. Furthermore, because of the wind direction, the result suggested similar impacts throughout the urban area in rough proportions.

2.3.3 Pavement

Pavement damage attributed to heavy vehicles such as trucks depends on some factors including weight, axle configuration of the vehicle and the design of the roadway. However, by all accounts, heavy truck traffic results in pavement damage significantly greater than passenger vehicles¹⁸. The Congressional Budget Report (2011) of “Spending and Funding for Highways” estimated that the pavement damage by trucks ranged from 5 to 55 cents per mile depending on the weight of the truck, vehicle configuration (axles) and location where it operates. In general, past studies of highway impact assessment are broadly classified into highway cost allocation (HCA) and pavement damage costs (PDC). Highway cost allocation study compares revenues collected from various highway users to the expenses incurred by them. The principle behind the study was to assess the equity of existing highway user tax structure and identify if changes in the structure are needed. It typically covered a broad range of costs such as maintenance, repair, reconstruction, congestion, crash and environmental costs (FHWA 1982, 1997, 2000). In marked contrast, PDC considers only costs associated with pavement reconstruction, rehabilitation, and maintenance. The literature in this section tries to cover both aspects of pavement damage costs related to heavy trucks.

Highway Cost Allocation –

National Cooperative Highway Research Program (NCHRP) 378 discusses in detail the practice and mythologies being used in highway cost allocation studies. The two broad methods discussed were an incremental method (developed by Oregon in 1937) and federal

¹⁸ Shirley, Chad. "Spending and Funding for Highways." (2011).

method which had mixed approach to pavement rehabilitation. The federal method had been widely accepted because incremental method gave an undeserved benefit of economies of scale to heavier vehicles. The most significant improvement in federal method during 1990's was the application of National Pavement Cost Model (NAPCOM) which made the model practical to be used by states. However, some states have conducted their cost allocation studies. In all 32, states have performed at least 87 cost allocation studies since the first research was conducted¹⁹. A similar approach was adopted by Bruzelius (2004) which reviewed four alternative methods (econometric approach, direct approach, indirect approach and Club and Equity approach) to estimate marginal infrastructure costs. Another study conducted by Agbelie et al. (2016) investigates 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 cost and shared costs. The attributable cost was allocated to the vehicle classes, equivalent single axle loads, and equivalency factor and passenger car equivalent whereas average cost was assigned to the number of vehicle miles traveled adjusted to vehicle width. The results of the study found that out of 13 vehicle classes defined by FHWA, classes 1 to 4 (passenger cars) were overpaying and classes 5 to 13 (trucks) were underpaying their cost responsibility. In particular, vehicle class 2 (automobile) paid 10% more whereas vehicle class 9 (five-axle truck) underpaid by 19%.

¹⁹ <https://www.oregon.gov/das/OEA/Documents/2015report.pdf>, accessed on June 5th, 2016.

Pavement Damage Cost (PDC) –

Pavement damage cost studies are being further classified into empirical or 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 variables affecting pavements (age, surface type, a traffic condition and climate). The engineering approach is based on the derivation of the cost function with road-use variables and sometimes called as a bottom-up approach (Bossche et al. 2001). Studies covering both approaches are addressed in this section. To estimate the highway pavement damage cost attributed to truck traffic, Bai et al. (2010) conducted a study in southwest Kansas. The research focused on truck traffic associated with the meat industry and developed a systematic pavement damage estimation procedure which synthesized methodologies including 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 pavement deterioration model developed by HERS. In the end, the 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 industry. Based on the results, the highway damage cost was estimated to be \$1,727 per mile or \$0.02 per truck per mile.

A similar study was conducted by Saber et al. (2009) evaluated 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 trucks. The study used two type of vehicle (Type – 9 and 10) classified by Federal Highway Administration (FHWA) and three gross vehicle weight (80,000 lbs, 100,000 lbs, and 120,000 lbs) to form five scenarios. The net present worth for each scenario was then evaluated at 5%/year interest rate and for 20 years. Results of the study which included the fatigue cost of bridges concluded that \$100 per vehicle per year is not adequate to recover the costs imposed by these trucks and fees be increased to \$5,545/truck/year. The tradeoff between overweight truck fees and their relative efficiency have been studied to assess the damage cost and its recovery. Dey at al. (2014) conducted a study to estimate pavement and bridge costs caused by overweight trucks. The research focused on two types of fee structure; flat fee and axle based damage cost. The study found that when axle distribution is ignored in flat fee structure, trucks did not pay a fair share to the damage imparted by them. In marked contrast, weight-based fee structure varied from 2 to 14 cents per ton-mile. The comparative analysis in the study thus provides an insight of damage recovery fee types for setting up of the overweight trucking costs.

To investigate the correlations between heavy truck weight and its infrastructure damage cost, Timm et al. (2007) conducted a study which developed a framework that combined the Mechanistic-Empirical Pavement Design Guide (MEPDG) and life cycle cost analysis to determine the 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 volume ranging from 250 to 8,000 trucks/day. The results of the study showed that small change in weight distribution resulted in significant impact on pavement damage and its cost (1.5 to 2 times). It also revealed that cost increased

when the volume of permitted axle exceeded 10 percent of the total legal loaded shaft. A similar study conducted by Gibby et al (1990) evaluated the impact of trucks on pavement maintenance costs. The analysis of the data involved two types of models, linear and multiplicative. The results of these model development process suggested that linear models offered negative coefficients and were a poor fit. On the contrary multiplicative models provided good fits. Using the multiplicative model, the study tried to evaluate various factors influencing the pavement maintenance cost. The results concluded that the heavy truck traffic causes approximately 90 times more maintenance cost compared to the passenger car. The 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.

2.3.4 Safety

The economic cost of motor vehicle crashes was estimated to be \$242 billion in 2010. The cost included lost productivity, medical expenses, legal and court costs, emergency service costs (EMS), insurance administration cost, congestion costs, property damage and workplace losses²⁰. Crashes involving large truck are further considered to be more harmful than the other crashes because of its size and weight. On average, every year more than 4,000 people are killed and nearly 100,000 injured involving large truck crashes²¹.

The first attempt to quantify the cost of trucks and buses was made by Miller et al. (1991) which computed the value based on threat-to-life severity. The crash severity scale was based on the medical classification of injury developed by physicians and ranged from

²⁰ <https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812013>, accessed on January 18th, 2016.

²¹ <http://saferoads.org/wp-content/uploads/2015/07/2015-02-06-Large-Truck-Fact-Sheet.pdf>, accessed on May 20th, 2016.

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 injuries by body region did not vary with vehicle type. Later on, 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 differentiations among the vehicle type were more clearly defined.

A similar study was conducted by Zaloshnja et al. (2003) focused on crash cost for large trucks and its type. The study used data from 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 found to be inconsistent with different states using them (Miller et 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 major crash cost categories. The results of the study estimated average cost to be \$59,153 (in 2000 dollars) per crash for trucks weighing more than 10,000 pounds and it increased to \$88,483 (in 2000 dollars) per crash for truck-tractors with two or three trailers. Based on these results it was estimated that average annual cost of large-truck involved in crashes during 1997-1999 exceeded \$19.6 billion. Out of which \$6.6 billion accounted for productivity losses, \$3.4 billion in resource costs and \$ 9.6 billion in the quality of life losses.

To study the public concern about the magnitude of large truck crashes, Lyman et al. (2003) conducted a study which evaluated large truck crashes versus the risk per unit of travel over 25 years (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 collected from US Census Bureau (2001) and estimated of vehicle miles traveled, licensed drivers and large truck registration were collected from FHWA. The results showed 12% increase in death rate for passenger vehicle occupants involving a large truck. Whereas when occupant fatalities were compared to 100 million truck miles traveled, occupant death rate reduced by 49% (4.52 in 1975 to 2.3 in 1999). This was because of stricter requirements including a safety inspection, commercial driver licensing and increase in use of seat belts.

Crash cost is considered as the external cost from a societal perspective. Forkenbrock (1999) conducted a study which focused on these external costs (accident, emission, noise, operation, and maintenance) for truck freight transportation. The analysis of the research showed that the external costs accounted for 13.2% of private costs and to internalize the cost, user fees should be increased threefold. The crash cost was estimated to be approximately \$25 and \$15 million per 100 million for passenger car and large truck respectively. Even though the cost per 100 million vehicle miles traveled was less for a large truck, the fatal accident rate was one-third greater than a passenger car.

A similar study was conducted by Hagemann et al. (2013) which focused on the crash related cost of commercial vehicles due to delay and property damage. The delay cost included additional travel time, fuel consumption and emission resulting from the accident caused traffic queues. Property damage cost was based on Insurance Services Office (ISO) data that described insurance claims from commercial vehicles. Depending on the results, 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 crash

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 cost accounted for \$12,996, emission accounted \$302, and fuel consumption accounted for \$675 per crash. Adding these cost would represent true crash cost per incident and may have a significant impact on overall cost estimation.

2.4 Shortcomings of the Existing Research

The research work discussed above provides a comprehensive literature review of the current and existing research in the area of freight policies directly impacting the public. The first section of the literature review discusses the overview of policy directions and lacks the local accountability of truck traffic. The studies show that the implementation of 'operational' and 'increase in truck size and weight' policies has been ineffective and suggests alternatives such as rail for improved productivity (Spasovic et al. 2009, Holguin-Veras et al. 2008, Giuliano et al. 2005, "Comprehensive Truck Size and Weight Limits Study," April 2016, Kawamura et al. 2016).

The next section of the literature deals with the freight demand models which could be used by public agencies to evaluate policies for modal shift from road to rail to alleviate the externalities. Although the literature presents the additional complexity of multimodal assignment problem, it lacks the truck freight demand and its effects on other modes. The studies provide efficient algorithms to solve the network assignment problem and shows how the solution algorithms can be applied to various fields. The current work applies the principle to conduct freight demand network assignment by considering the congestion effects on the truck and in turn its impact on other modes.

The last section of the literature review discusses the estimation of various externalities associated with a change in truck demand. The literature suggests that potential policy interventions by the federal government can influence the externalities leading to increasing motor fuel taxes, charging user fees, and imposing greenhouse gas pricing, re-regulating freight rail rates and investing in freight rail corridors²². However, to support these actions, the actual cost of trucks regarding congestion, pavement damage, emission cost and safety costs needs to be evaluated.

The above summary of the literature review gives a brief overview of the relevant research work conducted in quantifying the impact of the truck from different perspectives. However, to quantify the actual impact, a comprehensive approach is needed. The research conducted in this study tries to address this problem by developing a framework which includes major externalities associated with trucks.

²² <http://www.nrel.gov/docs/fy13osti/55636.pdf>, accessed on March 12th, 2016.

CHAPTER 3

METHODOLOGY

The chapter focuses on developing a policy framework using freight demand models for analyzing the impact of trucks on a regional network with policy implications. Transportation policies and strategies can significantly influence the demand and supply within the region and freight demand models can act as a tool for evaluating and regulating supply chain system. Section 3.1 of methodology presents an overview of policies and its interaction with the demand and supply, and Section 3.2 discusses the framework development.

3.1 Methodology Overview

Transportation policies address imbalances between the demand and the supply of the existing infrastructure to mitigate the challenges faced by the industry. However, to better understand how a policy that is impacting a region can be evaluated one needs to understand the linkages between transportation demand and transportation supply. Figure 3.1 below shows the controlling factors on each demand and supply side.

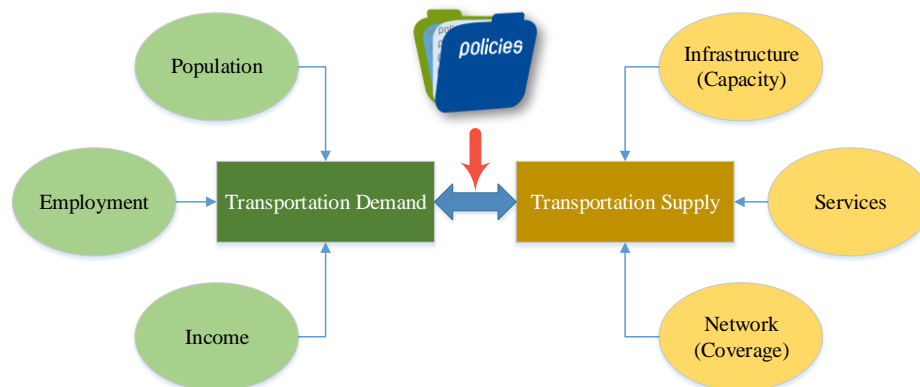


Figure 3.1 The relationship between demand, supply and its controlling factors.

The interaction between the demand and supply is interdependent, and there is a direct relationship between the controlling factors and the transportation demand/supply. For example, as the population in the region increases, there is more need of goods, which are being consumed. In the same way, if the employment rate is higher in the region, more people will tend to travel, demanding more roadways to commute to work. Higher income will lead to a higher number of trips leading to more demand. On the supply, the higher the capacity, the better the supply system. Similarly, greater the volume (services) that can be transported per unit of time, the healthier the system is. Denser the network, the greater are opportunities to choose a route.

To incorporate the demand and supply of the transportation for a particular region, regional transportation models are developed. These models are a fundamental yet vital set of functions, which are capable of providing a systematic analytical platform to evaluate alternatives in a controlled environment. Traditionally, "four-step" travel demand-modeling uses a set of procedures used by planners to predict the trips made within the region²³. The first step 'trip generation' involves analysis of population and socioeconomic parameters (auto ownership, household income, etc.) to estimate trip production and attraction. The second step predicts trip interchanges for the first step within the region. Modal split, the third step projects the division of trips between the available modes and the last step is traffic assignment in which modal trips are assigned to actual paths. The research in this study focuses on the formulation and solution of traffic assignment and its interaction with mode choice. The following section discusses these in detail. The

²³ https://www.fhwa.dot.gov/planning/tmip/publications/other_reports/snapshot_travel_modeling/ch01.cfm, accessed on June 5th, 2016.

assignment problem identifies minimum impedance between each origin and destination and loads the trips to the network by utilizing the minimum impedance path. The volume of trip interchange is accumulated on each link that belongs to individual paths and is added until the entire trip table has been loaded.

The change in transportation policy can thus influence the demand and supply of transportation network and significantly influence the traveler behavior in selecting the path resulting change in traffic volume on the links. The loaded volumes on the network, therefore, can help to evaluate the transportation costs and income because of a policy scenario.

3.2 Conceptual Development of the Framework

The framework uses transportation policy as an input and the relationship between the demand and supply on a transportation network is modeled by developing three freight demand models. The proposed models are then used to simulate the movement of freight to estimate the network flows that reflect a policy change. The cost-benefit analysis, which is based on economic theory, is further used to calculate the benefits as the direct cost saving to quantify the impact of the policy. The impacts can be quantified regarding user cost benefits, environmental and safety benefits by comparing the policy results to the baseline case that represents a status quo.

The framework shown in Figure 3.2 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 change. Each step of the framework is explained in detail in the following sections.

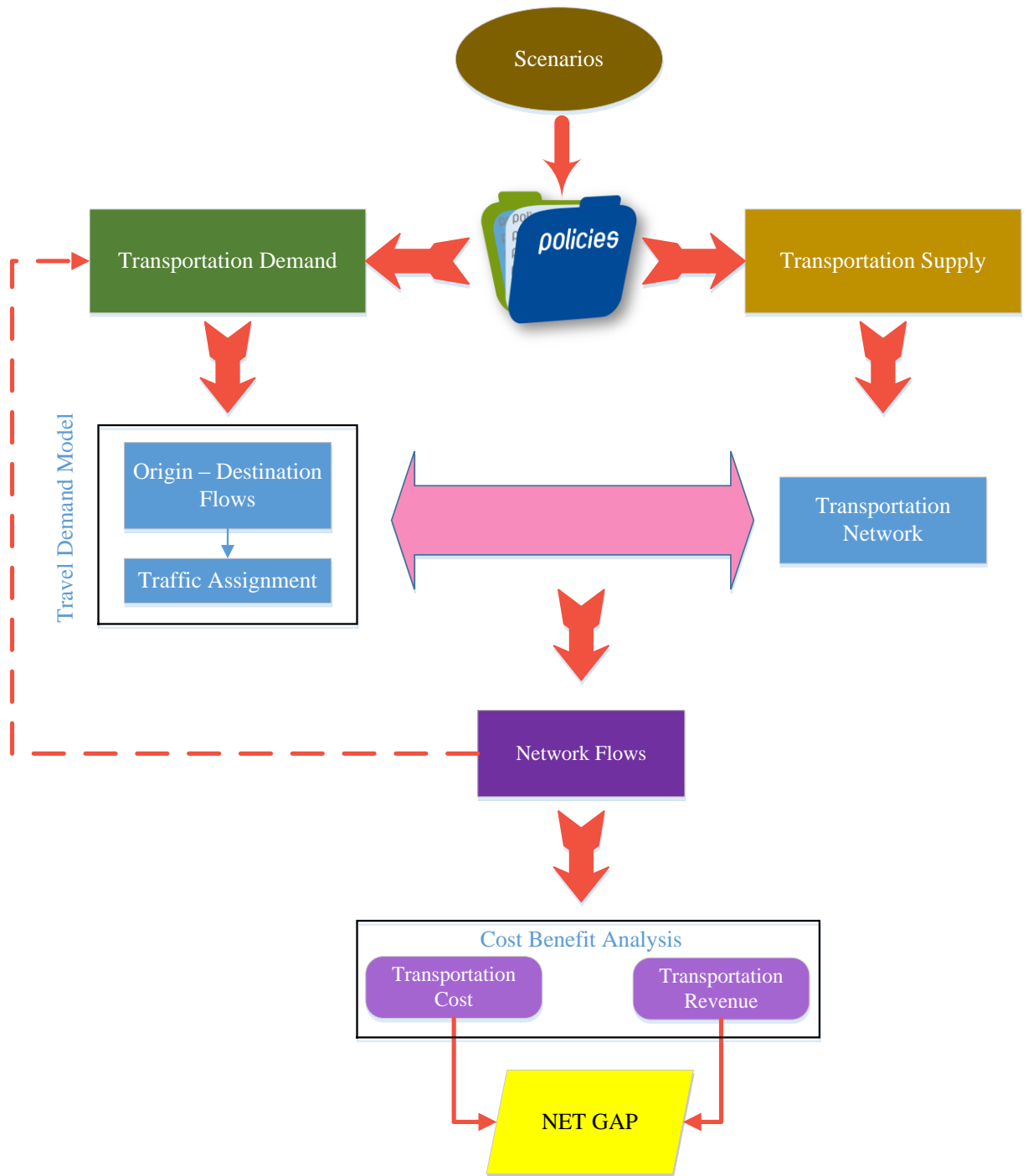


Figure 3.2 Policy framework.

Note: All the cost savings are added on an annual basis and are calculated based on the vehicle miles traveled and vehicle hour travel outputs.

3.2.1 Freight Demand Models

Three freight demand models have been discussed in the methodology, which builds on the interaction of congestion and travel decisions that result in the flow of vehicles in the network (Sheffi 1985). The approach relies on modeling the interaction between congestion and travel decisions to reach an equilibrium. The methods used to determine the equilibrium flows and travel times are based on nonlinear optimization techniques. Details of network equilibrium can be found in [Appendix A](#). The first model is based on assignment in which freight gets allocated to lowest cost path. The shipper's preference via-a-vis a mode is not taken into account. The second model is a logit model, and in this model, the customer preferences for truck and rail are taken into consideration based on mode's service and price. The third model is a variable demand model in which the amount of freight varies as a function of travel time on the least cost path. An increase in travel cost on least cost path reduces (kills) the demand by a marginal amount.

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

O, D = Represents origin and destination within the network. These are not mutually exclusive as they can be utilized for different trips at the same time

ij = Represents a pair between the origin and destination

a, p = Represents link and path in the network respectively

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

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

δ_{ap} = Represents a binary parameter which equals 1 if link (a) is part the path (p), otherwise 0.

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

c^*_p = Represents least cost of traveling on path p

c_a = Represents unit (average) generalized cost of travel on arc a

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

$c_a = c_a(f_a)$ this represents monotonically increasing the function of flow on the link (arc) as shown in Figure 3.3

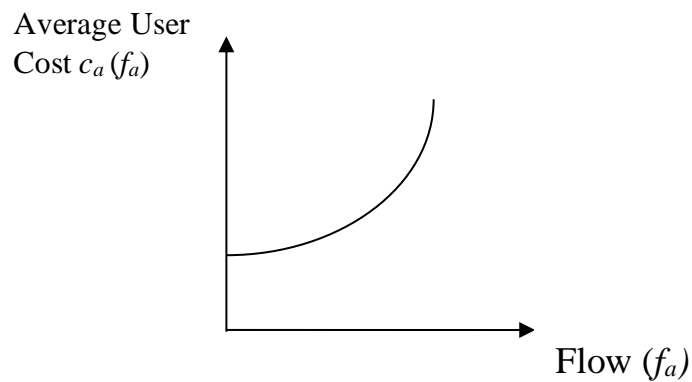


Figure 3.3 Average cost link performance function concerning flow.

Definition of Work Flow Pattern: For each origin (O) – destination (D) pair, at user equilibrium, the cost of all used paths is equal, and (also) less than or equal to the cost of any unused path. The definition, therefore, suggests that at equilibrium, the paths connecting origin-destination pair can be divided into groups: paths, which carry the flow, and paths that do not carry the flow. The mathematical representation can be as shown as below:

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

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

Where:

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

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

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

Conceptual Formulation of the Model: The theoretical formulation of the model is based on equivalent minimization method and involves the formulation of the mathematical program, the solution to which is the user equilibrium flow pattern. The concept is applied to allocate trips to paths up to a point when no further improvements in average travel cost are possible for traveler even if it were to switch paths for given set of conditions:

- The flow on each link is a sum of the flows on all paths that contain the link (or are going through the link)
- The number of trips originating from an origin and going to a destination is equal to the sum of the flows of all paths that connect that particular origin and destination
- The model allocated trips across the modes (or best modal paths)
- All links and path flow must be positive

Assumptions: The route choice models discussed are based on the following assumptions

- User equilibrium model assumes that motorist know all link travel times with certainty whereas stochastic user equilibrium models are based on the assumption that each motorist may perceive a different travel time and act accordingly

- At equilibrium, no traveler/trip can improve its average travel cost by unilaterally switching paths
- There are no artificial limits imposed on the link flow, but the flow is governed by a link flow-capacity functions

Model 1 – Assignment Model

The model uses standard user equilibrium network assignment, which is based on choice modeling approach to determine the freight being assigned on the network. This method provides motorists with a selection of the path from origin to destination with an assumption that every motorist will try to minimize his/her travel cost. The trips are assigned to alternative paths by assigning probabilities. The probabilities, in this case, represent the likelihood of moving from one node to another by using a particular link. The advantage of using such behavioral model is that multiple paths are considered at the time of trip assignment and trips are assigned based on minimized cost. The travel cost changes as the flow of link changes and at equilibrium condition, the travel cost on all used paths connecting origin (O) – destination (D) pair will be less than or equal to the unused paths. The travel cost on a particular path (p) is, therefore, a sum of the travel time on the links comprising this path (p). Similarly, the link flow can be expressed as a function of the path flow, which means that the flow on each link (arc) is the sum of the flows on all paths going through the link (arc). The mathematical formulation of the user equilibrium model along with the constraints is represented in [Appendix A](#).

Solution Algorithm: The solution of the user equilibrium program in this model is based on heuristic equilibration techniques of incremental assignment. The method involves the determination of minimum path cost as a major component of the algorithmic solution. A

portion of the origin-destination matrix is loaded at each iteration. To account the behavioral route choice, the algorithm uses stochastic network loading mechanism to determine the distribution of travelers using each path. The distribution is computed using the probability of selecting each alternative route, and the flow is assigned accordingly. The advantage of using this network loading technique is its sensitivity to small changes in the network. The travel times are then updated and the generalized cost, which is 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 the same process is repeated. Following are the steps used in solution algorithm.

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

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

Step 2: 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 3: Flow summation for n^{th} iteration is the sum of flows from previous iteration plus the flow from the current iteration. Set $f_a^n = f_a^{n-1} + u_a^n, \forall a$.

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 improved version of model one discussed earlier. It includes the behavioral interpretation in which customer preference is accounted for the mode choice in addition to the route choice behavior. The fundamental notion is that traveler is

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 in which the network includes both truck and rail mode. In other words, the solution includes the flow pattern over the roadway network as well as rail for each origin-destination pair. The problem is referred as combined modal split/traffic assignment problem. Some of the assumption made in this case are as follows:

- 1) The selected origin-destination pair in the network are connected by rail mode as well as roadway network
- 2) The level of service offered by rail is independent of the roadway network
- 3) The capacity of rail is large enough so that congestion effects on rail do not occur

At equilibrium condition, the travel time on both modes (road, rail) should be equal if both modes are being used. In other words, the rail link is considered in the same fashion as other links in the network. Assuming the origin-destinations are connected by rail, the mathematical formulation of the user equilibrium model, in this case, is represented in [Appendix A](#).

Solution Algorithm: The solution of the user equilibrium program in this model tries to achieve the user equilibrium condition between the two modes in addition to the equilibrium over the basic network. In another word, the travel times on both modes (rail vs. truck) be equal if both modes are being used. If only one mode is being used, the travel time on it should be lower than the travel time on the unused mode. The steps used can be summarized as below:

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

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

Step 2: Logit Model. Calculate probability (p_m) for origin (O) and destination (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 four.

Step 3: Calculate trips (T_{ij}^m) for a mode (m) for origin (O) destination (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 $f_a^n = f_a^{n-1} + u_a^n, \forall a$.

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 path, it would decrease marginally if the travel time increases. In most cases, the demand function would be the same for all origin-destination, however, might 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 less than travel times on unused path. Also, it satisfies the demand function concerning O-D trips. The mathematical expression in [Appendix A](#) represents the user equilibrium equations.

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 $f_a^0 = 0, \forall a$. Where (N) is the total number of iterations set.

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

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 a 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 $f_a^n = f_a^{n-1} + u_a^n, \forall a$.

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.

3.2.2 Network Flows

The demand models discussed above demonstrates powerful mathematical programming in modeling transportation network problems and are based on the principle of the decision-making process in selecting mode/route between origin and destination. 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. The technique helps in analyzing the change

in traffic flow patterns within the network. The traffic flow on the network is further used to compute the vehicle miles traveled (VMT) and vehicle hour travel (VHT). This 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 a key metric in transportation planning and being used in policy decisions for infrastructure investments²⁴. Some of the advantages of using these performance measures are as follows:

- VMT can act as a primary indicator of traffic flow for policy makers and transportation professionals and has widely been accepted by agencies²⁵.
- The measures can be used to influence policy in many ways. For example, by providing more attractive alternative mode can help reduce the VMT.
- VMT bears the direct relationship to some other parameters including congestion, emission, and safety.
- VHT demonstrates the extra time spent, and the relates to the economic impact on drivers and businesses based on the lost productive time, wasted fuel and maintenance cost due to extra time spent²⁶.

These performance measures have been used for both personal and commercial vehicle travel demand and can be used as a resource to quantify the impacts within the region. The measures act as input to the cost-benefit analysis discussed in the following section.

3.2.3 Cost Benefit Analysis

The cost-benefit analysis in the framework is based on the method, in which the analyst calculates the benefits as direct cost savings or in another words reduced transportation costs. The changes can, therefore, be quantified in monetary terms and used to evaluate the

²⁴ <http://www.dot.ca.gov/hq/tpp/sb743.html>, accessed on April 8th, 2016.

²⁵ https://www.fhwa.dot.gov/policyinformation/travel_monitoring/tvt.cfm, accessed on April 15th, 2016.

²⁶ <https://psrc.github.io/trends/2015/10/14/delay/>, accessed on May 20th, 2016.

cost-effectiveness of the system. The VMT and VHT are used to determine the various user costs and agency costs, including travel time, fuel consumption, vehicle emission, 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:

3.2.4.1 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 vehicle hour travel by the value of travel time for autos and trucks. The vehicle hour travel was calculated from the network flows of demand model and the value of travel time cost was calculated based on the guidelines of the USDOT. The steps below show the progress of calculation:

Step 1: Determine the monetary 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 hour travel for passenger cars and trucks

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

$$TTC = \sum_m TTC_m = TTC_{Auto} + TTC_{Truck} \quad (3.1)$$

Where

m = mode of travel (Auto and Truck)

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

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

Notation:

TTC = Total travel time cost (\$)

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

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

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

O = Vehicle occupancy rate (persons/vehicle)

3.2.4.2 Fuel Consumption Cost. Fuel consumption is a function of vehicle flow parameters which is derived from the model, 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 to determine the cost of consumption. The steps below show the progress of the calculation

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

Step 2: Determine the percentage of vehicles by vehicle class

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

Step 4: Fuel consumption cost can be calculated using all the above data and the equation below:

$$FCC = \sum_m FCC_m = FCC_{Auto} + FCC_{Truck} \quad (3.2)$$

Where

m = mode of travel (Auto and Truck)

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

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

Notation:

FCC = Total fuel consumption cost (\$)

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

$FCR_{Auto}^{Speed}, FCR_{TruckGasoline}^{Speed}, FCR_{TruckDiesel}^{Speed}$ = Fuel consumption rate for autos, truck gasoline and truck diesel concerning speed bands (gallon/vehicle-mile)

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

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

$VMT_{Auto}^{Speed}, VMT_{Truck}^{Speed}$ = Vehicle miles traveled by autos and trucks concerning speed bands (miles).

3.2.4.3 Emission Cost. Vehicles emit pollutant materials throughout their lifecycle and are broadly classified into primary and secondary pollutants²⁷. 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 oxides (NOx) are being considered in this research. These pollutants are necessary to be

²⁷ Center for Disease Control and Prevention Agency

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 the model fleet

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

Step 4: Emission cost can be calculated using all the above data and the equation below:

$$EC = \sum_m EC_m = EC_{Auto} + EC_{Truck} \quad (3.3)$$

Where

m = mode of travel (Auto and Truck)

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

Where

$${}^{Auto}EC_{CO} = \sum_{i=1}^s \{ (VMT_{Auto}^{Speed})_i * [(P_{AG} * (ER_{COG}^{Speed})_i) + (P_{AD} * (ER_{COD}^{Speed})_i)] * MC_{CO} \}$$

$${}^{Auto}EC_{HC} = \sum_{i=1}^s \{ (VMT_{Auto}^{Speed})_i * [(P_{AG} * (ER_{HCG}^{Speed})_i) + (P_{AD} * (ER_{HCD}^{Speed})_i)] * MC_{HC} \}$$

$${}^{Auto}EC_{NO_x} = \sum_{i=1}^s \{ (VMT_{Auto}^{Speed})_i * [(P_{AG} * (ER_{NO_xG}^{Speed})_i) + (P_{AD} * (ER_{NO_xD}^{Speed})_i)] * MC_{NO_x} \} \text{ And}$$

$$EC_{Truck} = Truck EC_{CO} + Truck EC_{HC} + Truck EC_{NO_x}$$

Where

$$Truck EC_{CO} = \sum_{i=1}^s \{ (VMT_{Truck}^{Speed})_i * [(P_{TG} * (ER_{COG}^{Speed})_i) + (P_{TD} * (ER_{COD}^{Speed})_i)] * MC_{CO} \}$$

$$Truck EC_{HC} = \sum_{i=1}^s \{ (VMT_{Auto}^{Speed})_i * [(P_{TG} * (ER_{HCG}^{Speed})_i) + (P_{TD} * (ER_{HCD}^{Speed})_i)] * MC_{HC} \}$$

$$Truck EC_{NO_x} = \sum_{i=1}^s \{ (VMT_{Auto}^{Speed})_i * [(P_{TG} * (ER_{NO_xG}^{Speed})_i) + (P_{TD} * (ER_{NO_xD}^{Speed})_i)] * MC_{NO_x} \}$$

The summation above stands for summation over the number of speed bins.

Notation:

s = number of speed bins

EC = Total emission cost (\$)

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

$Auto EC_{CO}, Auto EC_{HC}, Auto EC_{NO_x}$ = Emission cost of autos for carbon monoxide, hydrocarbon

and

nitrogen oxide respectively (\$)

$Truck EC_{CO}, Truck EC_{HC}, Truck EC_{NO_x}$ = Emission cost of trucks for carbon monoxide, hydrocarbon

and nitrogen oxide respectively (\$)

$VMT_{Auto}^{Speed}, VMT_{Truck}^{Speed}$ = Vehicle miles traveled by autos and trucks with respect to speed bins

(miles).

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

$ER_{COG}^{Speed}, ER_{HCG}^{Speed}, ER_{NOxG}^{Speed}$ = Emission rate of carbon monoxide, hydrocarbon, and nitrogen oxide respectively for vehicles using gasoline with respect to speed band (grams/mile)

$ER_{COD}^{Speed}, ER_{HCD}^{Speed}, ER_{NOxD}^{Speed}$ = Emission rate of carbon monoxide, hydrocarbon, and nitrogen oxide respectively for vehicles using diesel with respect to speed (grams/mile)

$MC_{CO}, MC_{HC}, MC_{NOx}$ = Mitigation cost of carbon monoxide (CO), hydrocarbons (HC), and nitrogen dioxide (NOx) respectively (\$/gram)

3.2.4.4 Pavement Cost. Pavement damage depends on some factors including the weight of the vehicle, axle configuration and the design of the roadway. However, a study conducted by the U.S. General Accounting Office (GAO) determined that the road damage caused by truck be over thousand times higher than that of the car^{28,29}. To access the highway cost incurred by vehicle class, Federal Highway Administration conducted a cost allocation study.³⁰ The study allocated cost per mile for pavement reconstruction, rehabilitation and resurfacing based on different vehicle classes contributing to pavement distress that necessitate the improvements. An estimate of the pavement improvement cost is calculated using the study, and the following steps are used:

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

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

$$PC = \sum_m PC_m = PC_{Auto} + PC_{Truck} \quad (3.4)$$

²⁸ <http://archive.gao.gov/f0302/109884.pdf>, accessed on June 20th, 2016.

²⁹ <https://truecostblog.com/2009/06/02/the-hidden-trucking-industry-subsidy/>, accessed on May 18th, 2016.

³⁰ <https://www.fhwa.dot.gov/policy/hcas/final/>, accessed on September 5th, 2016.

Where

m = mode of travel (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 respectively (\$)

VMT_{Auto}, VMT_{Truck} = Vehicle miles traveled by autos and trucks respectively (miles).

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

3.2.4.5 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 the dissertation. 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 incident

Step 2: Determine the recommended monetized value for crashes

Step 3: Calculate the total cost of accident from the equation below:

$$SC = \sum_m SC_m = SC_{Auto} + SC_{Truck} \quad (3.5)$$

Where

m = mode of travel (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 traveled by autos and trucks respectively (miles).

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

UC_F, UC_I, UC_P = Unit cost of fatal, injury and property damage incidents respectively

(\$/incident)

3.2.4.6 Toll Revenue. Tolls are a valuable source of revenue to both, building the roads and maintain existing roads. The expected benefits range from reduced congestion to predictable trip times and lower taxes to pay for the road itself. It involves the imposition of a per-use fee on motorists for a given highway facility. Depending on the tolling system in place, motorists either are charged a flat-rate toll or a ticket and the rates are determined

by the distance traveled or exits passed. Irrespective of the method used in tolling, the revenue can be calculated by cost between the interchange by mode (auto/trucks) and the volume traversing the interchange. The tolling system, in this case, is considered distance based and can be computed using following steps:

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

Step 2: Determine the volume traversing the segment

$$TR = \sum_m TR_m = TR_{Auto} + TR_{Truck} \quad (3.6)$$

Where

m = mode of travel (Auto and Truck)

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

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

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 (\$/mile)

VMT_{Auto}, VMT_{Truck} = Vehicle miles traveled by autos and trucks respectively (miles).

3.2.4 Policy Impact Analysis

The policy impact analysis can help decision-makers to quantify the effectiveness of the policy by comparing it to the present baseline case and measuring the changes as a result of it (Figure 3.4). The comparison of different policy measures can thus better assist to develop investment strategies including significant capital investments. Two approaches are adopted to compare the policies with baseline case. The first approach deals with the economic aspect of a policy by comparing the cost-benefit results of a policy to the baseline case. The second approach, on the contrary, tries to identify the change in vehicle miles traveled (VMT) and vehicle hour travel (VHT) on the roadway network as a result of the policy.

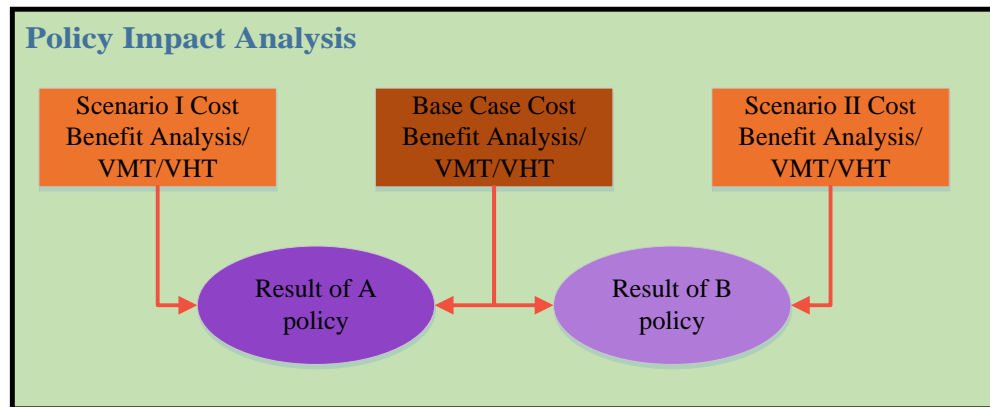


Figure 3.4 Comparing policy scenarios with baseline.

3.3 Summary

The developed framework in the methodology can, therefore, be used as a tool to quantify the impact of truck traffic with policy implications. It uses demand model to estimate user volumes on the transportation network that in turn can be used to quantify the social consequences of trucks. The framework can help highway designers with a change in hourly traffic volumes, deficiencies in the existing system and develop construction

priorities of future transportation systems as a result of policy changes. A recap of steps involved in the analysis are as follows -

- a) Based on the origin and destination matrices perform the traffic assignment - Baseline Case
- b) The model output provides an estimate of volume on transportation network which serves as input to the developed framework
- c) Calculate the cost savings by using the VMT and VHT
- d) Repeat above steps from 'a' to 'c' to calculate the cost of the new scenario
- e) Compare the results with Baseline Case to evaluate the impact of the new scenario

By using the process mentioned above, the framework is not only able to calculate the changes regarding cost-benefits but also able to recognize where and how much impact it has on the network.

CHAPTER 4

CASE STUDY

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

4.1 Geographic Location and Regional Influence

The geographic location of the case study includes the thirteen counties of New Jersey and its surrounding areas of southern New Jersey, eastern Pennsylvania, southern New York and Connecticut region. The region consist of Port Newark and Port Elizabeth, which sit side by side within the cities of Newark and Elizabeth east of the New Jersey Turnpike. According to 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 maritime ports, the region serves as "land bridge" to move containers via west coast through the rail. These intermodal rail yards serve as the local distribution nodes accommodating trans-continental shipping of containers and other commodity flows.

Since the port is a significant generator of trucks, the case study focuses on the trucks going in and out of the port area. The major trucking corridors connecting these ports include New Jersey Turnpike, Interstate 287, Interstate 78, Interstate 80, Interstate

295 and Route 17³¹. These corridors in some cases serve as a primary truck corridor for an entire length of roadway within the state. Based on the zonal information available from North Jersey Transportation Planning Authority (NJTPA), ports lie within four zones (Numbered 1693, 1694, 444, 445) and three special trip generators nodes (Numbered 570, 571, 1800) as shown in Figure 4.1. The case study covers 2553 zones (pink) including 1590 zones (green) under NJTPA region and a roadway network connecting these zones.

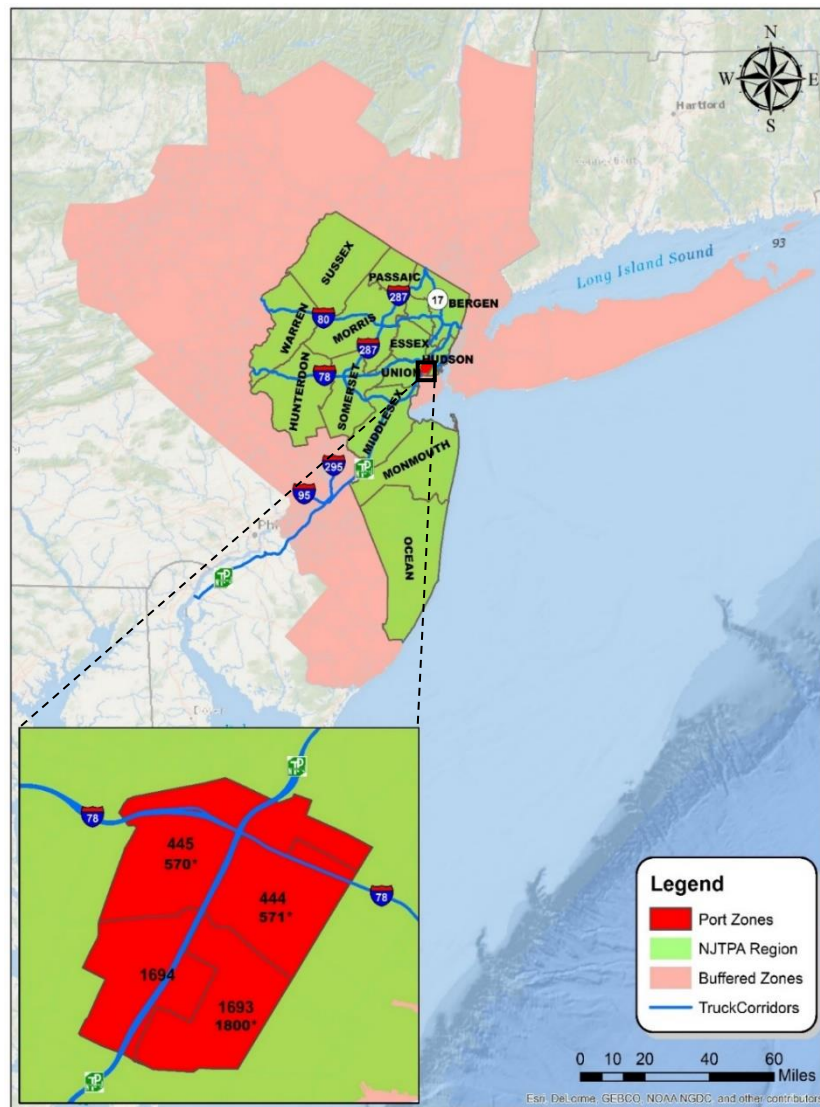


Figure 4.1 Blown up look at the port Newark and Elizabeth zones.

³¹ The New Jersey Comprehensive Statewide Freight Plan – September 2007

Even though the NJTPA region is covered by local buffers around them, there were still some truck trips that were generated outside the buffered region. These trips are represented by external zones (Figure 4.2) and act as entry points (or gateways) into the region. These external zones serve as background volumes coming from outside the area in addition to the volumes considered within the area. The detail explanation of truck trips generated from the external regions can be further found in [Appendix B](#).

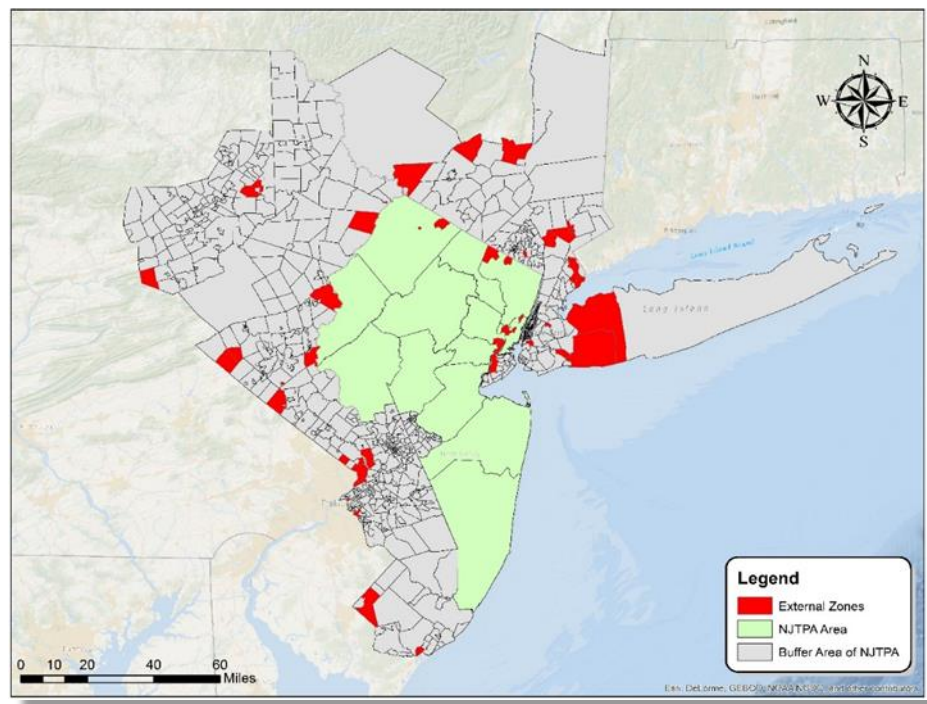


Figure 4.2 External zones surrounding NJTPA area.

Selected Corridor

Among the major trucking corridor within the region, Interstate 78 and 80 provides a critical link in freight movement especially I-78 which is considered as an essential link for the freight movement to/from port facilities in Newark. 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 state of Pennsylvania border to New York City crossing five major counties (Warren, Hunterdon, Somerset, Union, and Essex). Over the period, the corridor has emerged as the dominant competitor to Interstate 95. The cluster of low-cost warehouse and distribution centers and lack of tolls along with lower traffic volumes make I-78 corridor attractive. In addition to serving as a significant conduit for freight flows, the eastern corridor also serves the densely populated New York metropolitan market and the city via Holland tunnel, mainly east of Interstate 278. The interstate can therefore significantly influence not only freight flows but also affect the surrounding communities. The corridor thus serves as a perfect example to quantify the change in truck traffic on a regional network because of policy change.

4.2 Policies and Scenarios

The framework discussed in Chapter 3 of the dissertation enables planners and policy makers to test alternative policies and can provide a decision maker with comparative costs and benefits of alternative policies. Two policies, which are being tested in the case study are as follows –

- 1) Tolls on I-78
- 2) Dedicated Truck Lane on I-78

Tolls on I-78

Ideally, the state agencies are free to impose tolls on roads, bridges, and tunnels that have been built and maintain without federal funds but limit the imposition of tolls on existing federal-aid highways especially Interstate Highways. However, the Congressional Budget Office (CBO) projects that after FY2020 the gap between surface transportation revenues

and spending will average \$20 billion annually³². The search for additional revenue to fill this gap is generating renewed interest in expanding toll financing. A recent report published by Congressional Research Service (August 2016) discusses tolling on highways. The report discusses the possibility of authorizing the states to toll federal-aid highways as they see fit, or even allowing portions of an interstate to be converted to toll roads.

It is expected that policy such as this would change in truck traffic 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 the changes in truck traffic and to answer some of the "what if" scenarios. For example, will the toll roads have sufficient traffic willing to pay a toll? How does the availability of competing non-tolled routes allow the motorist to evade tolls? Which travelers are expected to be affected most? Will the generated revenue be enough to counter its expenditures?

With the recent federal policy encouraging the use of tolling to attract investment and generate revenue, tolls are expected to be implemented on non-tolled interstates shortly. It is, therefore, essential to investigate the impact of the change in truck demand on the highway system as a result of this policy change.

³² Congressional Budget Office, Projections of Highway Trust Fund Accounts Under CBO's March 2016 Baseline (<https://www.cbo.gov/sites/default/files/51300-2016-03-HighwayTrustFund.pdf>, accessed on May 20th, 2017). 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.

Dedicated Truck Lane on I-78

Another interesting policy considered in the case study is of the dedicated truck lane. The increased freight movement on U.S highways especially on interstates where large trucks constitute a significant portion of traffic has resulted in transportation planners debating the efficacy of separating truck traffic. The primary issue with dedicated truck lane policy is the cost and financing them and can vary significantly depending on the right-of-way availability, topography and a host of other factors. However, the underline argument of the dedicated truck lane is that it gives an opportunity to significantly improve the effectiveness of the freight mode giving them an opportunity to pilot the size and weight increases. It also helps to reduce congestion, improve safety, and can offset the maintenance cost of general-purpose lanes. Moreover, moving truck traffic on the separate lane can improve the comfort and convenience of those traveling in passenger vehicles.

As a result, state agencies are actively looking at dedicated truck lane policy and its implications. For example, Georgia DOT recently proposed dedicated truck lane along I-75 corridor near Atlanta³³. It is expected that policy such as dedicated truck lane can thus affect the truck traffic within the region. Estimating the potential benefits compared to its cost can not only help decision-makers to make an informed decision but also address some key questions. For example, can there be saving regarding improved travel time, safety, congestion, and reduced emission? If not, should the trucks be charged with a toll on these lanes to recover the cost? The proposed framework in the case study can thus be used to answer some of these questions.

³³ <http://www.dot.ga.gov/BuildSmart/Projects/Documents/MMIP/Projects/I-75%20Commercial%20Vehicle%20Lanes.pdf>, accessed on August 8th, 2017.

Description of Scenarios

Four scenarios are being discussed in this section of the case study based on the two policies and three demand models used in the framework. The baseline scenario reflects the existing condition (as is) with any changes. Table 4.1 below shows a brief description of each scenario followed by its detail description. The scenarios considered in each case is based on the current traffic condition available for the year 2015.

Table 4.1 Description of Scenarios

Scenarios	Year 2015
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
III	Variable demand , Tolls on I-78 , No alternate mode (Rail) available
IV	Fixed demand , No tolls on I-78 , No alternate mode (Rail) , and Dedicated Truck Lane on I-78 available

Baseline Scenario: The scenario is based on the existing North Jersey Transportation Planning Authority (NJTPA) model data. It represents more than 6.5 million origin-destination pairs for each time-period (AM, MD, PM, NT) by vehicle type (SOV, HOV, Truck) and purpose of trip (home-based work, home-based shopping, home-based other and non-home based). The existing transportation network consists of 57,171 links covering 2553 zones within the study area. The baseline scenario, therefore, assumes that currently no tolls are applied on Interstate 78, and no dedicated truck lane is available.

Scenario I: In this scenario, the tolls are being introduced in both direction throughout Interstate 78, and the travel demand is assumed to be fixed similar to the base case. The

sensitivity of toll by time-of-day (TOD) is not considered now but can be modeled. Additionally, 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. The freight in this scenario is therefore expected to get allocated to the lowest cost path within the network.

Scenario II: This scenario considers an alternative mode of transportation is being available (rail) in addition to the tolls mentioned in Scenario I. The process is further complicated by allowing freight users to choose a mode of transportation in addition to route choice. The scenario assumes that based on the price bundle of travel time and rate of moving freight, the shippers will choose either mode (rail vs. truck) before the trips are being assigned on the roadway network. The mode choice for freight, therefore, is based on the probability of trucks or rail being chosen. The demand in this scenario is assumed to be fixed, and the capacity of the rail is presumed to be sufficient to handle the additional diversion of the truck to rail.

Scenario III: The fixed demand assumption in earlier two scenarios is relaxed in this case, and no alternative mode (rail) of transportation is available for the shipper. However, the tolls on I-78 in both direction similar to Scenario I is still considered. The scenario thus allows the change in demand (α) to reflect the increased travel cost (Δ) on the least cost path. This interaction between the demand and supply in an equilibrium condition can help assess the effect of toll policy change on the transport system. The scenario thus not only considers the allocation of freight to the lowest cost path within the network but also captures the characteristics of change in mobility.

Scenario IV: The scenario is similar to Scenario I except for no tolls on I-78. Instead, a dedicated truck lane is added to I-78 providing additional capacity along the corridor. The demand in the scenario is assumed to be fixed, and no alternative mode (rail) is available. The change in truck traffic because of policy change can, therefore, be captured in the scenario as a result of the better supply system.

4.3 Application of Policy Scenarios in Cube Environment

The scenarios discussed in the above section are simulated within the Citilabs Cube/Voyager environment by using the real world data available from NJTPA. The programs used to develop these scenarios included network, matrix and highway program in a cube environment. The advantage of using these programs is that it provides the flexibility and grants control language referred as a scripting language to modify the process if needed. It further allows the user to provide instructions for performing planning operations.

The details of each scenario along with its flowchart and step being adopted can be found in this section. Each scenario includes a feedback loop with an iterative process for accurate representation of the level of congestion.

Baseline Scenario: The baseline scenario uses three inputs for highway assignment process as shown in Figure 4.3. First, it includes the network, which consists of series of links and nodes and contains data on the characteristics of the roadway. Second is the trip table which represents the demand between origin and destination by trips purpose (HBW, HBS, HBO, and NHB) and trip type (Auto and Trucks). The third input is turned prohibitions which are used to add time to specific turning movements (left turning) or to

prohibit them altogether. All these three inputs in baseline scenario represented the real world data for the selected region of the case study and assumed to represent existing condition.

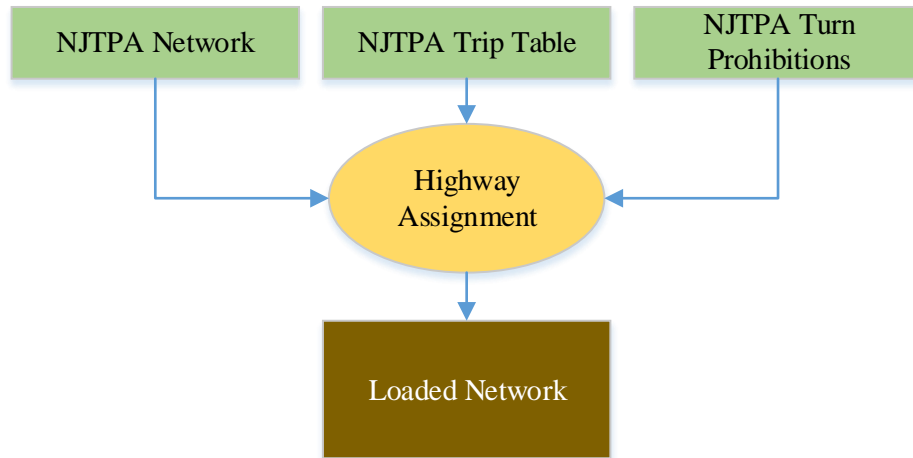


Figure 4.3 Flowchart of assignment process for baseline scenario.

Scenario I: The scenario modifies the baseline scenario to incorporate toll route choice in highway assignment process. It uses a binary logit model to distribute the trips between the tolled route and non-toll route for given origin-destination trips in each iteration of equilibrium assignment process. The model structure is applied for each trip purpose (HBW, HBS, HBO, NHB, and Trucks) and is based on the utility function that estimates the tradeoffs between the generalized costs and considers the traveler's characteristics. The logit equation used in the scenario as shown below:

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

Where

α = time coefficient (per min)

ΔT = time saving between toll road and non-toll road (in mins)
 β = cost coefficient (\$ per min)
 GC = generalized cost including the toll cost and operating cost (\$)
 c = toll bias constant
 etcbias = bias towards selecting toll routes using ETC payment

The relationship between α and β coefficient creates an implied value of time and varies with the trip purpose and vehicle type in the scenario. Figure 4.4 shows the flowchart of the scenario within the cube environment followed by the step-by-step process being adopted. [Appendix D](#) includes the developed script within cube voyager to apply logit based route choice model.

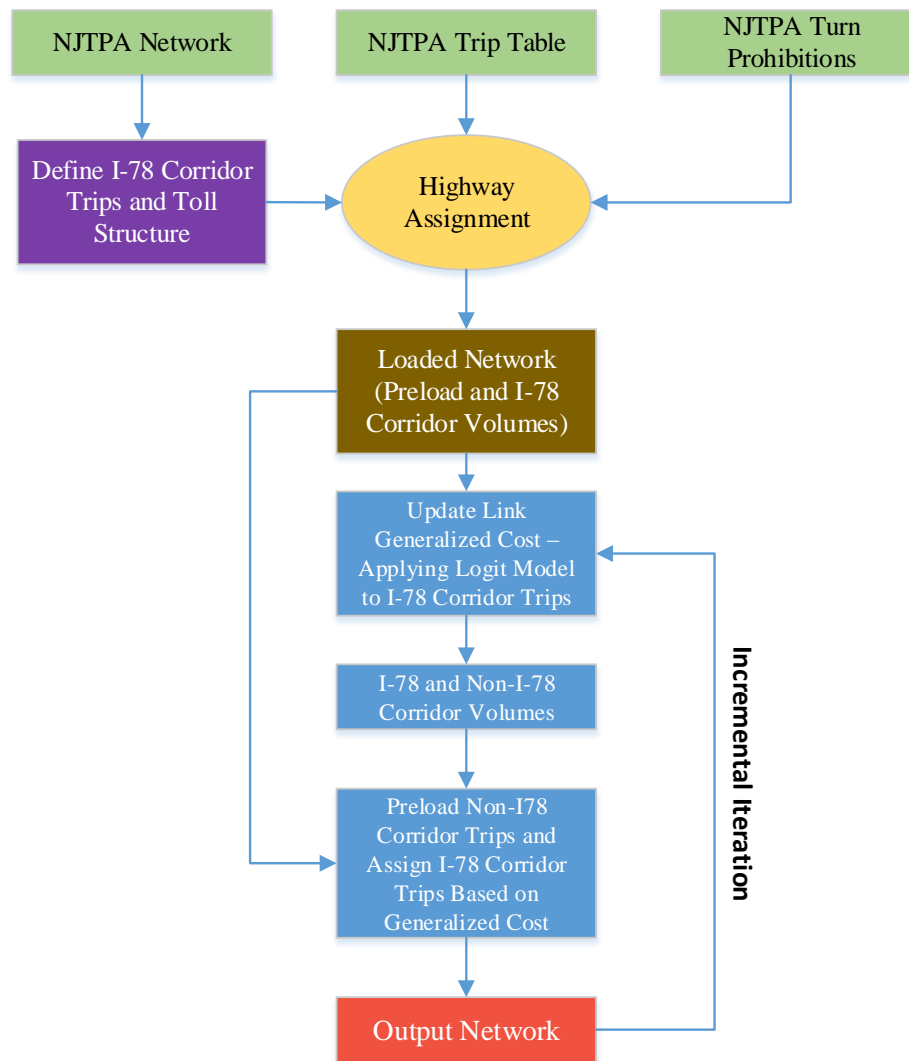


Figure 4.4 Flowchart of assignment process for scenario I.

The steps representing the flowchart are described as below:

- Define I-78 links within the network
- The next step defines the origin-destination pairs that would be potential I-78 users and may be affected by the scenario. This is done by skimming the network based on the minimum travel time (free flow) and by identifying if the O-D pair that includes I-78 links
- The following step determines the number of assigned volumes on each link are potential I-78 users. This is done by further skimming the trip tables by vehicle type and payment method for I-78 trips and Non-I-78 trips.
- In this step, the Non-I-78 trips are preloaded on the network since their path is not subject to change. Once this is done, the logit model is applied to potential I-78 trips, and the generalized cost is computed for both toll route and non-toll routes.
- The process is continued until equilibrium is achieved.

Scenario II: In addition to the complex behavioral route choice assignment, a mode split for freight movement is introduced in this scenario. Similar to traveler's behavior, freight choice of transport carrier can be couched in a utility function, and the decisions can be attributed by choosing a mode 'm' between origin and destination. The attributes depend on multiple factors including transport rate, travel time, reliability and flexibility of service. For our analysis purpose, transport rate and travel time are considered, and logit model is applied to perform a mode choice. The flowchart (Figure 4.6) shows the process being implemented in the cube. The selected pair of O-D's (Zones) representing the major freight supply nodes in Eastern Pennsylvania and Port of Elizabeth and Newark was considered in this scenario (Figure 4.5). These zones represented as external zones serve the Leigh Valley area in Pennsylvania which includes nearly 59 million square feet of industrial property and 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 in economic growth³⁴. A sample script developed for Scenario II for AM period is shown in [Appendix D](#).

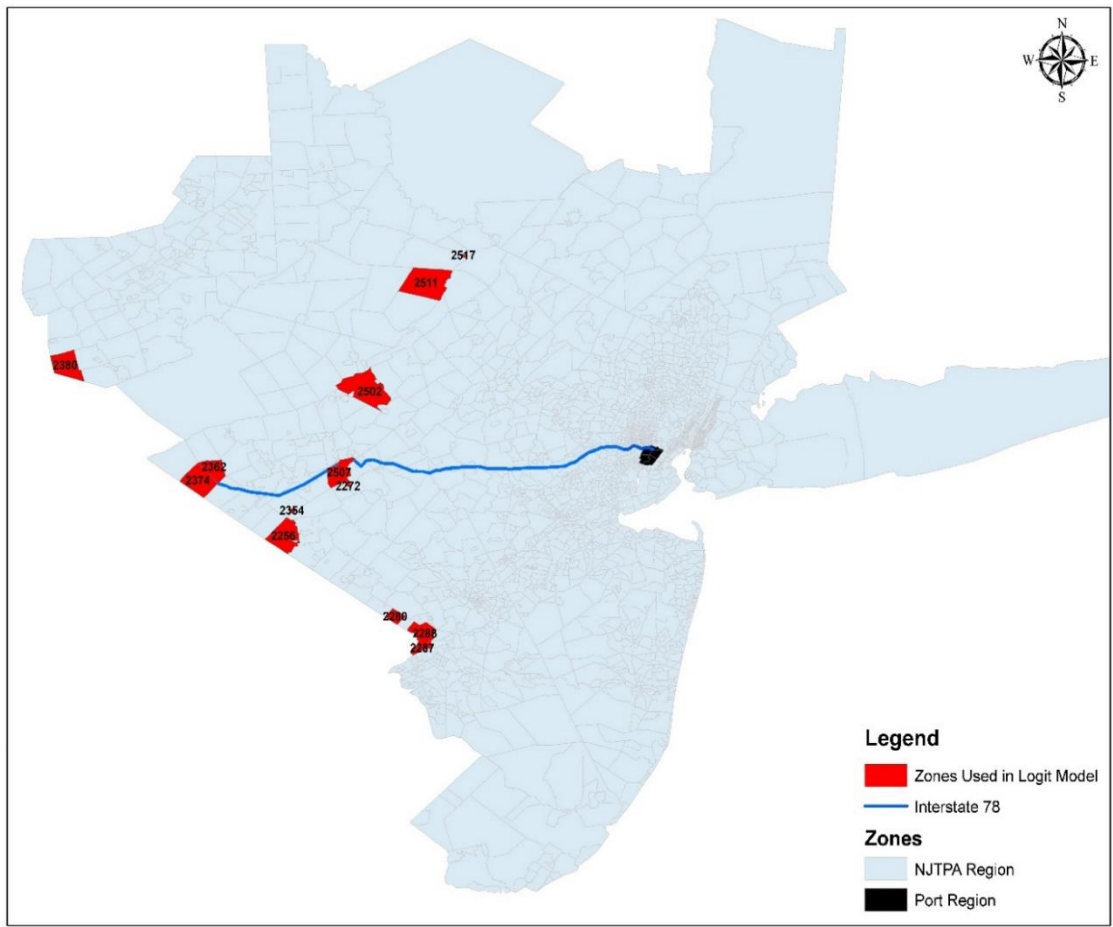


Figure 4.5 Selected zones in scenario II for mode split assignment process.

³⁴ <http://lehighvalley.org/pennsylvania-wins-national-recognition-with-help-from-the-lehigh-valley/>, accessed on June 20th, 2017.

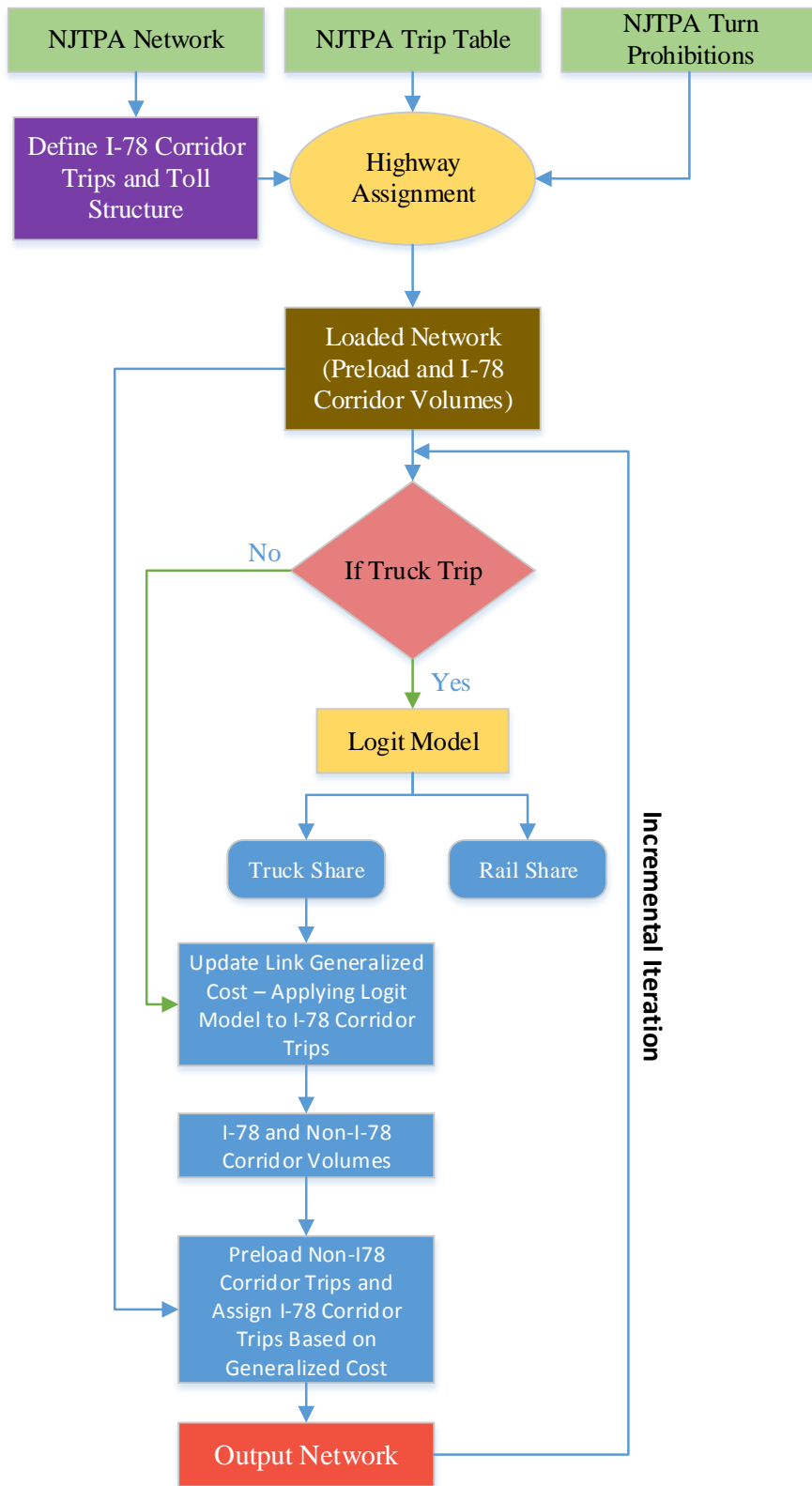


Figure 4.6 Flow chart of mode split assignment process for scenario II.

Scenario III: As discussed earlier the scenario represents variable (elastic) demand for freight movement in addition to the route choice assignment. This allows freight to change the destination or forego the trip altogether. For case study purpose, zones (red colored) shown in Figure 4.7 were selected and marginal change in demand for these origin-destination trips was allowed. These zones represent a number of truck terminals along with special trip generators within the region and include the long haul truck trips entering and existing the region. The flowchart in Figure 4.8 shows altered O-D trips used in assignment step, and [Appendix D](#) includes the script developed in the cube.

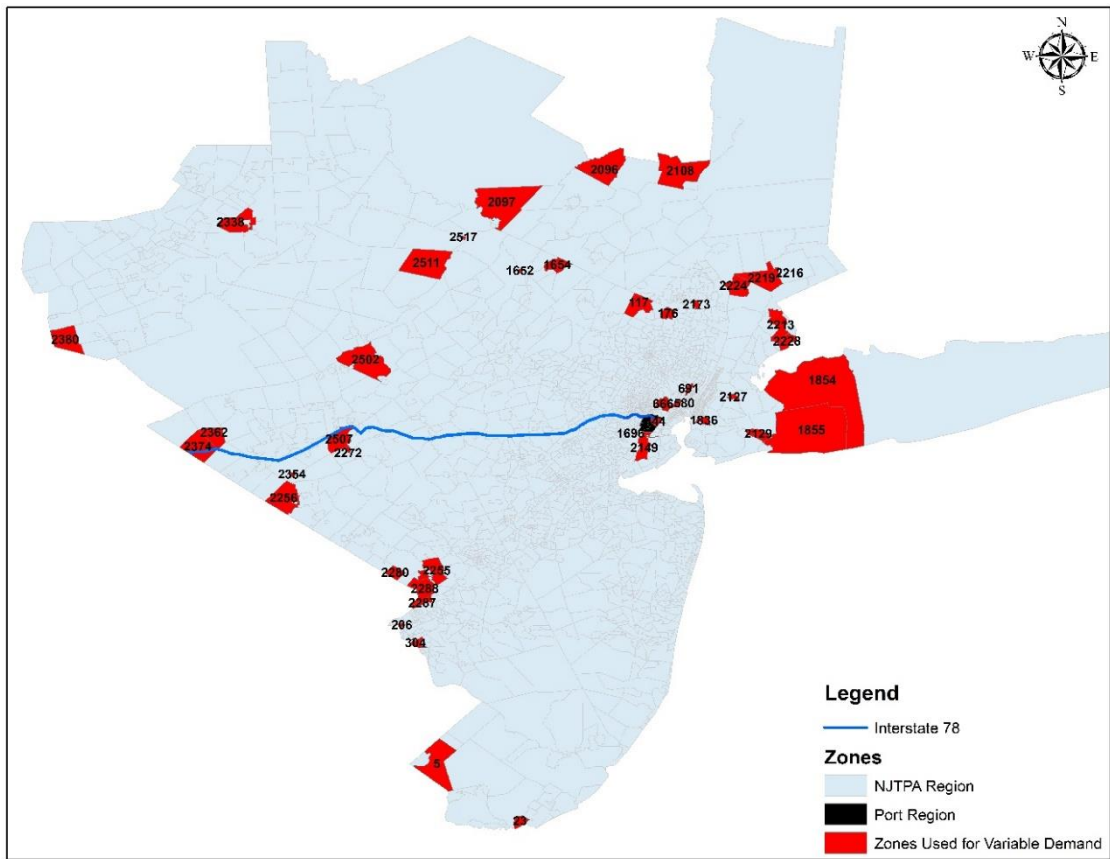


Figure 4.7 Selected zones in scenario III for variable demand.

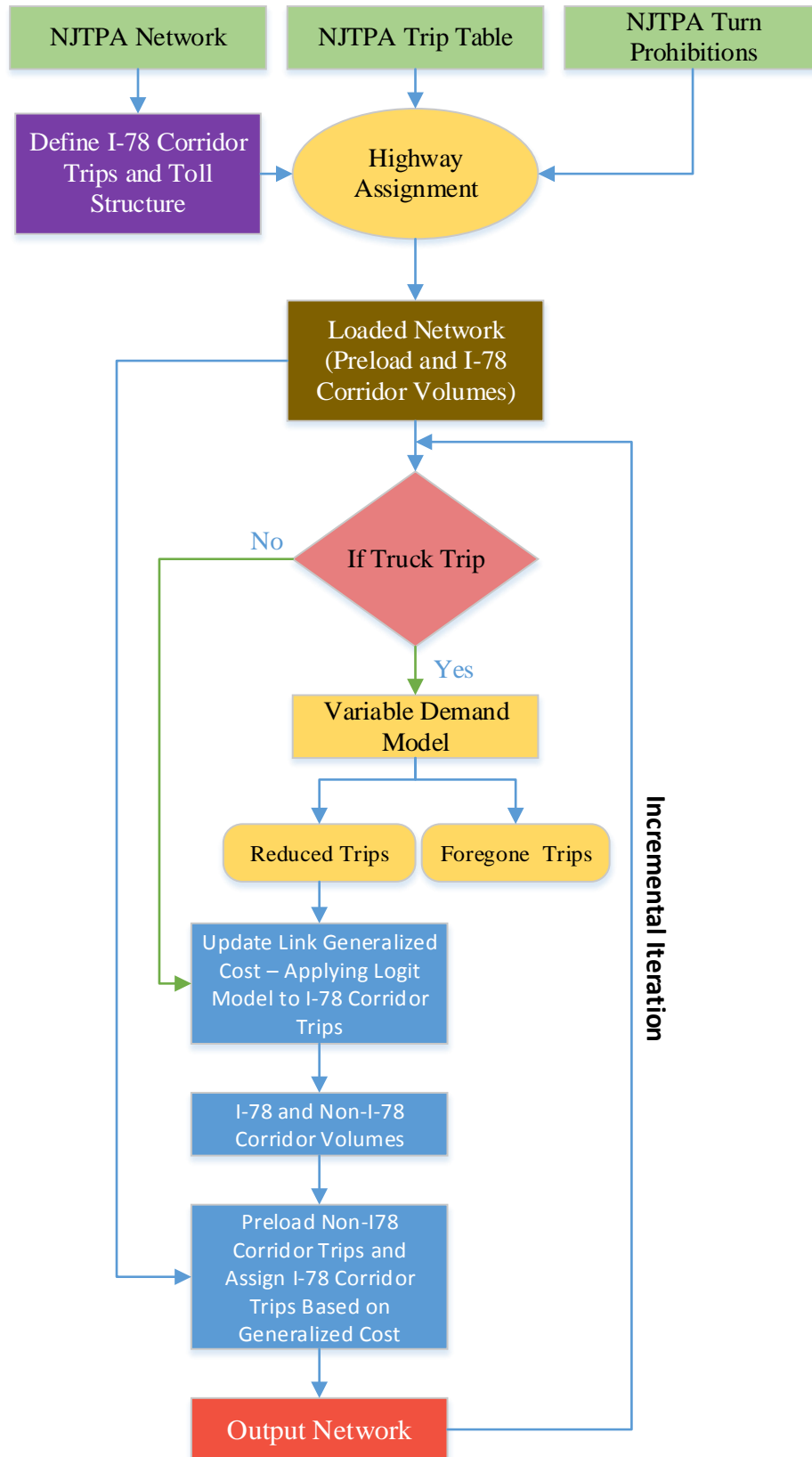


Figure 4.8 Flow chart of joint distribution/assignment process for scenario III.

Scenario IV: The scenario represents the additional capacity available on I-78 and ignores the tolls on the interstate. To develop the scenario the network program within the cube environment was used to build the dedicated truck lane on I-78. A series of links and nodes, with the links representing roadway segments and nodes representing their point of the intersection, were added. The newly added links representing dedicated truck lane were considered as one-way links in each direction and passenger cars were restricted to use these lanes. The operational and physical characteristics of the existing I-78 network were matched with the dedicated truck lane. The capacity and speed of the dedicated truck lane were computed based on the NJTPA guidelines and were based on the relationship between facility type and area type. Figure 4.9 below shows the flowchart in developing the scenario IV, and [Appendix D](#) includes the script used.

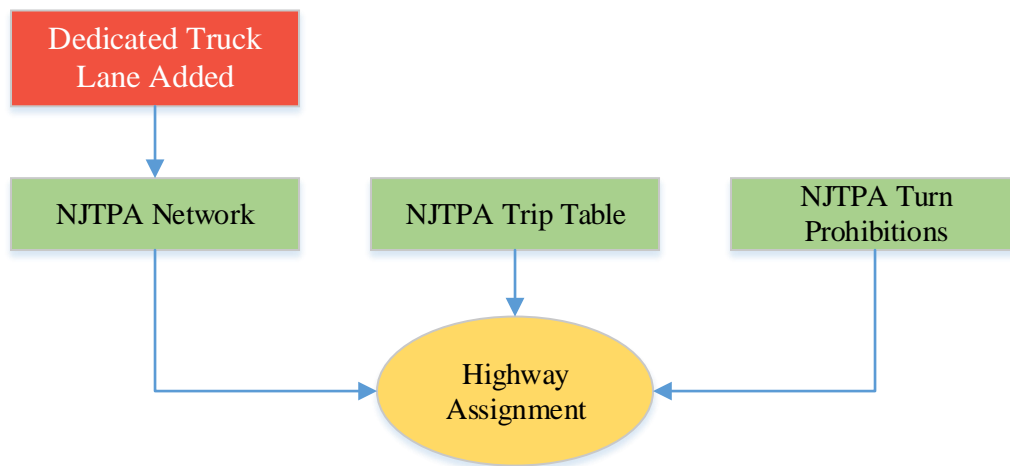


Figure 4.9 Flow chart of assignment process for scenario IV.

4.4 Model Parameters and Case Study Data

The section presents the parameters used in proposed models along with the data used for the cost-benefit analysis. Multiple sources have been used depending on the availability of the data. For model parameters, the physical characteristics of the roadway such as speed, capacity, and the number of lanes were based on the North Jersey Model Development Report³⁵. Similarly, the socioeconomic data and the estimates of freight volume designated for port area and a comprehensive highway network is obtained from the North Jersey Regional Transportation Model (NJRTM-E). The roadway network consists of 57,171 road links from 40 counties in the state of New Jersey, New York, Connecticut and Pennsylvania.

For the case study purpose, the toll values of 10 cents per mile for auto and 60 cents per mile for trucks were considered. Similarly, the operating cost of autos and trucks were assumed to be 10 cents per mile and 31 cents per mile respectively. These costs are based on the existing toll structure placed within the region (for example NJ Turnpike). The E-ZPass penetration rates were assumed to be 67% for autos and 87% for trucks based on the existing pattern observed at Delaware Water Gap Toll Bridge³⁶. The other parameters used in route choice model involves the coefficients for the value of time and cost, toll bias constants, etc bias constants. The table below shows the values used in the case study and provides a brief description of each one of them.

³⁵ <http://www.njtpa.org/getattachment/Data-Maps/Travel-Demand-Modeling/Model-Development-Report8G.pdf.aspx>, accessed on January 17th, 2017.

³⁶ http://www.drjtbc.org/wp-content/uploads/March_Minutes_2017.pdf, accessed on April 18th, 2017.

Table 4.2 Toll Diversion Model Parameters

	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)	-1.0	-1.0	-1.0	-1.0	-1.9
ETC Bias Constant (etc bias)	0	0	0	0	0

The relationship between α and β coefficients represents the value of time and is represented in $\$/hr = [\alpha / \beta] * 60$. The values of time are lower for auto trips compared to its counterpart trucks because of the higher sensitivity to goods movement and higher driver wages. The toll bias (c) accounts for the preconceived reluctance of travelers to use toll roads and the values considered in the case study were based on observed reluctance (I-295 vs I-95) Similarly, etc bias term implies towards selecting payment method at electronic toll collection. Due to lack of availability of data these values for the case study purpose were assumed to be zero. These biases can influence the route choice behavior and therefore needs careful consideration when applying. The developed framework can alter these values if sufficient data is available.

The model parameters used in logit model is based on the utility function (Section 3.2.2) of choosing a mode between rail and truck and explores the shipper's demand for alternative modes. The coefficients considered are -0.009 for transport rate, -0.007 for transit time and the constant term is given by -2.1. Each mode (truck and rail) are assumed to have same shipping rate (\$100) and transit time for rail is assumed to be 120 mins. The same shipping rates provides an opportunity to compare the modes with respect to time only. In this case, attribute of the shipment with respect to size of shipment and its perishability or fragility is ignored. Similarly, special considerations regarding

accessibility to a particular mode are not considered. However, if the sufficient data is available these can be considered in future research work. The negative coefficients suggest that all else constant, an increase in transport rates for given mode decreases shippers demand. Similarly, an increase in transit time also reduces shippers demand. The reference for these shipper mode choices can be found in McCarthy (2001) and Levin (1978).

For variable demand model, the parameters were assumed based on the generalized cost function verses demand for each time-period of the day (AM, MD, PM, NT) for the selected O-D pairs. Table 4.3 shows the alpha and beta coefficients considered in the model.

Table 4.3 Variable Demand Model Parameters

	AM	MD	PM	NT
Alpha	0.0036	0.0031	0.0031	0.0061
Beta	-0.7279	-0.5193	-0.6251	-0.9463

4.4.1 Cost-Benefit Analysis Data

The section represents the critical components of data used for cost-benefit analysis ([Section 3.2.4](#)) of the case study.

Travel Time Cost

The vehicle hour travel was calculated from the network flows of demand model and the value of travel time cost was calculated based on the guidelines of the USDOT.

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

The dollar value of the travel time cost per driver/passenger and cost of one hour of operating a truck are obtained from the Bureau of Labor Statics (BLS)³⁷ and the American Transportation Research Institute (ATRI)³⁸ report respectively.

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

The average vehicle occupancy can vary by county and roadway group; however, for the case study purpose, the occupancy rates were considered from New Jersey Congestion Management System (NJCMS) database which represents the area.³⁹

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

The annual vehicle hour travel is calculated network flows of demand model and the average value of travel time to travel the distance. For analysis purpose, the number of workdays per year is assumed to be 250.

Step 4: The travel time cost is therefore calculated using the Equation 3.1 in

[Section 3.2.4.1.](#)

Fuel Consumption Cost

As discussed in [Section 3.2.4.2](#) fuel consumption cost depends on some parameters. The steps below discuss each of these parameters and the associated data.

³⁷ State Occupational Employment and wage estimate (http://www.bls.gov/oes/current/oes_nj.htm#00-0000, accessed on June 5th, 2017).

³⁸ American Transportation Research Institute report in September 2014

³⁹ For peak time period = 2.59 and off peak = 2.50

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

The fuel consumption rate depends on two major components – vehicle type and the speed. Table C.1 in [Appendix C](#) shows the values obtained from the Intelligent Transportation System Deployment Analysis System (IDAS) manual which provides consumption rates for automobiles and trucks in 5 miles per hour (mph) increments (from 0 to 105).

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 C.2 in [Appendix C](#).

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)⁴⁰. Table C.3 in [Appendix C](#) shows the monthly average values of 2014 gasoline and diesel prices.

Step 4: Fuel consumption cost can, therefore, be calculated using Equation 3.2 in [Section 3.2.4.2](#)

Emission Cost

The primary pollutant such as carbon monoxide (CO) and secondary pollutants such as hydrocarbons (HC), nitrogen oxides (NO_x) are being considered in this research. These pollutants are necessary to be considered because they are directly related to fossil fuel

⁴⁰ 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, accessed on June 5th, 2017.

consumption, which is highly dependent on vehicle characteristics, travel speed and road characteristics.

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 and vehicle functional classification as shown in Table C.4, C.5 and C.6 in [Appendix C](#). The emission rate for each pollutant relies on the vehicle fuel type (gasoline/diesel).

Step 2: Determine the percentage of vehicle class

The percentage of each vehicle and fuel type for the region were considered based on NJCMS data and is summarized in Table C.2 in [Appendix C](#). The traffic count percentage shown in Table C.7 was re-categorized based on vehicle type (auto/truck) and fuel type (gas/diesel). It was assumed that LDGV, LDGT1, LDGT2, LDDV, LDDT, and MC are autos and HDGV and HDDV are trucks.

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

The cost of mitigation for contaminants varies from location to location and because of lack of data, the default values available from IDAS manual are considered. These values are shown in Table C.7 in [Appendix C](#).

Step 4: Emission cost can be calculated using all the above data and the Equation 3.3 in [Section 3.2.4.3](#)

Pavement Cost

As discussed in methodology, a major study conducted by Federal Highway Administration (FHWA) was considered to calculate the cost of pavement reconstruction, rehabilitation and resurfacing based on pavement distress caused by vehicle classes. The study focused on highway agency expenses incurred in the provision and preservation of the road infrastructure.

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

The cost responsibility for pavement improvements is based on per mile basis by vehicle class and weight range. Table C.8 in [Appendix C](#) shows the cost responsibilities which were used.

Step 2: Pavement cost is calculated using Equation 3.4 in [Section 3.2.4.4](#)

Safety Cost

The safety cost is calculated using the vehicle miles traveled, collision rates and monetized values of the crashes. The steps involved in calculating the cost are shown below with detail description.

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

The average crash rates per million vehicle miles traveled were used from IDAS manual which provides the rates base on volume/capacity (v/c) ratio, type of the vehicle

(auto/truck), facility type (freeway/arterial) and type of crash (fatal/injury/property). Tables C.9, C.10 and C.11 in [Appendix C](#) shows the values being used for the case study.

Step 2: Determine the recommended monetized value for crashes

Highway Safety Improvement Program (HSIP) manual which provides costs based on the KABCO scale were used in the case study calculation and are shown in Table C.12 of [Appendix C](#).

Step 3: Safety cost is calculated using Equation 3.5 in [Section 3.4.2.5](#)

Toll Revenue

The toll revenue in the case study is computed based on per mile basis.

Step 1: Determine the toll rates for the vehicle class (auto/trucks) per mile

The toll rates can vary by vehicle axle class (auto/trucks), peak/non-peak and by E-ZPass/cash. For analysis purpose, the toll cost per mile is considered and are based on the existing New Jersey Turnpike rates. The toll values are assumed to be 10 cents per mile for autos and 60 cents per mile for trucks.

Step 2: Determine the volume traversing on Interstate 78

The volume traversing on Interstate 78 can be obtained from the demand model and can thus be used to calculate the revenue based on the vehicle mile traveled and the per mile cost assumed.

4.5 Regional Impact of Policy Scenarios

As discussed in [Section 3.2.5](#) of Chapter 3, the regional impact of each policy scenario is measured by comparing it to Baseline Case. The two primary metrics used in the case study are – vehicle miles traveled (VMT) and vehicle hour travel (VHT) for assessing the network-wide impacts. These metrics play an integral role in analyzing each scenario and can be used to measure not only the change in travel but also the change over time. VMT is a leading measure used for both personal and commercial travel demand and thus are being used to evaluate the policy decisions. While VMT measures the change in traffic volume on links, VHT helps to gages the delays associated with increased congestion. The use of both the matrices makes them a robust analytical measure to be used within transportation planning to evaluate policy impacts. In addition to these matrices, the case study also includes the measure of cost savings, which is accrued across the modeled network on an annual basis (250 weekdays).

The matrices discussed above are used as tools to help transportation agencies to quantify the impact of scenario. It can further tailor the demand for service to the available capacity and can represent the real social cost of individual trips. For example, toll 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. The

additional revenue generated by the toll policy to balance the inequity concern can, therefore, support these projects within the affected communities. Similarly, analysis of dedicated truck lane policy in the case study can help agencies to evaluate not only change in demand on the corridor level but also assess the cost savings because of reduced emission and improved safety.

4.6 Summary

The chapter focuses on the application of the methodological framework to a real-world case to demonstrate the use of assignment problem based on the decision-making process in selecting mode and route choice. The results of the case study can, therefore, be used to analyze and evaluate the effects of policies and make a prediction of flow patterns and associated travel costs. The costs are estimated regarding congestion, pavement, environmental and safety and compared to the baseline to better understand the effects of policy change. The analysis can further be used to balance the inequity concerns raised by the introduction of a policy by identifying capital improvements for affected communities.

CHAPTER 5

RESULTS OF THE ANALYSIS

The results of the case study analysis focus on first verification of equilibrium condition by comparing the generalized cost for a sample pair of O-D's. The next section of the analysis concentrates on the change in vehicle miles traveled (VMT) and vehicle hour travel (VHT) for New Jersey counties. The change in VMT and VHT are compared to baseline scenario to identify the region being impacted as a result of policy change. The following section computes the costs and the revenue generated from scenarios.

5.1 Verification of Equilibrium

The proposed objective of the analysis is to evaluate the equilibrium solution and which in turn can be used for analyzing the future year traffic conditions. Table 5.1 shows an example of the solution, which satisfies the equilibrium condition for a pair of O-D's from two counties (Union, and Hunterdon) through which Interstate 78 passes. The generalized cost in Table 5.1 differs for autos and trucks because the operating cost and toll cost are different as discussed earlier. Based on the results it was observed that ten iterations were sufficient to attain an equilibrium for most O-D's pairs. The equilibrium thus suggests that no traveler can improve his/her travel cost by unilaterally changing the routes. The Table 5.2 for Scenario II compares the values of probability for road and rail networks between successive iterations and reaches equilibrium when the difference between them is minimum. So in this case equilibrium is attained when the probabilities between successive iteration has minim difference. This represents a special case because as the congestion on network increases the probability of choosing a truck mode reduces by marginal amount.

Since a small pair of O-D's has been selected as shown in Figure 4.5 for the Scenario II, ten iterations were assumed to be sufficient to reach the equilibrium.

Table 5.1 Example of Equilibrium for the O-D Pairs from Union and Hunterdon County (\$/person-hr) – Scenario I

Union						Hunterdon					
O-D Pair	Iteration	I-78 Auto GC	Non I-78 Auto GC	I-78 Truck GC	Non I-78 Truck GC	O-D Pair	Iteration	I-78 Auto GC	Non I-78 Auto GC	I-78 Truck GC	Non I-78 Truck GC
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 5.2 Example of Equilibrium Condition for the O-D Pair – Scenario II

O-D Pair	Iteration	Truck	Rail
2517 - 1800	1	0.9	0.1
	2	0.9	0.1
	3	0.89	0.11
	4	0.89	0.11
	5	0.9	0.1
	6	0.9	0.1
	7	0.89	0.11
	8	0.89	0.11
	9	0.89	0.11
	10	0.89	0.11
2507 - 571	1	0.92	0.08
	2	0.92	0.08
	3	0.92	0.08
	4	0.92	0.08
	5	0.92	0.08
	6	0.92	0.08
	7	0.91	0.09
	8	0.91	0.09
	9	0.9	0.1
	10	0.91	0.09

5.2 Change in VMT and VHT

The results of the change in VMT and VHT discussed in this section are divided into two groups – changes on the I-78 route and changes on other than I-78 (non I-78) routes. For analysis purpose, these groups are further represented based on the county level. The advantage of county-level analysis is that it can help identify the impacts on a local level by comparing it with baseline scenario and overall increase/decrease in VMT, VHT. The results represented are based on daily changes in VMT and VHT.

5.2.1 Analysis of Scenario I

Evaluation of policy Scenario I in the framework results in a significant impact on I-78 corridor. The Interstate 78 passes through five counties within the New Jersey namely Essex, Union, Somerset, Hunterdon, and Warren. The change in VMT on I-78 within these counties is being discussed below. Figure 5.1 shows the daily VMT's for both baseline scenario and scenario I concerning autos and trucks.

Several observations can be made from the Figure 5.1. First, it seems as the vehicle miles traveled on I-78 reduces significantly in counties such as Hunterdon, Somerset, and Warren suggesting that the alternate routes not being congested enough for travelers to choose I-78. However, as the congestion increases in densely populated eastern counties (Essex and Union), the drop in vehicle mile traveled on I-78 reduces, suggesting that travelers prefer I-78 over the alternate congested route and are willing to bear the additional cost of tolls on I-78. The table also suggests that trucks are more sensitive to Scenario I compared to autos. Another observation can be made that, the drop in truck VMT percentages (Figure 5.1) for Essex (-21%), Somerset (-29%) and Union (-19%) counties are less compared to auto VMT percentages. The results suggest that trucks are ready to bear the addition cost to avoid congestion compared to autos.

Because of these changes on I-78, the secondary roadway (non I-78 links) within the counties see increased VMT as shown in Figure 5.2. The increased VMT is mostly observed in the western part of New Jersey (example: Warren) and along the I-78 corridor. The results suggest that these counties would be affected most if the policy scenario I were to be implemented.

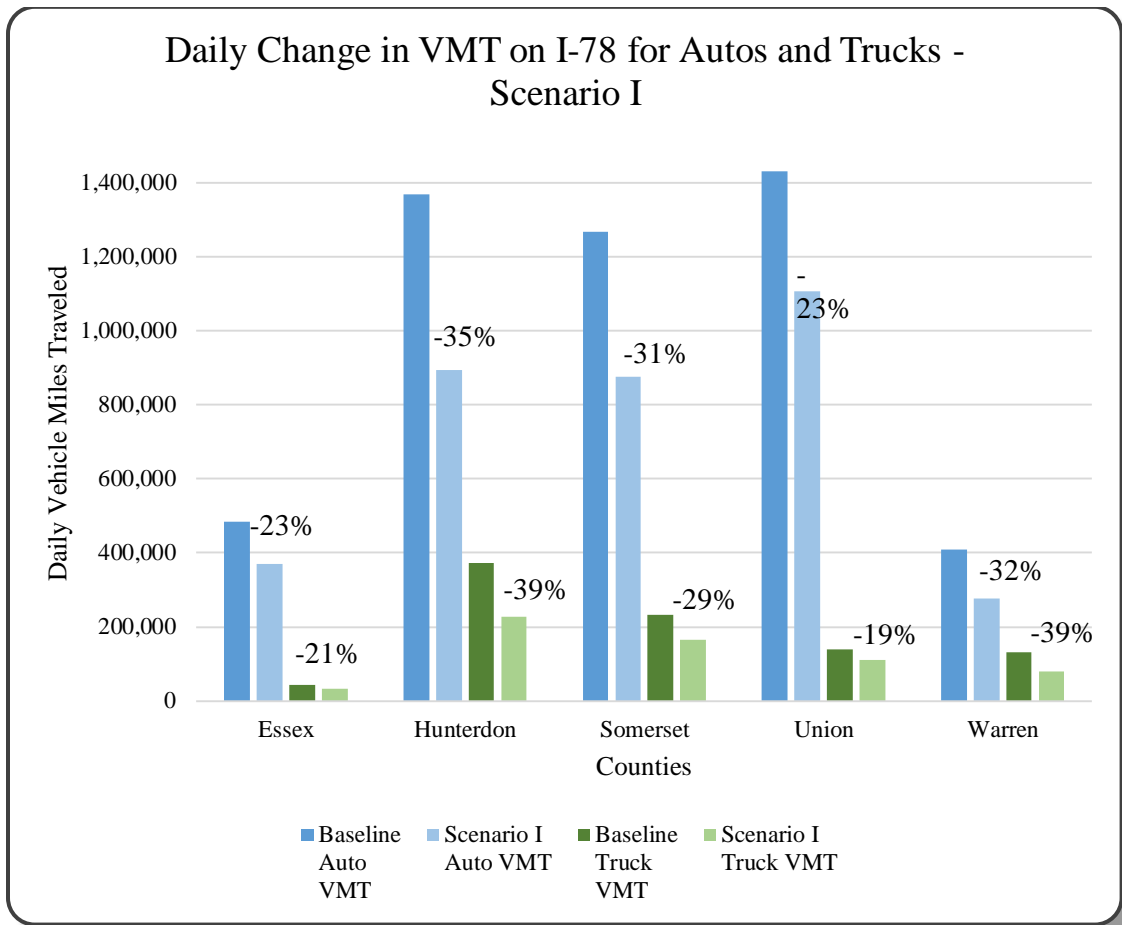


Figure 5.1 Daily VMT comparison on I-78 between baseline scenario and scenario I.

However, at the same time, it is interesting to note that the overall daily VMT reduces network-wide by 0.3% for autos and 1.8% for trucks⁴¹. The VHT, on the contrary, increased by a marginal amount of 0.6% for autos whereas truck VHT is reduced by 1.0%⁴². The overall impact of policy scenario I is still significantly less in terms of cost-benefit analysis discussed in the Section 5.3. This suggests that the overall impact of policy scenario I would still be better off than the existing condition when compared network-wide.

⁴¹ Refer Table 5.6 – $(35,719,200,680-35,831,963,125)/35,831,963,125 = -0.003$ (-0.3%) and $(2,370,156,704-2,414,817,925)/2,414,817,925 = -0.018$ (-1.8%)

⁴² Refer Table 5.6 – $(808,844,955-804,388,168)/804,388,168 = 0.006$ (0.6%) and $(44,700,582-45,136,283)/45,136,283 = -0.01$ (1.0%)

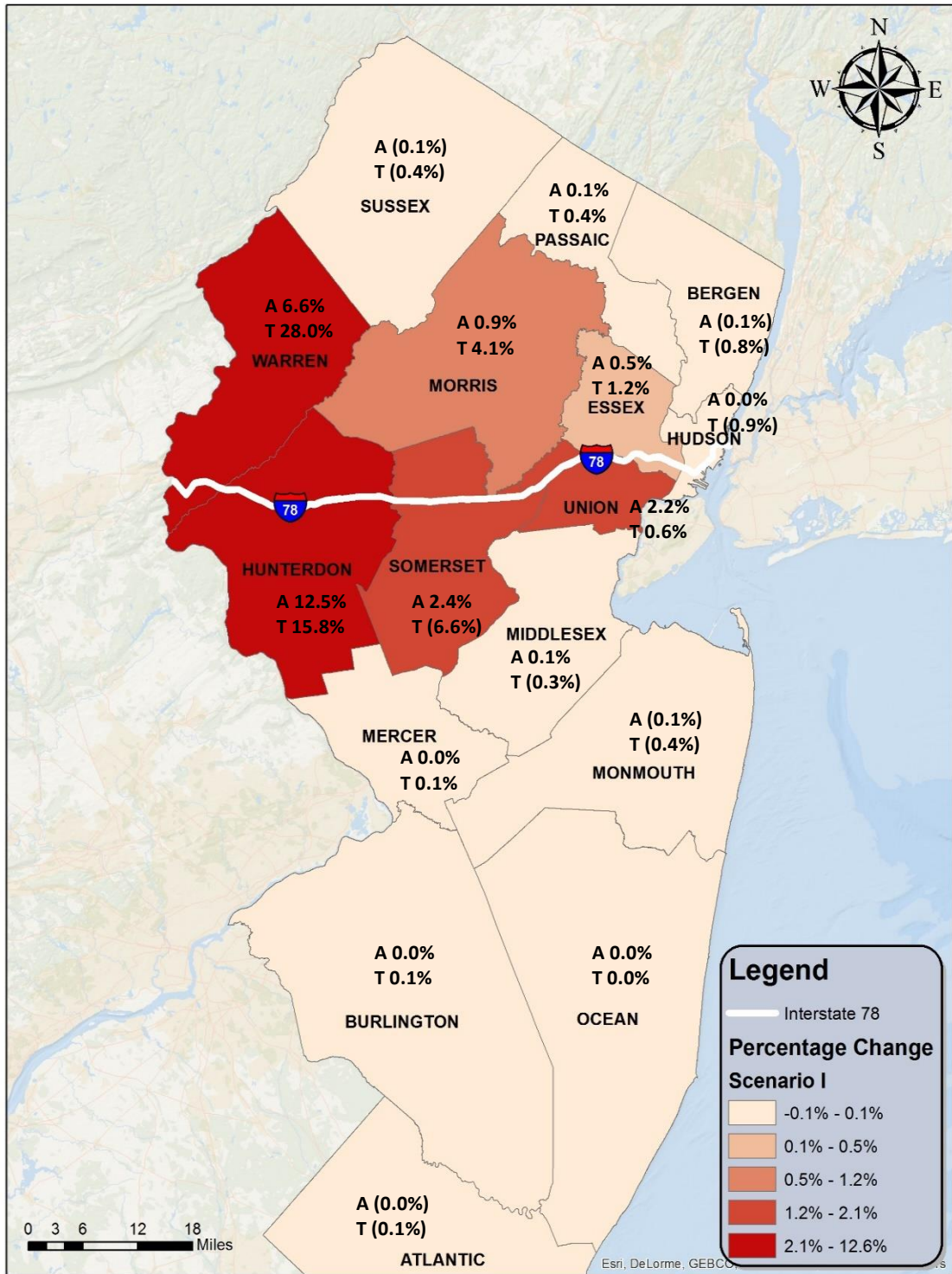


Figure 5.2 Change in daily VMT for non I-78 routes baseline scenario and scenario I. (Note: A and T in above figure represents Autos and Trucks respectively)

Sensitivity Analysis

A toll sensitivity analysis was performed by varying toll rates (\$/mile) for passenger cars (autos) and trucks resulting in the range of traffic retention on Interstate 78. As seen from the table below, traffic retention ranges from 100% for no-toll scenario (existing condition) to 56% for auto and 30% for trucks under various toll prices. As the toll price increases, the retention of traffic on I-78 reduces significantly, especially for trucks.

Table 5.3 Sensitivity Analysis of Daily VMT on I-78

Toll Rates	Auto VMT	Truck VMT	Auto Retention	Truck Retention
Existing Condition (No Tolls)	4,963,586	916,522	100%	100%
Case I - \$0.05/mile Autos \$0.30/mile Trucks	3,884,321	762,164	78.3%	83.2%
Case II - \$0.10/mile Autos \$0.60/mile Trucks	3,527,271	616,128	71.1%	67.2%
Case III - \$0.20/mile Autos \$1.20/mile Trucks	2,787,347	280,337	56.2%	30.6%

It should also be noted that the toll sensitivity analysis mentioned above could not be construed to represent the toll rates to be implemented. The optimal toll can, therefore, be assessed by maximizing social welfare of all travelers in the network. Section 5.3 assess the overall cost-benefit analysis for different tolling schemes using the developed framework.

5.2.2 Analysis of Scenario II

A similar comparison between baseline and scenario II can be conducted. However, before we compare the scenarios regarding the change in VMT/VHT, it would be interesting to see how Scenario II affects the shipper preferences to choose carrier (truck vs rail) given the availability of alternate mode. The choice, in this case, depended on mode's service (increased travel time cost + tolls) and price bundle (rate). This results in shipper choosing the alternative mode (rail) due to increased cost. One the assumptions made during the analysis is that rail has sufficient capacity available to handle the additional demand.

For the analysis purpose, select link analysis was performed to identify the zones using I-78 and a group of potential O-D pairs (trips going in/out of the port area) was selected as shown in Figure 4.5. The analysis shows that about 18% of truck trips (700 trips) were being diverted to rail as a result of policy scenario II (Figure 5.3)

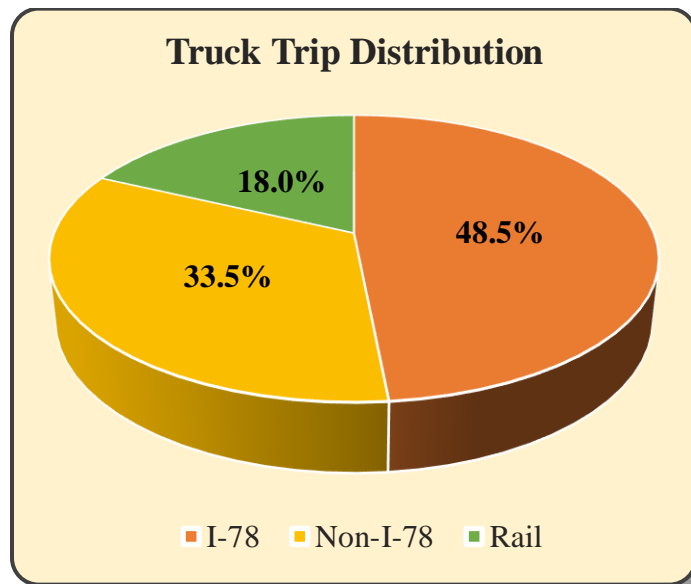


Figure 5.3 Percentage truck trip distribution for scenario II.

Whereas, the remaining 82.0% would still prefer roadway network representing 3186 trips. Out of which, around 48.5% representing 1,884 trips would still be using route using I-78 to reach the destination, and 33.5% representing 1,302 trips would use an alternate route of non I-78 (Figure 5.3).

The percentage change in VMT on I-78 compared to baseline is as shown in Figure 5.4. Observations similar to the scenario I can be made in this case as well. Although, when the results of Scenario II were compared to Scenario I they do not yield a significant difference on I-78 between them because a small pair of selected O-D going in/out of the port area is considered in Scenario II. Additionally, out of which only 18.0% are expected to shift to the alternative mode. However, the mode shift significantly affects the overall network especially the non I-78 routes on a county level. Figure 5.5 shows the change in VHT of scenario II when compared to scenario I. Based on the analysis; it was estimated that the overall VHT reduces by 207 hours/day and 664 hours/day for autos and trucks respectively. The counties, which greatly benefited from the reduction of VHT in this case, were Essex, Hudson and Morris County. On the contrary, Union County was the most affected county with increased VHT. However, when compared on the annual basis throughout the network significant timesaving's can be seen as a result of policy scenario II. The annual cost savings because of the scenario is further being discussed in Section 5.3.

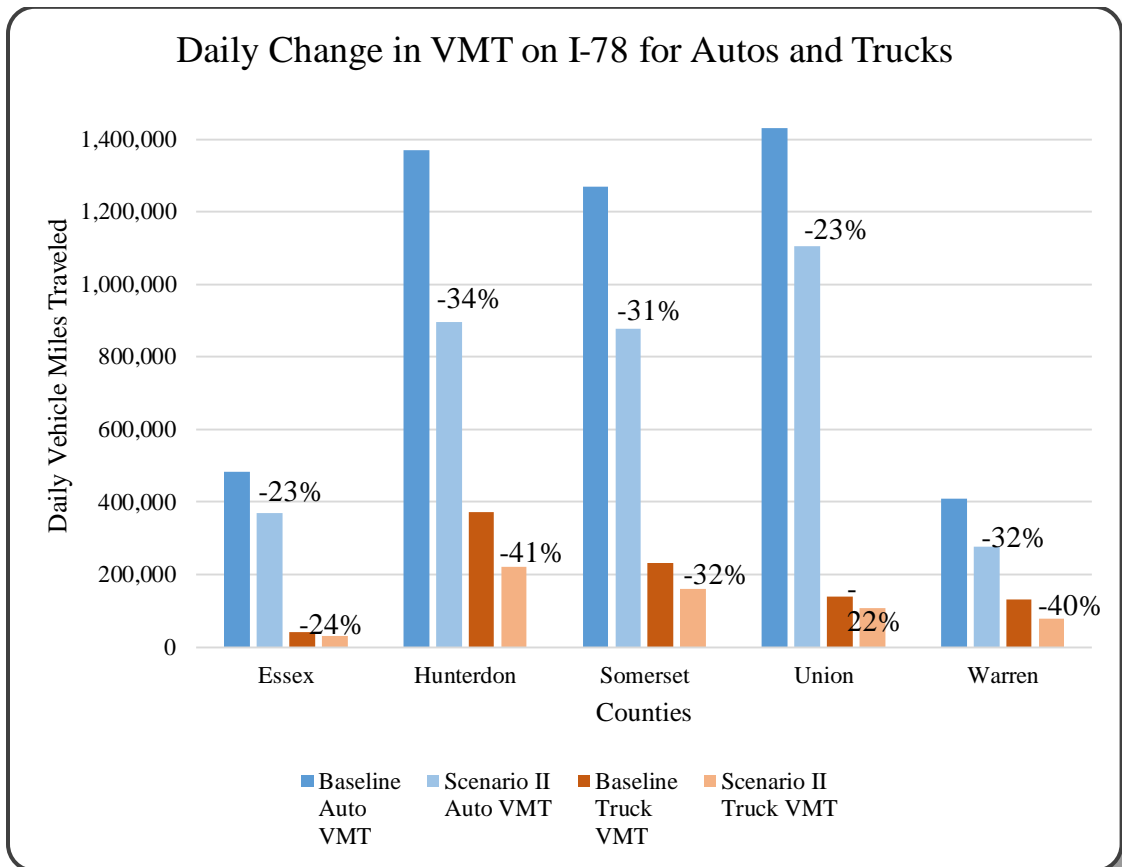


Figure 5.4 Daily VMT comparison on I-78 between baseline scenario and scenario II.

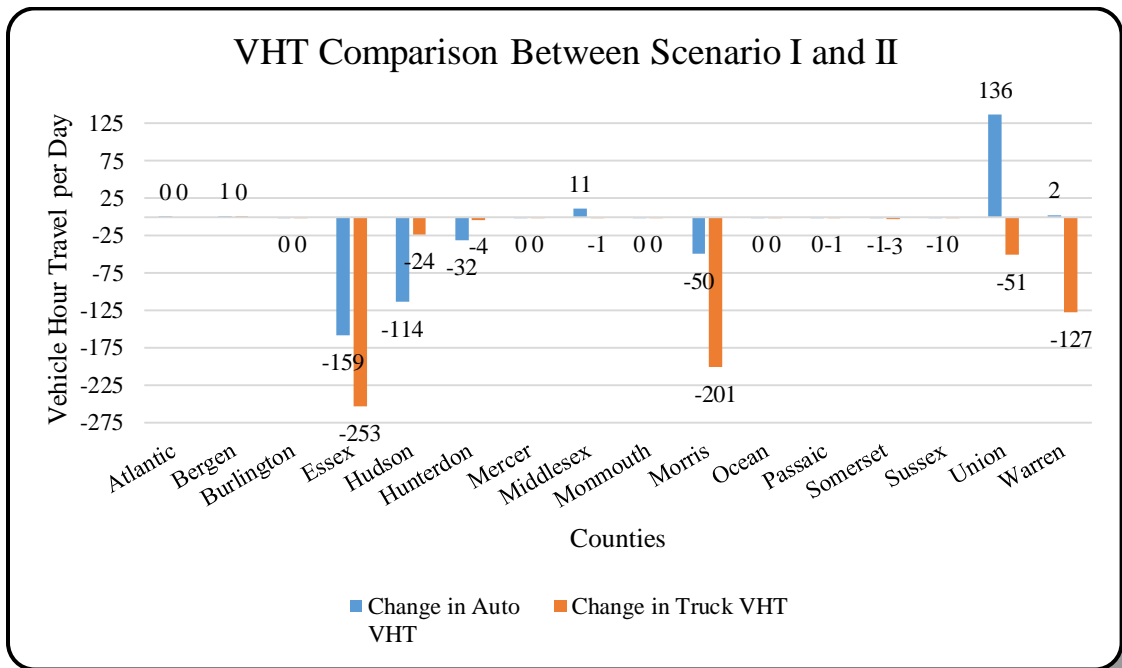


Figure 5.5 Change in VHT – comparison between scenario I and scenario II.

5.2.3 Analysis of Scenario III

Evaluation of policy Scenario III first identifies the change in demand for O-D pairs among the selected zones. Out of 368 O-D pairs selected during the analysis, the majority of the O-D pairs (83.2%) were being impacted as a result of policy scenario III (Figure 5.6). At the same time, a small percentage (6.3%) of O-D pairs saw demand increased, and the remaining (10.6%) were not affected.

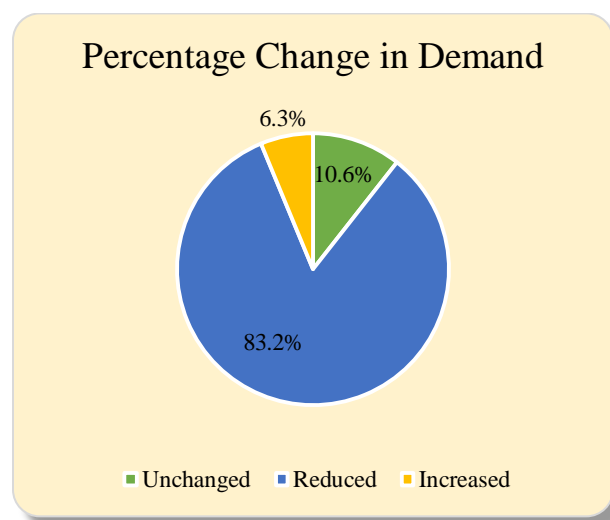


Figure 5.6 Percentage change in demand for O-D pairs.

As discussed in Section 4.3, the selection of the zones in the analysis was based on the major truck trips being observed within the region. The impact of the change in VMT/VHT was measured along I-78 as well as non I-78 routes. The daily VMT on I-78 in this scenario reduced by 29% and 33% for autos and trucks respectively when compared with baseline. The cost-benefit analysis of the scenario is further discussed in Section 5.3, which measures the cost savings as a result of scenario III.

5.2.4 Analysis of Scenario IV

Similar to above scenarios the VMT and VHT in this scenario was also compared to the baseline case. The analysis found that as the daily VMT for autos and trucks both grew on I-78 by more than 80 thousand and 18 thousand respectively (Table 5.4). However, at the same time, the VHT on I-78 reduced by 144 hours/day and 8 hours/day for autos and trucks respectively making I-78 more attractive route.

Table 5.4 Comparison of VMT (Auto/Trucks) with Baseline for I-78

County Name	Auto VMT			Truck VMT		
	Baseline	Scenario IV	Difference	Baseline	Scenario IV	Difference
Essex	483,027	490,123	7,096	41,717	43,494	1,777
Hunterdon	1,369,100	1,391,940	22,840	372,702	375,894	3,192
Somerset	1,269,017	1,292,635	23,618	232,962	239,215	6,253
Union	1,432,276	1,454,487	22,210	138,472	144,963	6,491
Warren	410,165	414,964	4,799	130,669	131,530	861
			80,564			18,573

The scenario not only improves the overall performance on I-78 but also helps to reduce the VMT's on the secondary routes within the network. Figure 5.7 below shows the reduced daily VMT's on non I-78 routes. The overall reduction resulted in more than 62 thousand and 16 thousand vehicle miles traveled for autos and trucks respectively. Additionally, it reduced VHT by more than 2 thousand/day for autos and 348/day for trucks. Even though no toll revenue is collected in this policy scenario, the region impact can be quantified using the cost savings in the following section.

Increase/Decrease in Daily VMT on Non I-78 Routes

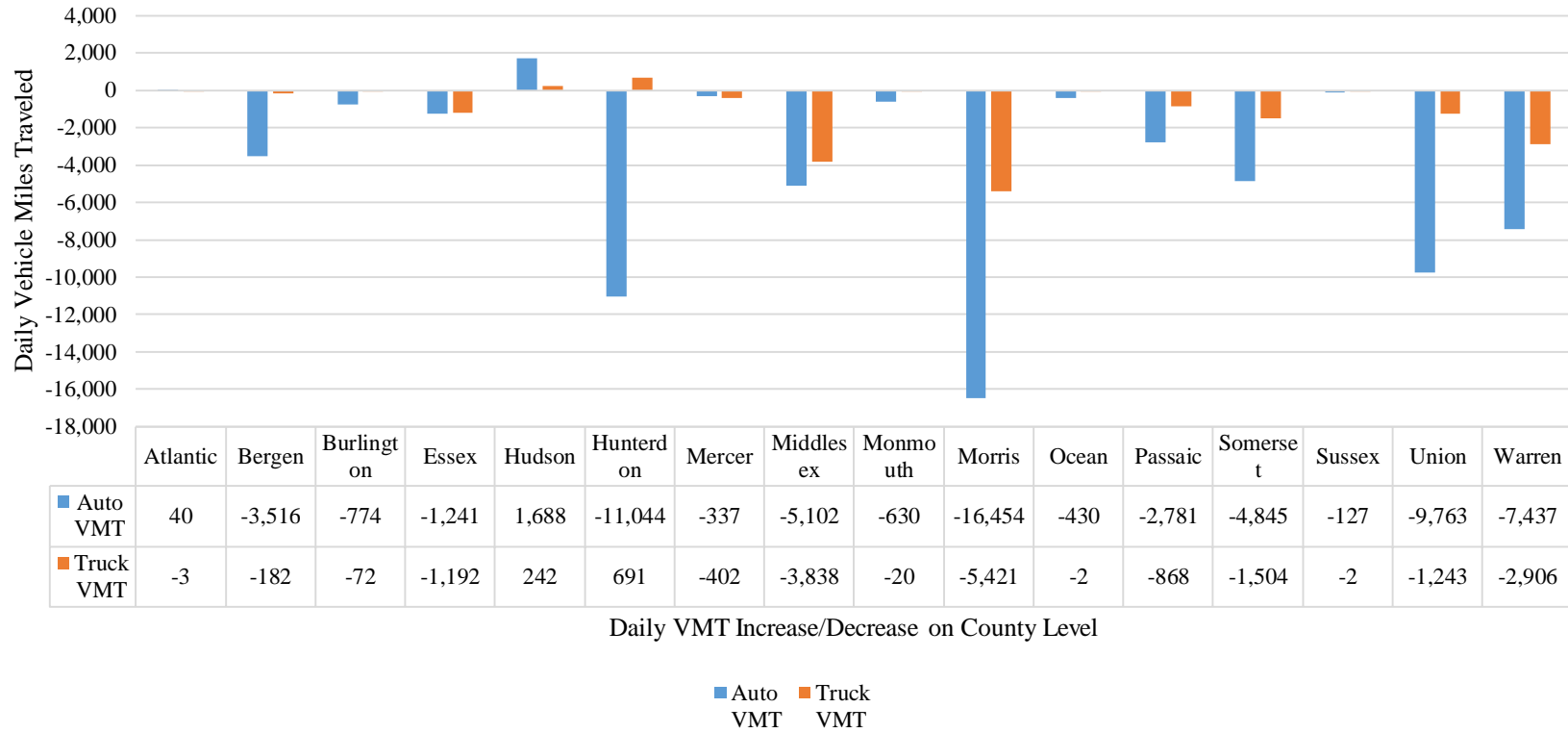


Figure 5.7 Daily change in VMT for non I-78 routes on county level.

5.3 Cost-Benefit Analysis of Scenarios

The cost-benefit analysis in this section focuses on the systematic evaluation of economic advantages (benefit regarding revenue) and disadvantages (concerning costs) of each scenario (Section 4.2) regarding travel time cost, emission, pavement damage, and safety on an annual basis. The analysis evaluates the difference between the base line and scenarios to answer if any additional benefits can be achieved by the implementation of a scenario. The objective is to analyze the effects into monetary terms to provide decision makers the cost-effectiveness of policies and anticipated impacts on a regional level.

The annual estimates are calculated based on the current year of 2015 for each of the scenarios described earlier. However, given the availability of future data and assuming the traffic grows at constant rate, the framework can be used to analyze future year as well. The extrapolation method mentioned below can then be used to determine the cost saving for a particular year.

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

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

t_o = initial year of analysis;

t = expected year to be implemented

S = scenario

j_s = annual rate of change in cost in scenario S between the current and future

The methodology described in Section 3.2.4 and the data from Section 4.4.1 is used to compare the cost-benefits network-wide.

Optimal Toll

A policy such as tolls can influence travel behavior especially for truckers, which considers them as a financial burden and thus preventing them from choosing a toll road. The avoidance of these toll facilities by truckers not only increase delays on secondary routes but also result in safety concerns. The framework discussed in the dissertation can, therefore, help to determine the optimal toll with an objective of maximizing the overall benefits on a regional level. Sensitivity analysis with varying tolls was performed to obtain these values. Due to time constraints and the computational efforts, only three cases were considered. Using the same process more toll values/cases can be evaluated. The intent here was to show the process which can be used to determine the toll values which can give the best outcome. Table 5.4 shows the comparison of different toll values and their respective cost-benefit analysis network-wide. The analysis in the table shows that even though the revenue increased with increased toll rates, the overall benefits did not. The lower toll rates certainly attracted more traffic on I-78 and vice versa, however, the maximum benefit was observed under Case II. These toll values set in Case II were further used in all scenario mentioned in the case study.

Table 5.5 Sensitivity Analysis for Optimal Toll Rates

		Baseline	Case I*	Cost Savings	Case II**	Cost Savings	Case III***	Cost Savings
Annual VMT	Autos	35,831,963,125	35,720,667,553	111,295,572	35,719,200,680	112,762,446	35,731,630,522	100,332,603
	Trucks	2,414,817,925	2,378,489,746	36,328,179	2,370,156,704	44,661,220	2,360,204,611	54,613,314
	Total	38,246,781,050	38,099,157,299	147,623,751	38,089,357,384	157,423,666	38,091,835,133	154,945,917
Annual VHT	Autos	804,388,168	807,572,734	(3,184,565)	808,844,955	(4,456,786)	816,100,978	(11,712,810)
	Trucks	45,136,283	44,689,088	447,195	44,700,582	435,701	44,961,836	174,447
	Total	849,524,452	852,261,822	(2,737,370)	853,545,537	(4,021,085)	861,062,814	(11,538,363)
Travel Time Cost	\$10,625,967,705	\$10,668,035,811	(\$42,068,106)	\$10,684,841,850	(\$58,874,145)	\$10,780,693,921	(\$154,726,216)	
Truck Travel Time Cost	\$2,146,619,914	\$2,125,351,938	\$21,267,976	\$2,125,898,563	\$20,721,351	\$2,138,323,454	\$8,296,460	
Environmental Cost	\$1,481,209,397	\$1,476,297,660	\$4,911,736	\$1,475,874,942	\$5,334,455	\$1,479,160,859	\$2,048,537	
Fuel Cost	\$5,292,554,547	\$5,260,991,848	\$31,562,700	\$5,254,102,346	\$38,452,202	\$5,253,441,754	\$39,112,794	
Safety Cost	\$3,294,331,668	\$3,278,819,501	\$15,512,167	\$3,279,353,728	\$14,977,940	\$3,286,919,140	\$7,412,528	
Pavement Cost	\$91,952,586	\$90,864,415	1,088,170	\$90,631,411	1,321,174	\$90,362,921	1,589,664	
Total Cost	\$22,932,635,816	\$22,900,361,173	\$32,274,643	\$22,910,702,839	\$21,932,977	\$23,028,902,050	-\$96,266,234	
Revenue	\$0	\$105,716,284	\$105,716,284	\$180,600,925	\$180,600,925	\$223,468,595	\$223,468,595	
Net Gap			\$137,990,926		\$202,533,902		\$127,202,362	

*Case I – (\$0.05/mile for Autos and \$0.30/mile for Trucks)

**Case II – (\$0.10/mile for Autos and \$0.60/mile for Trucks)

***Case III – (\$0.20/mile for Autos and \$1.20/mile for Trucks)

5.3.1 Cost Benefit Analysis of Scenario I

Table 5.6 Comparison of Annual Vehicle Miles Traveled, Vehicle Hour Traveled, Costs and Revenue between Baseline Scenario and Scenario I

		Baseline	Scenario I	Cost Savings
Annual VMT	Autos	35,831,963,125	35,719,200,680	112,762,446
	Trucks	2,414,817,925	2,370,156,704	44,661,220
	Total	38,246,781,050	38,089,357,384	157,423,666
Annual VHT	Autos	804,388,168	808,844,955	(4,456,786)
	Trucks	45,136,283	44,700,582	435,701
	Total	849,524,452	853,545,537	(4,021,085)
Travel Time Cost		\$10,625,967,705	\$10,684,841,850	(\$58,874,145)
Truck Travel Time Cost		\$2,146,619,914	\$2,125,898,563	\$20,721,351
Environmental Cost		\$1,481,209,397	\$1,475,874,942	\$5,334,455
Fuel Cost		\$5,292,554,547	\$5,254,102,346	\$38,452,202
Safety Cost		\$3,294,331,668	\$3,279,353,728	\$14,977,940
Pavement Cost		\$91,952,586	\$90,631,411	1,321,174
Total Cost		\$22,932,635,816	\$22,910,702,839	\$21,932,977
Revenue		\$0	\$180,600,925	\$180,600,925
Net Gap				\$202,533,902

5.3.2 Cost Benefit Analysis of Scenario II

Table 5.7 Comparison of Annual Vehicle Miles Traveled, Vehicle Hour Traveled, Costs and Revenue between Baseline Scenario and Scenario II

		Baseline	Scenario II	Cost Savings
Annual VMT	Autos	35,831,963,125	35,718,983,151	112,979,974
	Trucks	2,414,817,925	2,357,791,759	57,026,166
	Total	38,246,781,050	38,076,774,909	170,006,141
Annual VHT	Autos	804,388,168	808,786,466	(4,398,297)
	Trucks	45,136,283	44,468,466	667,817
	Total	849,524,452	853,254,932	(3,730,480)
Travel Time Cost		\$10,625,967,705	\$10,684,069,209	(\$58,101,504)
Truck Travel Time Cost		\$2,146,619,914	\$2,114,859,451	\$31,760,462
Environmental Cost		\$1,481,209,397	\$1,475,055,832	\$6,153,565
Fuel Cost		\$5,292,554,547	\$5,245,088,629	\$47,465,918
Safety Cost		\$3,294,331,668	\$3,278,012,346	\$16,319,322
Pavement Cost		\$91,952,586	\$90,287,021	1,665,565
Total Cost		\$22,932,635,816	\$22,887,372,489	\$45,263,327
Revenue		\$0	\$177,865,299	\$177,865,299
Net Gap				\$223,128,626

5.3.3 Cost Benefit Analysis of Scenario III

Table 5.8 Comparison of Annual Vehicle Miles Traveled, Vehicle Hour Traveled, Costs and Revenue between Baseline Scenario and Scenario III

		Baseline	Scenario III	Cost Savings
Annual VMT	Autos	35,831,963,125	35,718,802,945	113,160,180
	Trucks	2,414,817,925	2,360,435,006	54,382,919
	Total	38,246,781,050	38,079,237,951	167,543,099
Annual VHT	Autos	804,388,168	808,855,964	(4,467,796)
	Trucks	45,136,283	44,524,459	611,824
	Total	849,524,452	853,380,423	(3,855,971)
Travel Time Cost		\$10,625,967,705	\$10,684,987,285	(\$59,019,580)
Truck Travel Time Cost		\$2,146,619,914	\$2,117,522,378	\$29,097,535
Environmental Cost		\$1,481,209,397	\$1,475,227,217	\$5,982,180
Fuel Cost		\$5,292,554,547	\$5,246,207,372	\$46,347,175
Safety Cost		\$3,294,331,668	\$3,278,355,619	\$15,976,049
Pavement Cost		\$91,952,586	\$90,360,485	1,592,101
Total Cost		\$22,932,635,816	\$22,892,660,356	\$39,975,460
Revenue		\$0	\$180,580,891	\$180,580,891
Net Gap				\$220,556,352

5.3.4 Cost Benefit Analysis of Scenario IV

Table 5.9 Comparison of Annual Vehicle Miles Traveled, Vehicle Hour Traveled, Costs and Revenue between Baseline Scenario and Scenario IV

		Baseline	Scenario IV	Cost Savings
Annual VMT	Autos	35,831,963,125	35,836,415,238	(4,452,113)
	Trucks	2,414,817,925	2,415,280,747	(462,822)
	Total	38,246,781,050	38,251,695,985	(4,914,935)
Annual VHT	Autos	804,388,168	803,674,152	714,016
	Trucks	45,136,283	45,047,245	89,039
	Total	849,524,452	848,721,397	803,055
Travel Time Cost		\$10,625,967,705	\$10,616,535,550	\$9,432,155
Truck Travel Time Cost		\$2,146,619,914	\$2,142,385,356	\$4,234,558
Environmental Cost		\$1,481,209,397	\$1,482,444,365	(\$1,234,968)
Fuel Cost		\$5,292,554,547	\$5,302,803,834	(\$10,249,286)
Safety Cost		\$3,294,331,668	\$3,292,080,955	\$2,250,713
Pavement Cost		\$91,952,586	\$91,968,543	(15,957)
Total Cost		\$22,932,635,816	\$22,928,218,601	\$4,417,215
Revenue		\$0	\$0	\$0
Net Gap				\$4,417,215

The tables above not only shows the change in annual vehicle miles traveled and vehicle hour traveled within the region but also provides the cost savings for each scenario. For example, Table 5.6 shows the comparison between baseline and scenario I. The result of the analysis showed increased travel time cost for autos, which accounted for 0.55% compared to the baseline⁴³. However, at the same time the environmental cost, fuel cost, pavement damage cost and safety cost reduced in the scenario as a result of overall reduced annual VMT's. Additionally, the scenario generates more than 180 million dollars annually in revenue. The savings because of policy scenario I is almost 4.4 times more than the cost associated with it⁴⁴.

Similar analysis between baseline scenario and scenario II suggests that savings increases by 4.8 times more than the cost associated with it⁴⁵. When scenario I is compared to scenario II, the revenue drops by 1.5%, but at the same time, overall savings increase by almost 10.2%⁴⁶. The drop in the revenue for scenario II was because of the diversion of truck trips on alternative mode (rail). Furthermore, scenario II results in not only reducing the travel time cost for autos compared to the scenario I but also helps savings other costs associated with reduced VMT's.

Another comparison between baseline scenario and scenario III suggests that the overall savings, in this case, results in more than 200 million dollars, which is almost 8.9%

⁴³ Refer Table 5.6 – $(\$10,625,967,705 - \$10,684,841,850) / \$10,625,967,705 = -0.0055$ (-0.55%)

⁴⁴ Refer Table 5.6 – Total Savings/Total Cost = $(\$20,721,351 + \$5,334,455 + \$38,452,202 + \$14,977,940 + \$1,321,174 + \$180,600,925) / \$58,874,145 = 4.4$

⁴⁵ Refer Table 5.7 – Total Savings/Total Cost = $(\$31,760,462 + \$6,153,565 + \$47,465,918 + \$16,319,322 + \$1,665,565 + \$177,865,299) / \$58,101,504 = 4.8$

⁴⁶ Refer Table 5.6 and 5.7 – $(\$177,865,299 - \$180,600,925) / \$180,600,925 = -0.015$ (-1.5%) and $(\$223,128,926 - \$202,533,902) / \$202,533,902 = 0.102$ (10.2%)

higher than the scenario I and 1.2%, lower than scenario II⁴⁷. However, if the toll revenue were to be excluded from all three scenarios, the savings for scenario III would be 82.2% higher than the scenario I and 11.7% lower than scenario II⁴⁸.

The last scenario discussed in the case study includes dedicated truck lane, which would need additional cost of construction to be considered in the cost-benefit analysis. Table 5.7 shows the cost-saving excluding the cost of construction. For the analysis purpose, the cost of construction was considered \$183,757 per lane mile⁴⁹. The dedicated lane along I-78 would result in constructing 70 miles each direction. Therefore, the cost of constructing a dedicated truck lane along I-78 would cost \$25,725,980. Since the cost-benefit analysis is on an annual basis, the cost of construction also needs to be computed on the annual basis. Capital recovery discounting formula mentioned below can be used to annualized the cost of construction.

$$\text{Annual Capital Recovery Cost} = P * CRF$$

Where

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

i = interest rate

n = number of years

⁴⁷ Refer Table 5.6, 5.7, 5.8 – $(\$220,556,352 - \$202,533,902) / \$202,533,902 = 0.089$ (8.9%) and $(\$220,556,352 - \$223,128,626) / \$220,556,352 = -0.012$ (-1.2%)

⁴⁸ Refer Table 5.6, 5.7, 5.8 – $(\$39,975,460 - \$21,932,977) / \$21,932,977 = 0.822$ (82.2%) and $(\$39,975,460 - \$45,263,327) / \$45,263,327 = -0.117$ (-11.7%)

⁴⁹ <http://www.state.nj.us/transportation/refdata/research/reports/NJ-2016-003.pdf>, accessed on April 5th, 2018

The interest rate i applied in the calculation is prescribed by the Office of Management and Budget for analyzing the cost-effectiveness of public investments⁵⁰. For 20 year, the rate is 3.2%, which is considered for analysis purpose below:

$$= \$25,725,980 \frac{0.03(1+0.03)^{20}}{(1+0.03)^{20} - 1} = \$1,761,322$$

The results from the above analysis suggest that the annual cost of recovery for constructing a dedicated truck lane would be still less than the annual savings (\$4,417,215). Similarly, even if the higher rate of interest (5%) were to be considered still the cost of recovery (\$2,064,319) would be less than annual savings (\$4,417,215) for scenario IV.

5.4 Summary

The first section of the chapter focuses on the analyzing the equilibrium condition in which no traveler can improve his/her travel cost by unilaterally changing the routes. The analysis concludes that ten iterations were sufficient to attain an equilibrium condition for most O-D pairs. The following section of the chapter then discusses the result of the change in VMT and VHT's for each policy scenarios along the I-78 corridor as well as non I-78 routes on the county basis. Each of the scenarios was compared to baseline case, and a sensitivity analysis was conducted to evaluate the retention of traffic onto I-78 as well as to determine the optimal toll rate to be considered during the cost-benefit analysis. The objective of the cost-benefit analysis in the succeeding section was to quantify the impact into monetary terms, which can further help decision makers to make informed decisions.

⁵⁰ <https://www.wbdg.org/FFC/FED/OMB/OMB-Circular-A94.pdf>, accessed on April 1st, 2018

CHAPTER 6

CONCLUSION AND FUTURE RESEARCH

Planning for freight transportation needs an understanding of current conditions and issues, major trends that are likely to evolve and challenges faced by the users. The issue for agencies is, therefore, to act as both infrastructure provider and holders of general public interest. They often make policy decisions that reflect improving regional mobility and addressing concerns related to safety, security, and environmental issues. However, for states to develop and implement policies that can adequately address the challenges, there is a need for a policy framework that can evaluate the impact of the policies, infrastructure improvements and its effect on users. The lack of the framework makes it difficult for state/metropolitan planning organizations to implement investment strategies in the best possible way.

6.1 Methodological Framework

The proposed framework in the research tries to fill the gap by developing a modeling framework to address and quantify the relationship between the change in truck volumes, decision-makers (policies and infrastructure improvements) and public interests. The methodology uses demand and supply network equilibrium concept to assign travelers on the network and involves choosing a mode and route choice over the network. The models discussed in the methodological framework therefore represents a unique modeling approach enabling realistic predictions of traffic flow as a result of policy change. The associated costs are further estimated based on the flow patterns to evaluate the effects of

the policy in monetary terms. The framework thus provides a sound approach to estimate the relationship between the policy and its effects.

6.2 Research Contributions

The modeling framework discussed above was used to demonstrate how alternative policies and its impact on a regional level can be evaluated in the form of case study. Four scenarios representing two policies were evaluated. The case study particularly focused on analyzing the relationship between a change in truck volume to and from the Port Newark/New York area and the roadway network performance. The ports connectivity included intricate networks of the highway, rail, and the most densely populated area in the nation. Trucks being the major mode of transportation for carrying freight, the region served as a perfect test bed for evaluating impacts of policy measures and infrastructure improvements. The data available from North Jersey Transportation Planning Authority was used in the case study and the cost-benefit analysis based on economic theory was used to ascertain the change in truck volume as a result of policy scenarios. The cost-benefit analysis discussed included highway maintenance savings, user cost benefits, safety and environmental benefits. The monetary benefits from the case study can help decision maker to make better investment decisions.

Each scenario discussed in the case study was compared to baseline and the cost savings were estimated (Refer Section 5.3). The results of the cost-benefit analysis concluded that scenario II which consist of tolls on I-78 along with alternative mode (rail) availability would produce maximum benefit among other scenarios. The cost savings was estimated to be approximately more than \$223 million dollars annually out of which

roughly 80% of the savings was due to the additional revenue generated by the tolls⁵¹. The reduced vehicle miles traveled as a result of 700 trucks being diverted to rail accounted for the rest. The analysis of the results thus can help decision makers to prioritize policies that will benefit both public and freight transportation needs. In addition to this, the results discussed in Section 5.3 also shows how the framework can be used to determine the optimal toll value which would yield maximum benefit. Sensitivity analysis was performed with toll values ranging from 5, 10 and 20 cents per mile for autos and 30, 60 and 120 cents per mile for trucks. The results of the analysis concluded that 10 and 60 cents per mile for autos and trucks respectively would yield maximum benefit. The framework thus shows the capability of identifying the optimal toll process. Due to time constraints and computational effort, only three cases were considered, however, more cases can be considered in future.

The results from the above case study conducted thus provide an example of how the framework is successfully able to evaluate policy scenarios and quantifying their impacts. It further helps to understand the freight issues and identify capital improvement to address the deficiencies. For example, the additional revenue generated from the toll policy can be used to compensate the travelers that could not avoid traveling on the tolled roads in the form of transportation improvements within his/her community. The statewide transportation improvement program (STIP) which provides the list of transportation improvements planned can be used to identify projects within the region. For instance, “Camp Meeting Avenue Bridge over Trenton Line, CR 602” was selected. The project is

⁵¹ Refer Table 5.7 – $(\$177,865,299/\$223,128,626)*100 = 79.71\% \sim 80\%$

located in Somerset County through which I-78 passes and tolls on I-78 would impact the community within the region. The purpose of the project was to address the deficiencies and meet current functional characteristics/requirements to provide safe and efficient vehicular and pedestrian crossing of CSX-West Trenton line railroad. The estimated cost of \$8.45 million dollars can, therefore, be supported from the annual toll revenue of \$177.86 million dollars generated from scenario II (Refer Section 5.3.2). These equity and fairness concerns, as a result, can be addressed ensuring that scarce resources are allocated to areas which are being affected by a policy change.

To this end, the proposed methodological framework and the results from the case study analysis demonstrate the capability to contribute to transportation planning activities and assist decision makers to make informed decisions. More importantly, the research enables to analyze "what if" scenarios that quantify the impacts of the transport policy in terms of highway safety, congestion, environment, and the infrastructure improvements. The dissertation thus makes several contributions to the field of transportation planning. First, the developed framework can be used as a tool by planning agencies to evaluate a policy decision in terms of cost-benefit analysis. Second, the research can be used by planning authorities as starting point to formulate policies and address deficiencies of existing infrastructure improvements. Third, comparison of multiple policy scenarios can assist decision maker with insights to make better investment decisions.

6.3 Future Research Work

Several directions for future research can be identified in the course of this dissertation. First, the assignment model in the framework can be further be improved to take into

account auto travelers preferences in selecting an alternative mode in addition to selecting alternative paths. Similarly, the second model discussed in the framework can be enhanced to consider rail capacity and its costs. The existing model assumes the alternate mode (rail) has sufficient capacity and ignores the cost evaluation on rail mode. Another approach in the third model can be included in which the total number of trips leaving each origin is known, but their destination is to be determined in conjunction to equilibration process. The current approach does not consider this. The current form of framework assumes that the travel time on a given link depends only on the flow through that link and does not consider its interaction with other links. This assumption may fail to represent real-world situation especially with heavy traffic on two streets, un-signalized intersections and left turning movements. Finally, the most comprehensive way would be to combine all the models developed in the framework in a unified way to four dimensions of travel choice – whether to take a trip, by which mode, to what destination and by which route. In addition to the core improvements in the framework, the application of these proposed models in the real world would depend on accurate traveler’s characteristics such as travel timesaving’s, income and the bias towards selecting a route. The real world decision-making process needs to be accounted for which will allow improving the performance of the framework. To this end, the parameters such as toll bias used in the framework can be calibrated based on location and its characteristics. The calibration process cannot be omniscient, and therefore may miss information to make perfect models. However, the process will help produce more reasonable and realistic results.

Finally, additional scenarios such as dedicated truck lane with tolls on I-78 for both autos and trucks can be evaluated. Another scenario where only trucks pay tolls on the

dedicated truck lane can also be looked into. Lastly, given the data availability and its accuracy, the results of the research can be further improved. A comparative study of the case study considered in the dissertation can be found in [Appendix E](#).

APPENDIX A

DEMAND AND SUPPLY NETWORK EQUILIBRIUM CONCEPTS

The section discusses the demand and supply network equilibrium for urban transportation network with emphasis on the modeling traveler's behavior of route choice. The concept of equilibrium analysis for transportation systems is presented first. The problem to be solved using this approach is then stated along with its rationale for choosing such approach.

Traditionally if the impact of particular policy or design is likely to be limited, the engineering analysis can isolate the component of the system individually. However, if the change is expected to be substantial, then it will not only affect the individual component that is being changed but have its effect on other parts of the system as well. For example, if the policy was to introduce tolls on the non-tolled interstate highway, the travelers may start avoiding the tolls, which in turn may result in increased congestion on arterials. Thus the traffic condition on road parallel to toll route may deteriorate as a result of it. Drivers on another part of the system may realize the change in their flow condition and alter their route accordingly. These diversions will change the flow and congestion throughout the system influencing the travel decisions. Ultimately, it is expected that these effects will lessen and after few days/weeks, the system may stabilize to the new equilibrium with no significant change occurring. The preceding example thus shows change in flow resulting from a policy change which is network wide and furthermore new flow patterns may be observed as a result of it. The notion of equilibrium, in this case, is similar to the physical equilibrium where flows are being pushed toward equilibrium by route switching. At equilibrium, the flows will be such that there is no incentive for route switching. The above

example shows that the equilibrium flow pattern as a result of policy change may involve unanticipated flow levels and congestion in parts of an urban network. The question can, therefore, be raised who are affected by the policy because some travelers may be better off while other may be worse off. The approach thus helps to account for the wide spectrum of changes concerning policy change. These changes can be measured regarding travel time, reliability, safety, accessibility of the service and other factors. Consider, for example, freight to be moved between two points and has two mode choices (truck vs. rail). If the congestion on the highway network increases significantly, the probability of using the network will decrease and shippers may either change the timing of the trip, use available alternative mode (rail) or may forgo the trip. Such interactions can be analyzed using performance function which describes how the level of service deteriorates with increased volume and demand function that describes how volume increases with the increased level of service. The equilibrium of demand/performance is reached over a network and can be presented in the following section.

Network Equilibrium

The transportation network in the urban area includes two types of elements: a set of points and a set of line segments connecting the points. These points can be represented as intersections (nodes), and line segments can be represented as streets (links) through which traffic moves. The mathematical definition of a network can, therefore, be defined as a set of nodes and a set of links (arcs) connecting these nodes. The network equilibrium, therefore, depends on the link travel time which depends on link flows. For example, let's assume that motorist who wishes to travel from origin to destination is known, and multiple possible paths are available to him. The question then becomes how these motorists are distributed on the possible paths. The process of determining flows on each path thus

involves a solution of demand performance equation. The flow on each link is the sum of the flows on many paths between origin and destinations. A performance function is, therefore, is defined individually for each link, and based on the flow. On the contrary, the demand for traveler depended on the motorist's behavior and based on the selection of alternative paths (routes) connecting origin-destination (O-D). Three network equilibrium problems are discussed based on which the models have been used in the framework.

Network Equilibrium with Alternate Routes

For a given highway network and origin-destination matrix as shown in Figure A.1, the problem is how the O-D matrix is assigned based on link performance functions. In this case, only motorist's flow is considered without any mode choice available to them. The interaction between the route chosen between all O-D pairs and the performance functions of all network links determines the equilibrium. The process is also known as traffic assignment is based on the principle that each will select the path between origin and destination to minimize his/her travel cost. The travel cost on each link changes with the link flow resulting in the change in paths. A stable condition is reached when no travelers can improve his travel cost by unilaterally changing routes reaching to a state of user-equilibrium condition (Wardrop 1952, Sheffi 1985). The assumption made in this case is that motorist has perfect information of travel time on all possible route, and all individuals are identical in their behavior. This presumption can be relaxed by making a distinction between perceive travel cost for an individual and the actual travel cost. The relaxed presumption thus leads to stochastic user equilibrium which is used in the modeled framework.

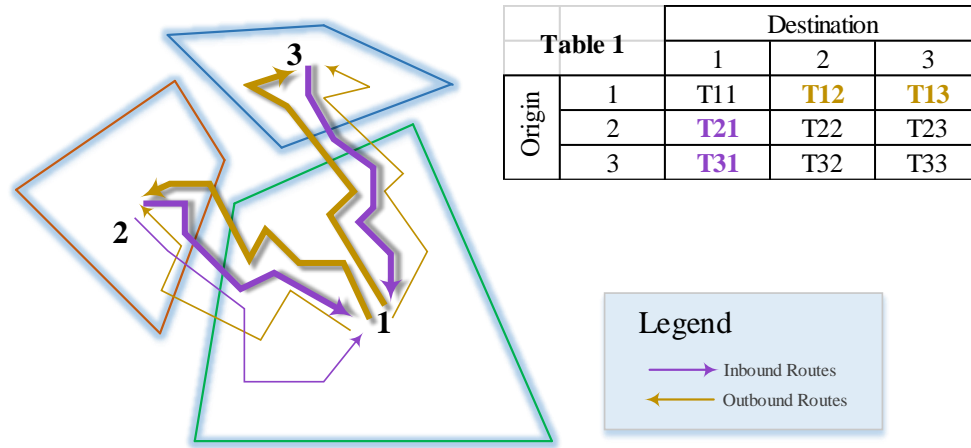


Figure A.1 Transportation network with alternate routes and fixed demand.

Multimodal Network Equilibrium with Alternative Routes

The complexity of the problem, in this case, is increased by the introduction of alternate availability of mode. The principle remains same as discussed earlier that each will try to minimize his/her own travel time, however, may not use the road network in this case. This analysis of network equilibrium problem in which the network includes both road and rail are referred as modal split/traffic assignment problem. For example, consider a network shown in Figure A.2 which illustrates the availability of alternative mode between O-D pair (1-3). It is assumed that the level of service offered by rail between O-D pair 1-3 is independent of roadway network flows and has the large capacity that congestion on rail network does not occur. The level of service (u_{1-3}) thus on rail network can be assumed to be constant and expressed regarding travel time units. The total demand between O-D pair (1-3) corresponds to the actual trips (T13, T31) by both the modes.

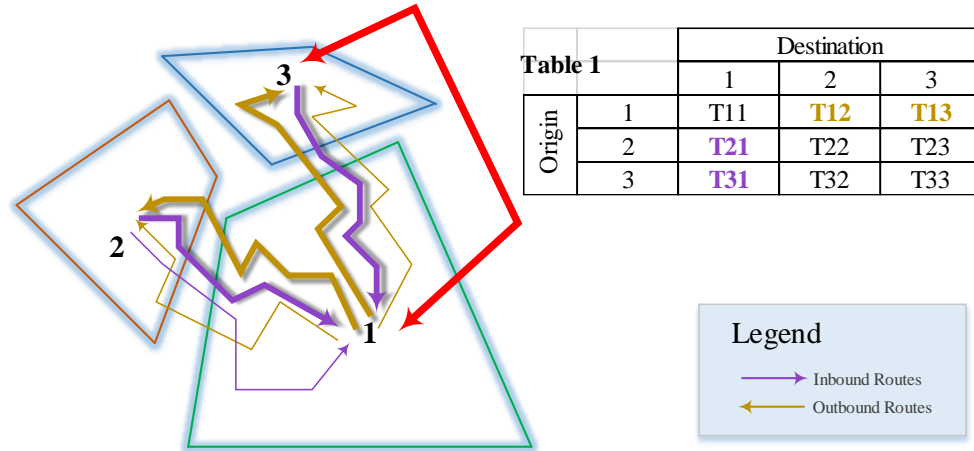


Figure A.2 Multimodal network with fixed demand.

The equilibrium condition in this case is defined by user equilibrium condition between the two flows (mode) in addition to the equilibrium over the network. So for example, if O-D pair (1-3) uses rail network, the travel times on both rail and roadway network should be equal. However, if only one mode roadway network is being used between O-D (1-3), then the travel time on roadway network should be lower than the travel time on the rail network. This suggests that the added rail network can be treated in the same fashion as any other link in the overall network. The travelers will, therefore, choose the mode with the lower impedance, similar to route choice with lowest travel time. However, mode choice involves complex decision process and is influenced by the number of factors. To account the complexity of mode choice the function such as logit formula (equation 1) accounts for situations in which travel times between rail and roadway are not equal at equilibrium.

$$q_{1-3} = \bar{q}_{1-3} * \frac{1}{1 + e^{(U_{road} - U_{rail})}}$$

Where U_{road} , U_{rail} minimum travel are times for roadway and rail respectively and q_{1-3} is the rail trip between O-D pair (1-3). \bar{q}_{1-3} Corresponds to the actual trip rate (by both

modes) for O-D (1-3). At equilibrium, both roadway and rail trip rates should satisfy the equation mentioned above in addition to the user equilibrium on roadway network.

Network equilibrium with Variable Demand

The user-equilibriums problems mentioned earlier assumes that the trip rates between every origin and destination are fixed and known. However, in the real world the trip rates may be influenced by the level of service on the given network and motorist may tend to use different mode or forego the trip altogether. To account this phenomenon, the demand can be a function of travel time between O-D and can be written as

$$q_{1-3} = D_{1-3}(U_{1-3})$$

Where (U_{1-3}) is minimum travel time between O-D (1-3) and $D_{1-3}(\cdot)$ is a demand function for trips between them. The demand function usually is same for all O-D's and may reflect population size, income distribution, and other factors. Figure A.3 below shows an example of a network in which the demand between O-D pairs (table 1) changed to new demand (table 2) as a function of travel cost. This suggests that as travel cost increases the demand decreases and vice versa.

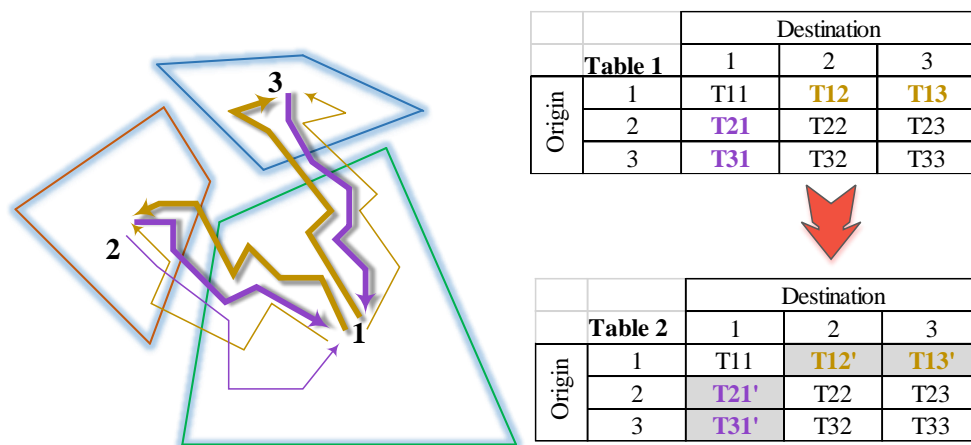


Figure A.3 Transportation network with variable demand.

The user equilibrium condition is addressed by finding the link flows, link travel times and the O-D trips rates that satisfy the condition of equilibrium. At equilibrium condition, the travel times on all used paths between any O-D pair are equal to or less than travel times on unused paths. Additionally, the O-D trips satisfy the demand functions. The equilibrium process is sometimes also referred user equilibrium with elastic demand.

The heuristic methods used in finding the user-equilibrium flow patterns include capacity restraint method and incremental assignment techniques. Both approaches deal with the trip loading mechanism on the network. The capacity restrained method involves loading all trips in an iterative scheme in which the travel times resulting from the previous assignment is used in the current iteration. The process continues until the stopping rule or convergence is achieved. Often the process may not give equilibrium solution, especially for large networks. Compared to this method, the incremental process tries to attain user equilibrium by assigns a portion of the O-D trips at each iteration. The travel times are then updated, and a portion of additional O-D trips are loaded on the network. As the number of increments grows, it may generate a flow closer to equilibrium. However, these methods may not always converge or produce a set of flows with user equilibrium solution. The details of the conceptual mathematical formulation for the network equilibriums are based on minimization of nonlinear objective function by applying a set of linear constraints. The mathematical base for each model is mentioned below:

Model 1

$$\text{Minimize } \sum_a \int_a^{f_a} c_a(x_a) dx_a$$

Subject to:

$$f_a - \sum_p \delta_{ap} h_p = 0, \forall a$$

$$T_{ij} - \sum_{p \in P_{ij}} h_p = 0, \forall ij$$

$$h_p \geq 0$$

Where T_{ij} = Total volume between origin-destination pair (ij)

The first constraint states that the flow on a link equal to the sum of flows on all paths that contain a link (a). The second constraint states that the demand between nodes i and j are equal to the sum of path flows that are available for travel between these nodes. The third constraint flow on the path (p) should be greater than 0. The notations for all other parameters used in above equation have been defined in chapter 3.

Model 2

$$\text{Minimize} \quad \sum_a \int_a^{f_a} c_a(x_a) dx_a$$

Subject to:

$$f_a - \sum_p \delta_{ap} h_p = 0, \forall a$$

$$T_{ij} - \sum_{p \in P_{ij}} h_p = 0, \forall ij$$

$$h_p \geq 0$$

$$T_{ij} = \sum_m T_{ij}^m, \forall ij$$

$$T_{ij}^m = p_m * T_{ij}, \forall m, ij$$

$$p_m = \frac{e^{V(x_m)}}{\sum_k e^{V(x_k)}}, \forall m$$

Where:

p_m = probability of mode (m) being chosen (In this case truck vs rail)

$V(x_m)$ = utility function for mode (m) that estimates the tradeoffs between the modes based on shipping rates, transit time etc. and can be represented as:

$$V(x_m) = a_m + b_{m1}x_{m1} + b_{m2}x_{m2}$$

a_m, b_{m1}, b_{m2} are constants and $x_{m1}, x_{m2} \dots x_{mn}$ are parameters considered for mode (m)

k = all modes available

T_{ij}^m = trips between origin (O) and destination (D) pair (ij) for mode (m)

The first three constraints are similar to the one mentioned in model 1 above. The fourth constraint states that the number of trips between origin (O) and destination (D) pair (ij) is equal to the summation of trips between the same pair (ij) over all available modes (m) being used. The fifth constraint states that the trips between origin (O) and destination (D) pair (ij) for a mode (m) is equal to the product of probability of a mode (m) times the number of trips between the same origin (O) and destination (D) pair (ij). The last constraint states that the probability of a mode (m) is equal to the ratio of the exponential of utility for a mode (m) over summation of exponential for all available modes (m).

Model 3

$$\text{Minimize } \sum_a \int_a^{f_a} c_a(x_a) dx_a$$

Subject to

$$f_a - \sum_p \delta_{ap} h_p = 0, \forall a$$

$$\Phi_{ij} - \sum_{p \in P_i} h_p = 0, \forall ij$$

$$\Phi_{ij} = T_{ij}(1 - \alpha_{ij} * \Delta C_{ij}^*), \forall ij$$

$$h_p \geq 0$$

Where: Φ_{ij} is the change in demand for origin (O) and destination (D) pair (ij).

The first constraint states that the flow on a link equal to the sum of flows on all paths that contain the link (a). The second constraint states that the change in demand between nodes i and j are equal to the sum of path flows that are available for travel between these nodes. The third constraint states that the change in trips (ij) is equal to the product of trips between the pair (ij) and the increased travel cost on least cost path (ΔC_{ij}^*) resulting in the marginal change in demand (α_{ij}). This constraint highlights the fact that trips between the origin (O) and destination (D) for the pair (ij) are variable rather than constant. The third constraint flow on the path (p) should be greater than 0.

Although, the mathematical formulation described above minimizes the objective function, such requirements are computationally prohibitive for large network of traffic assignment analysis. The primary reason for this is the effort required to calculate the shortest paths in the direction finding step. The convergence therefore sometime becomes difficult and therefore heuristic approach is considered in this case. Additionally, in practice, it is important that a good answer is achieved after a relatively small number of

iterations. Though, the number of iterations required for convergence is significantly affected by the congestion level on the network, usually four to six iterations are sufficient to find the equilibrium flow pattern over large urban networks. This number reflects the common practice in terms of the trade-offs among analytical accuracy, data limitations and computational time required.

APPENDIX B

NORTH JERSEY REGIONAL TRANSPORTATION MODEL – ENHANCED

The section refers to regional demand model being used in the dissertation -

Model Overview:

The North Jersey Regional Transportation Model –Enhanced (NJRTM-E), currently employed by the North Jersey Transportation Planning Authority (NJTPA), is used as a demand forecasting tool in the developed framework. The model is a four-step transportation model implemented within the Cube software platform and is capable of analyzing short/long range transportation plans. For the dissertation purpose, the traffic assignment step of the four-step transportation model is being focused on.

The model covers the thirteen counties in Northern New Jersey and the surrounding areas of New York and Pennsylvania. The surrounding areas serve as a buffer area for estimating travel into and out of the NJTPA detailed core area. The zones in the region are categorized into a series of area type. The determination of these area types was done using a relationship developed from population and employment densities. The socioeconomic data for each of these zones were provided at various geographic levels, from multiple agencies. The model consists of roadway network covering 55,230 road links from 40 counties in the state of New Jersey, New York, Connecticut and Pennsylvania. The following section focuses on components as part of highway assignment.

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 complete list of all the variables are listed below:

Highway Network Variables

Table 0-5 HIGHWAY LINK VARIABLES - PHYSICAL/OPERATIONAL VARIABLES

VARIABLE NAME	DESCRIPTION	UNIT	DEFINITION
A	A Node of a highway link	Integer	
B	B Node of a highway link	Integer	
DISTANCE	Distance of a highway link	Miles	
CAPACITY	Hourly lane capacity	VPH	Define by a look up table, a function of area type and facility type, unless overridden by user via FIXCAP
FT	Facility type	Integer from 1 to 12	FT is divided into 12 categories: 1. Freeway (limited access) 2. Expressway (grade separated at major facilities, signals at minor facilities) 3. Principal arterial divided 4. Principal arterial undivided 5. Major arterial divided 6. Major arterial undivided 7. Minor arterial 8. Collector/local 9. High speed ramp (direct freeway-freeway 55 mph) 10. Medium speed ramp (40 mph) 11. Low speed ramp/jughandle (25 mph) 12. Centroid connector
AT	Area type	Integer from 1 to 4	AT is divided into 4 categories: 1. CBD 2. Urban 3. Suburban 4. Rural
LANESAM	Number of lanes - AM Peak	Integer	Number of lanes in the AM Peak period.
LANESPM	Number of lanes - PM Peak	Integer	Number of lanes in the PM Peak period.
LANESOP	Number of lanes - Off Peak	Integer	Number of lanes in the Off Peak period.
LINKTYPE	Link permission code to utilize the link based on auto mode and toll	Integer from 1 to 16	Linktype is divided into 16 categories: 1. Free - all 2. Free - auto only 3. Free - truck only 4. Urban toll - all 5. Urban toll - auto only 6. Urban toll - truck only 7. Rural toll - all 8. Rural toll - auto only 9. Rural toll - truck only 10. Urban free - HOV only 11. Urban toll - HOV only 12. Urban toll - SOV, free HOV 13. Urban toll, free HOV 14. ETC only - all 15. ETC only - auto only 16. ETC only SOV and truck toll, free HOV
TERTYPE	Terrain Type. Default terrain type is defined based on counties and facility type: - Rolling Terrain: Sussex, Warren, Morris, Passaic, Hunterdon, Somerset, Rockland, Orange, Lackawanna, Wayne, Sullivan, and Luzerne - Mountainous: none - Level: all other counties and	Integer from 1 to 3	Tertype is divided into 3 categories: 1. Level 2. Rolling 3. Mountainous

	highways		
NLTLANE	Number of left turn lanes		Default=0
NRTLANE	Number of right turn lanes		Default=0
LWIDTH	Lane width	Feet	Default=12 feet
LSHOULD	Standard shoulder available	Flag	0 = Shoulder substandard or missing 1 = Standard shoulder (default)
TCD	Traffic Control Devices	Integer from 1 to 12, 99	TCD is divided into 13 categories: 1. Two-way stop 2. All-way stop 3. Yield 4. Ramp-meter 5. Signal-uncoordinated-actuated 6. Signal-uncoordinated-fixed 7. Signal-coordinated-restricted progression 8. Signal-coordinated-favorable progression 9. Signal-coordinated-maximum progression 10. Freeway diverge point 11. Freeway merge point 12. Uncontrolled - Shape Point 99. Unknown
NSIG	Number of signal in the link	Integer	User-specified, program will assume=1 if the value is not provided and TCD=5-9
SIGCYC	Signal cycle	Secs	User-specified, program default if the the value is provided
SIGCOR	Signal coordination	Integer from 0 to 3	SIGCOR is divided into 3 categories: 0. Uncoordinated Signal (Default) 1. Coord-unfavorable 2. Coord-favorable 3. Coord-max
GC	Green time/cycle ratio		Share of green time/cycle
ALCOEF	Alpha coefficient for Volume Delay Function in assignment		Calculated by program

BTCOEF	Beta coefficient for Volume Delay Function in assignment		Calculated by program
JFACT	Delay factor in HCM approximation of TCD-related delay		Calculated by program
JAFAC	Delay factor for Akcelik Formula		Calculated by program
ACCP	Number of access point		Program will provide default based on area type and facility type.
FIXCAP	Fix capacity	Flag	0 = not fixed (default) 1 = fixed capacity to specific value, retains settings of TCD, GC
FIXTIME	Fix Time	Flag	0 = not fixed (default) 1 = fixed
TOLL	Toll values - actual placement	Dollars	For toll diversion highway assignment
MCTOLL	Scaled toll values to balance by direction	Flag	0 = no toll (default) 1 = non-directional toll -0.5 and 0.5 = directional toll
TOLLAPC	Toll applied to vehicle types	Flag	0 = default 1 = set HOV toll to 0 2 = set truck toll to 0
TOLLCLASS	Toll class for lookup system	Integer from 0-99	0= no toll (default) 1-98 = obtained from lookup table 99 = toll value coded on link directly
TOLLFACAM	Base toll factor for AM Period		default = 1
TOLLFACPM	Base toll factor for PM Period		default = 1
TOLLFACMD	Base toll factor for Mid-Day Period		default = 1
TOLLFACNT	Base toll factor for Night Period		default = 1
FIXTOLL	Fix Toll	Flag	0 = not fixed 1 = fixed toll (default)
PARK	Parking permission code	Flag 0 or 1	PARK is divided into 2 categories: 1. Permitted parking - default values for

			FT=7 and AT=1,2; FT=8 and AT=1,2,3
			0. Not permitted - default for others
QUEFLG	Flag for queueing function	Flag	1 = additional queueing function is permitted in the volume delay function 0 = no additional queueing function is used
ZDELAY	Initial delay due to TCD		Calculated by program
ADDDelay	Additional delay applied to the link	Mins	Optional field - NJ Transit (not used)
SPEED	Link speed		Calculated by program, but user can override
T0	Free-flow travel time	Mins	Calculated by program, but user can override via FIXTIME parameter
TCODEAM	Transit travel time flag for AM Peak	Flag	0 = standard roadway (default) 1 = XBL 2= bus queue jump 9= exclusive bus link (BRT) Other codes available
TCODEOP	Transit travel time flag for Off Peak	Flag	0 = standard roadway (default) 1 = XBL 2= bus queue jump 9= exclusive bus link (BRT) Other codes available
TADDAM	Added time penalty to transit - AM	Mins	Link specific adjustment transit time - AM
TADDOP	Added time penalty to transit - OP	Mins	link specific adjustment transit time - OP
TSCALEAM	Transit time scaling factor - AM		Systematic adjustment factor - AM
TSCALEOP	Transit time scaling factor - OP		Systematic adjustment factor - OP
NONWALK	Index of non-walkable link	Flag 0 or 1	0-Walkable and pedestrian friendly 1-Non-walkable

NOTE:

Calculated by the program if their default values are not provided

To be maintained by the users

Table 0-6 HIGHWAY LINK VARIABLES - IDENTIFICATION VARIABLES

VARIABLE NAME	DESCRIPTION	UNIT	DEFINITION
NAME	Road name	String	Example: "New Jersey Turnpike"
SRI	State road identification	String	Example: "00000095" for New Jersey Turnpike
BEGIN_MP	Mile post of the beginning of the link	Miles	
END_MP	Mile post of the end of the link	Miles	
RT_LTR	Route lettering	String	Example: "I-95" for New Jersey Turnpike
COUNTY	County FIPS code	Integer	
PROJN	Conformity based project ID # obtained from NJTPA	Integer	
REFZONE	Zone where the link resides	Integer	

Table 0-7 HIGHWAY LINK VARIABLES - PERFORMANCE/USE VARIABLES

VARIABLE NAME	DESCRIPTION	UNIT	DEFINITION
COUNT1	The first set of counts	Integer	Final counts
YEARCT1	The year of the first set of counts	Integer	Year of counts
COUNT2	The second set of counts	Integer	Reserved for future use
YEARCT2	The year of the second set of counts	Integer	Reserved for future use
COUNT3	The third set of counts	Integer	Reserved for future use
YEARCT3	The year of the third set of counts	Integer	Reserved for future use

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 A.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.

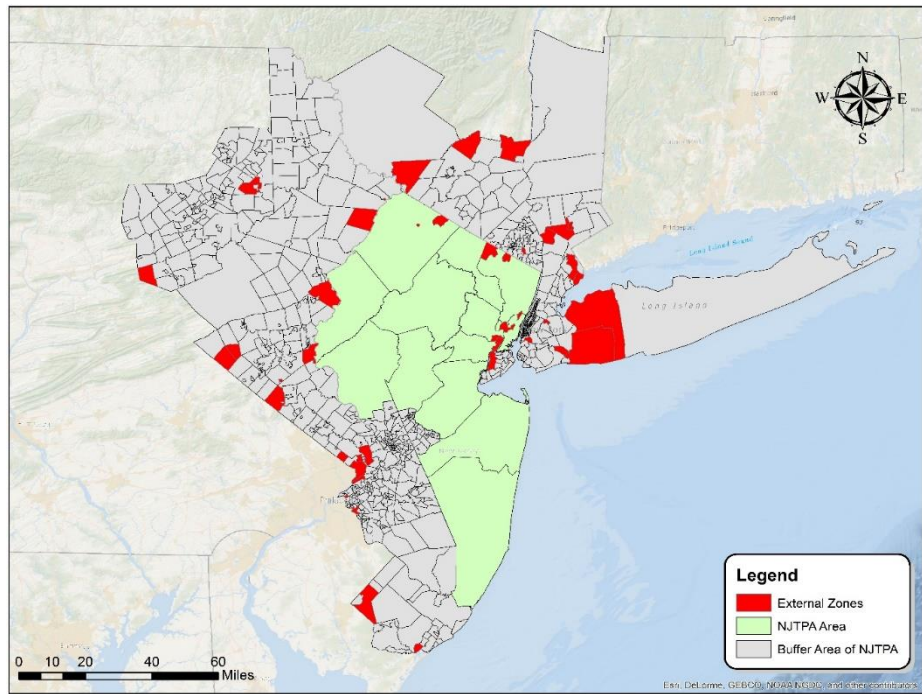


Figure B.1 External zones surrounding NJTPA area and intermodal terminals

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

The trip generation process was developed on 24-hour basis whereas trip distribution process used on condition, peak or off-peak, to control the distribution of travel. The final highway trip assignment was however performed by time-of-day for four periods (AM, PM, MD, NT) to account for congestion effects and diversion caused by congestion. The length of each period was defined based on travel trends and household survey trip distribution by time-of-day as shown in the table below:

Table B.1 Household Survey Trip Distribution by Time-of-Day (Continued)

Starting Time	HBW	HBNW	NHB	TOTAL
0:00 0:29	0.10%	0.13%	0.02%	0.26%
0:30 0:59	0.02%	0.07%	0.01%	0.10%
1:00 1:29	0.03%	0.04%	0.00%	0.07%
1:30 1:59	0.03%	0.02%	0.00%	0.05%
2:00 2:29	0.00%	0.02%	0.01%	0.02%
2:30 2:59	0.01%	0.00%	0.00%	0.01%
3:00 3:29	0.03%	0.01%	0.00%	0.04%
3:30 3:59	0.10%	0.01%	0.00%	0.12%
4:00 4:29	0.10%	0.03%	0.00%	0.12%
4:30 4:59	0.19%	0.04%	0.01%	0.24%
5:00 5:29	0.29%	0.07%	0.02%	0.39%
5:30 5:59	0.67%	0.23%	0.06%	0.96%
6:00 6:29	1.38%	0.43%	0.04%	1.86%
6:30 6:59	1.85%	0.97%	0.12%	2.94%
7:00 7:29	2.37%	1.90%	0.20%	4.47%
7:30 7:59	2.36%	2.69%	0.38%	5.43%
8:00 8:29	1.71%	2.58%	0.65%	4.94%
8:30 8:59	1.03%	2.08%	0.68%	3.79%
9:00 9:29	0.46%	0.96%	0.59%	2.02%
9:30 9:59	0.19%	1.22%	0.53%	1.94%
10:00 10:29	0.15%	0.99%	0.81%	1.95%
10:30 10:59	0.24%	1.11%	0.63%	1.98%
11:00 11:29	0.19%	1.17%	0.89%	2.25%
11:30 11:59	0.36%	1.41%	1.15%	2.92%
12:00 12:29	0.30%	1.01%	1.23%	2.54%
12:30 12:59	0.42%	1.18%	1.20%	2.80%
13:00 13:29	0.22%	1.11%	1.04%	2.37%
13:30 13:59	0.42%	0.96%	0.84%	2.22%
14:00 14:29	0.38%	1.57%	0.84%	2.79%
14:30 14:59	0.69%	2.22%	1.10%	4.01%
15:00 15:29	1.00%	2.64%	1.12%	4.76%
15:30 15:59	1.02%	1.96%	0.87%	3.85%
16:00 16:29	1.23%	1.83%	0.89%	3.95%
16:30 16:59	1.64%	2.01%	1.00%	4.66%
17:00 17:29	1.45%	2.17%	0.81%	4.42%
17:30 17:59	1.27%	2.19%	0.62%	4.08%
18:00 18:29	0.75%	1.73%	0.64%	3.13%
18:30 18:59	0.51%	1.99%	0.55%	3.04%
19:00 19:29	0.36%	1.58%	0.39%	2.33%

Table B.1 (Continued) Household Survey Trip Distribution by Time-of-Day

Starting Time	HBW	HBNW	NHB	TOTAL
19:30 19:59	0.28%	1.68%	0.41%	2.37%
20:00 20:29	0.15%	1.20%	0.29%	1.63%
20:30 20:59	0.23%	1.07%	0.19%	1.49%
21:00 21:29	0.22%	0.97%	0.26%	1.46%
21:30 21:59	0.17%	0.92%	0.13%	1.22%
22:00 22:29	0.13%	0.51%	0.11%	0.75%
22:30 22:59	0.18%	0.43%	0.06%	0.67%
23:00 23:29	0.11%	0.27%	0.06%	0.43%
23:30 23:59	0.02%	0.07%	0.05%	0.14%
Total	27.02%	51.45%	21.53%	100.00%

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 B.2 below shows the total percentage and peak percentage based on Table B.1 for each period split and capacity factors calculated based on it.

Table B.2 Capacity Factors Based on Time Split

Period (1)	Length in Hours (2)	Duration (3)	Peak Hour (4)	Total % (5)*	Peak Hour % (6)**	Capacity Factor = (6)/(5)
AM	3	6:00 AM-9:00 AM	7:30 AM-8:30 AM	23.43%	10.38%	0.4430
MD	6	9:00 AM-3:00 PM	11:30 AM-12:30 AM	29.79%	5.46%	0.1833
PM	3	3:00 PM-6:00 PM	4:30 PM-5:30 PM	25.73%	9.08%	0.3529
NT	12	6:00 PM-6:00 AM	7:00 PM-8:00 PM	21.05%	4.70%	0.2233
Total	24			100%		

*Total percentage based on duration (3) from Table B.1

**Total percentage based on peak hour (4) from Table B.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 B.2 shows the truck trip distribution by the time-of-day below:

Table B.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:

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

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

V/C is volume to capacity ratio

The volume-delay function developed in the model was calibrated by comparing the volumes and vehicle mile travel (VMT) by various classifications and statistical measures such as Root Mean Square Errors (RMSE). The calibration focused on replicating delay at major crossing points such as Lincoln Tunnel that influenced mode choice. Based on the results, the estimated vehicle mile travel (VMT) was within 3% of the observed data on a regional level. Similarly, when volume by county level was compared between estimated and observed, the range was within 5% (+/-). Based on the statistical measure of Root Mean Square Error (RMSE), the model had 35% on regional level which was within the FHWA standard. When R-square value by facility type was compared, it yielded value of 93% which was again higher than FHWA recommended regional R-square greater than 88%. In general, the overall model estimate replicated the observed data reasonably well.

Model Convergence

The model convergence function controls the model iterations as the iterative process approaches an optimal solution. The convergence function is mainly used in highway assignment to determine when volumes have achieved consistency between the iterations. The feedback process stops when the convergence reaches within the adopted tolerances. Highway assignment model convergence is achieved when the amount of traffic (congestion) of the individual network links is identical between iterations. Out of several

tests which can be used to determine if more iterations are necessary, two criteria's are utilized in the dissertation. These tests are as follows:

- a) **GAP** – This specifies the cutoff point based on the relative difference in system cost (volume*cost) between two iterations. The equation can be written as –

$$GAP_K = ABS(SUM_L(VE_K * COSTE_K) - SUM_L(V_{K-1} * COSTE_{K-1})) / SUM_L(V_{K-1} * COSTE_{K-1})$$

Where

K = the current iteration

SUM_L = summation over the links and, if appropriate, the turning movements in the network

VE_K = is the equilibrium weighted volumes for iteration K

$COSTE_K$ = is the cost based on the equilibrium volumes VE_K

- b) **MAXITERS** - Specifies the maximum number of assignment iterations to be performed. The maximum iterations allowed are 1000 iterations.

One of the reasons for using these two criteria is, in theory, equilibrium is reached when there is no ability for individual i-j path costs to improve. However, if there is a significant degree of congestion (which might occur in this case) it may be difficult (practically impossible) to reach a true state of equilibrium. Also, the basic measure of equilibrium is total system user cost – measured as time in most cases. Time which is a measurable quantity can be directly related to congestion, and thus most equilibrium formulations are based upon time.

APPENDIX C

TABLES USED IN CASE STUDY

The appendix includes the various table being used in the case study analysis.

Table C.1 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 user manual (Table B.2.9)

Table C.2 Percentage of Vehicle Classification Based on Fuel Type – NJCMS

Mode	Vehicle Class									Total
	LDG V	LDG T1	LDG T2	LDG T	HDG V	LDD V	LDD T	HD DV	MC	
Auto	59.55 %	30.01 %	9.88 %	0.00 %	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 %	75.0 0%	0.00 %	100.00 %

Source: NJCMS

Where:

- LDGV – Light Duty Gasoline Vehicle*
- LDGT1 – Light Duty Gasoline Truck 1*
- LDGT2 – Light Duty Gasoline Truck 2*
- HDGV – Heavy Duty Gasoline Vehicle*
- LDDV – Light Duty Diesel Vehicle*
- LDDT – Light Duty Diesel Truck*
- HDDV – Heavy Duty Diesel Vehicle*
- MC - Motorcycles*

Table C.3 Monthly Average Fuel Prices for 2015

Month	Gasoline	Diesel
Jan-2015	\$3.392	\$3.893
Feb-2015	\$3.434	\$3.984
Mar-2015	\$3.606	\$4.001
Apr-2015	\$3.735	\$3.964
May-2015	\$3.750	\$3.943
Jun-2015	\$3.766	\$3.906
Jul-2015	\$3.688	\$3.884
Aug-2015	\$3.565	\$3.838
Sep-2015	\$3.484	\$3.792
Oct-2015	\$3.255	\$3.681
Nov-2015	\$2.997	\$3.647
Dec-2015	\$2.632	\$3.411
Average	\$3.442	\$3.829

Source: Energy Information Administration

(https://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_nus_m.htm, accessed on January 5th, 2016)

Table C.4 Carbon Monoxide (CO) Emission Rates from IDAS Manual in Grams per Mile (Continued)

Speed Range	LDGV	LDGT1	LDGT2	LDGT	HdGV	LDDV	LDDT	HDDV	MC
0 5	53.73	57.64	67.91	60.72	52.81	4.35	4.87	32.91	138.01
5 10	28.61	31.37	36.96	33.04	38.12	3.23	3.62	24.47	68.11
10 15	19.53	21.87	25.76	23.04	25.88	2.26	2.54	17.16	36.91
15 20	15.97	18.15	21.38	19.12	18.57	1.66	1.86	12.60	25.53
20 25	12.91	14.92	17.58	15.72	14.08	1.28	1.43	9.68	19.71
25 30	9.98	11.79	13.89	12.42	11.28	1.03	1.15	7.78	15.88
30 35	7.97	9.65	11.37	10.17	9.55	0.86	0.97	6.55	13.05
35 40	6.51	8.09	9.53	8.52	8.55	0.76	0.85	5.77	11.00
40 45	5.39	6.90	8.13	7.27	8.09	0.70	0.78	5.32	9.62
45 50	4.55	6.00	7.07	6.32	8.08	0.68	0.76	5.14	8.79
50 55	4.36	5.80	6.83	6.11	8.54	0.68	0.77	5.19	8.63

Table C.4 (Continued) Carbon Monoxide (CO) Emission Rates from IDAS Manual in Grams per Mile

Speed Range		LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC
60	65	7.16	9.07	10.69	9.56	11.24	0.80	0.90	6.08	23.18
65	70	8.35	10.48	12.35	11.04	12.69	0.87	0.97	6.59	29.41
70	75	8.35	10.48	12.35	11.04	12.69	0.87	0.97	6.59	29.41
75	80	8.35	10.48	12.35	11.04	12.69	0.87	0.97	6.59	29.41

Source: IDAS documentation (excel sheet)

Table C.5 Hydrocarbon (HC) Emission Rates from IDAS Manual in Grams per Mile (Continued)

Speed Range		LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC
0	5	7.05	8.24	9.83	8.72	10.47	1.08	1.52	4.39	11.60
5	10	2.88	3.40	4.04	3.59	5.54	0.89	1.26	3.63	7.97
10	15	1.88	2.19	2.60	2.31	3.75	0.71	0.99	2.87	6.24
15	20	1.50	1.75	2.06	1.84	2.80	0.57	0.80	2.32	5.59
20	25	1.25	1.46	1.72	1.54	2.22	0.47	0.66	1.92	5.25
25	30	1.05	1.25	1.47	1.32	1.85	0.40	0.56	1.62	5.03
30	35	0.92	1.11	1.29	1.16	1.61	0.34	0.48	1.40	4.86
35	40	0.82	1.00	1.17	1.05	1.44	0.30	0.43	1.24	4.73
40	45	0.74	0.92	1.07	0.97	1.33	0.27	0.39	1.12	4.64
45	50	0.68	0.86	0.99	0.90	1.25	0.25	0.36	1.03	4.60
50	55	0.65	0.83	0.96	0.87	1.20	0.24	0.34	0.98	4.59
55	60	0.67	0.85	0.99	0.89	1.17	0.23	0.32	0.94	4.73
60	65	0.74	0.92	1.07	0.97	1.16	0.23	0.32	0.93	5.09

Table C.5 (Continued) Hydrocarbon (HC) Emission Rates from IDAS Manual in Grams per Mile

Speed Range		LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC
65	70	0.78	0.96	1.12	1.01	1.17	0.23	0.32	0.93	5.30
70	75	0.78	0.96	1.12	1.01	1.17	0.23	0.32	0.93	5.30
75	80	0.78	0.96	1.12	1.01	1.17	0.23	0.32	0.93	5.30

Source: IDAS documentation (excel sheet)

Table C.6 Nitrogen Oxide (NO_x) Emission Rate from IDAS Manual in Grams per Mile

Speed Range		LDGV	LDGT1	LDGT2	LDGT	HDGV	LDDV	LDDT	HDDV	MC
0	5	1.72	2.05	2.50	2.19	3.12	1.83	2.09	11.09	0.81
5	10	1.40	1.67	2.04	1.78	3.24	1.57	1.79	9.51	0.72
10	15	1.29	1.53	1.87	1.63	3.41	1.32	1.51	8.00	0.68
15	20	1.24	1.48	1.80	1.58	3.57	1.15	1.31	6.97	0.72
20	25	1.25	1.46	1.78	1.55	3.73	1.04	1.18	6.29	0.79
25	30	1.28	1.46	1.79	1.56	3.89	0.97	1.11	5.89	0.87
30	35	1.30	1.47	1.79	1.56	4.05	0.94	1.07	5.71	0.94
35	40	1.31	1.47	1.80	1.57	4.21	0.94	1.08	5.74	0.99
40	45	1.32	1.47	1.80	1.57	4.37	0.98	1.12	5.98	1.02
45	50	1.34	1.48	1.81	1.58	4.54	1.06	1.21	6.45	1.05
50	55	1.48	1.69	2.07	1.81	4.70	1.19	1.36	7.21	1.19
55	60	1.67	1.97	2.40	2.10	4.86	1.38	1.57	8.36	1.37
60	65	1.86	2.24	2.74	2.39	5.02	1.66	1.89	10.04	1.54
65	70	1.98	2.41	2.94	2.57	5.12	1.87	2.14	11.36	1.64
70	75	1.98	2.41	2.94	2.57	5.12	1.87	2.14	11.36	1.64
75	80	1.98	2.41	2.94	2.57	5.12	1.87	2.14	11.36	1.64

Source: IDAS documentation (excel sheet)

Table C.7 Mitigation Cost of Pollutants

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

Source: IDAS documentation (Table B.4.6)

Table C.8 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 Vehicle	0.00069
Single Unit Trucks	
<25,001 pounds	0.00758
25,001 - 50,000 pounds	0.03291
>50,000 pounds	0.16368
Total Single Units	0.01585
Combination Trucks	
<50,001 pounds	0.01023
50,001 - 70,000 pounds	0.02811
70,001 - 75,000 pounds	0.05312
75,001 - 80,000 pounds	0.06969
80,001 - 100,000 pounds	0.11716
> 100,001 pounds	0.26138
Total Combinations	0.03644
Total Trucks	0.02784
Total All Vehicles	0.00271

Source: <https://www.fhwa.dot.gov/policy/hcas/final/five.cfm> (Table V-9), accessed on May 12th 2016

Table C.9 Fatality Rates (Fatalities/Million Vehicle Miles Traveled) (Continued)

V/C Ratio	Freeway Auto (FFA)	Arterial Auto (FAA)	Freeway Truck (FFT)	Arterial Truck (FAT)
0.09	0.0066	0.0177	0.0066	0.0177
0.19	0.0066	0.0177	0.0066	0.0177
0.29	0.0066	0.0177	0.0066	0.0177

Table C.9 (Continued) Fatality Rates (Fatalities/Million Vehicle Miles Traveled)

V/C Ratio	Freeway Auto (FFA)	Arterial Auto (FAA)	Freeway Truck (FFT)	Arterial Truck (FAT)
0.39	0.0066	0.0177	0.0066	0.0177
0.49	0.0066	0.0177	0.0066	0.0177
0.59	0.0066	0.0177	0.0066	0.0177
0.69	0.0066	0.0177	0.0066	0.0177
0.79	0.0066	0.0177	0.0066	0.0177
0.89	0.0066	0.0177	0.0066	0.0177
0.99	0.0066	0.0177	0.0066	0.0177
1	0.0066	0.0177	0.0066	0.0177

Source: IDAS documentation (Table B.2.10)

Table C.10 Injury Rates (Injury/Million Vehicle Miles Traveled)

V/C Ratio	Freeway Auto (IFA)	Arterial Auto (IAA)	Freeway Truck (IFT)	Arterial Truck (IAT)
0.09	0.4763	1.6991	0.4763	1.6991
0.19	0.4763	1.6991	0.4763	1.6991
0.29	0.4763	1.6991	0.4763	1.6991
0.39	0.4763	1.6991	0.4763	1.6991
0.49	0.4763	1.6991	0.4763	1.6991
0.59	0.4763	1.6991	0.4763	1.6991
0.69	0.4763	1.6991	0.4763	1.6991
0.79	0.5318	1.6991	0.5318	1.6991
0.89	0.5318	1.6991	0.5318	1.6991
0.99	0.677	1.6991	0.677	1.6991
1	0.706	1.6991	0.706	1.6991

Source: IDAS documentation (Table B.2.11)

Table C.11 Property Damage Only (Property Damage/Million Vehicle Miles Traveled)
(Continued)

V/C Ratio	Freeway Auto (PFA)	Arterial Auto (PAA)	Freeway Truck (PFT)	Arterial Truck (PAT)
0.09	0.6171	2.4736	0.6171	2.4736
0.19	0.6171	2.4736	0.6171	2.4736
0.29	0.6171	2.4736	0.6171	2.4736
0.39	0.6171	2.4736	0.6171	2.4736
0.49	0.6171	2.4736	0.6171	2.4736
0.59	0.6171	2.4736	0.6171	2.4736
0.69	0.6171	2.4736	0.6171	2.4736

Table C.11 (Continued) Property Damage Only (Property Damage/Million Vehicle Miles Traveled)

V/C Ratio	Freeway Auto (PFA)	Arterial Auto (PAA)	Freeway Truck (PFT)	Arterial Truck (PAT)
0.79	0.7183	2.4736	0.7183	2.4736
0.89	0.7183	2.4736	0.7183	2.4736
0.99	0.8365	2.4736	0.8365	2.4736
1	0.9192	2.4736	0.9192	2.4736

Source: IDAS documentation (Table B.2.12)

Table C.12 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 Manual (Table 4.2)

APPENDIX D

CUBE VOYAGER SCRIPT FOR SCENARIOS

```

; Working Directory: C:\model2\Base\WithTolls\Model2\ INCLUDE THE LAST BACK SLASH
; TEMP Directory: C:\model2\Base\WithTolls\Model2\ INCLUDE THE LAST BACK SLASH
; Prefix: TPPL
; Output File: TOLLTEST5.PRN
; NJRTME Directory: C:\model2\c2015\ INCLUDE THE LAST BACK SLASH
; NJRTME SE Data File: 15VAZ\SEDATA00.DBF
; NJRTME AM Files
; Unloaded Network: AMHWYTOLL.NET This is an input into this process
; Loaded Network: AMHWYLOAD.NET This is an output of this process
; Trip Table: AMPKALLV_I78ONLY.MAT
; Turn Penalty File: 15VAN\HWAMTP.CRD
; NJRTME MD Files
; Unloaded Network: MDHWYTOLL.NET This is an input into this process
; Loaded Network: MDHWYLOAD.NET This is an output of this process
; Trip Table: MDPKALLV_I78ONLY.MAT
; Turn Penalty File: 15VAN\HWAMTP.CRD
; NJRTME PM Files
; Unloaded Network: PMHWYTOLL.NET This is an input into this process
; Loaded Network: PMHWYLOAD.NET This is an output of this process
; Trip Table: PMPKALLV_I78ONLY.MAT
; Turn Penalty File: 15VAN\HWAMTP.CRD
; NJRTME NT Files
; Unloaded Network: NTHWYTOLL.NET This is an input into this process
; Loaded Network: NTHWYLOAD.NET This is an output of this process
; Trip Table: NTPKALLV_I78ONLY.MAT
; Turn Penalty File: 15VAN\HWAMTP.CRD
; Operating Cost - Auto 0.1
; Operating Cost -Truck 0.31
; Value of Time 0.3525$ per minute Computed as average of trip purpose values of time per NJRTME
; NJRTME Logit Toll Road Model Parameters
; PctSOVETC 0.67 Percent of vehicles with ETC - SOV - (NJRTME was set for 0.65 based on 2000 data)
; PctHOVETC 0.67 Percent of vehicles with ETC - HOV - (NJRTME was set for 0.65 based on 2000 data)
; PctTrkETC 0.87 SJTPA NJRTME Ajusted Percent of vehicMaricopa
; AlphaHBW 0.1642 0.203 0.1642 0.1642Home Based Work 0.203
; AlphaHBS 0.1182 0.203 0.1182 0.1182Home Based Shop 0.203
; AlphaHBO 0.0888 0.095 0.0888 0.0888Home Based Other 0.095
; AlphaNHB 0.1468 0.13 0.1468 0.1468Non-Home Based 0.13
; AlphaTRK 0.1000 0.107 0.0933 0.1Truck coefficient 0.107
; BetaHBW 0.4324 8.02 0.4324 0.4324Home Based Work 8.02
; BetaHBS 0.3640 8.02 0.364 0.364Home Based Shop 8.02
; BetaHBO 0.2971 5.4015 0.2971 0.2971Home Based Other 5.4015
; BetaNHB 0.3610 5.9877 0.361 0.361Non-Home Based 5.9877
; BetaTRK 0.0680 0.107 0.152 0.068Truck 0.2378 0.1605 0.107
; TollBiasHBW -1.0000 0 -1.9704 0Home Based Work 0.812
; TollBiasHBS -1.0000 0 -1.4187 0Home Based Shop 0.812
; TollBiasHBO -1.0000 0 -1.0656 0Home Based Other 0.812
; TollBiasNHB -1.0000 0 -1.7616 0Non-Home Based 0.812
; TollBiasTRK -1.9000 0 0.933 0Truck 0.812
; ETCBiasHBW 0.0000 -0.203 -0.9195 0Home Based Work -0.203
; ETCBiasHBS 0.0000 -0.203 -0.7566 0Home Based Shop -0.203
; ETCBiasHBO 0.0000 -0.095 -0.6571 0Home Based Other -0.203
; ETCBiasNHB 0.0000 -0.13 -0.8514 0Non-Home Based -0.203
; ETCBiasTRK 0.0000 -0.107 0 0Truck -0.203
; Parameters for I-78 Path Variables
; I-78 Path Not I-78 Path
; I78 Links 0.5 2
; Non-I-78 Links 2 0.5
; Parameters for Truck vs Rail Mo 2Model 1 = Simple Assignment Model
; AlphaRail -2.1 Model 2 = Logit Model
; AlphaTruck 0.0 Model 3 = Variable Demand Model

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; Beta1 -0.009
; Beta2 -0.007
; Rail Rate $100.00
; Truck Rate $100.00
; Rail Time 120.0minutes
; Truck Time n/a minutes Estimated by NJRTME
; Parameters for Variable Demand Model
; AM MD PM NT
; Note: Equation is in the form Y= Alpha * X^2 + Beta * X + Constant (Demand vs Generalized Cost Equation)
; Alpha 0.0036 0.0031 0.0031 0.0061
; Beta -0.7279 -0.5193 -0.6251 -0.9463
; I-78 Potential Toll Road Users EB WB
; Btw Pennsylvania State Line and Y Y
; Btw NJ 31 and I-287 Y Y
; Btw I-287 and NJ 24 Y Y
; Btw NJ 24 and Garden State Parkw Y Y
; Btw Garden State Pkwy and NJ Tur Y Y
; I-78 Toll Road Parameters
; SOV Cost per Mile 0.1dollars per mileMinspeed 3.5
; HOV Cost per Mile 0.1dollars per mile
; Truck Cost per Mile 0.6dollars per mile Truck
; Skip AM Run 10 Enter YES to skip the AM Run
; Skip MD Run 10 Enter YES to skip the MD Run
; Skip PM Run 10 Enter YES to skip the PM Run
; Skip NT Run 10 Enter YES to skip the NT Run
; Max=20
; Use Average of 2 IteratiNO Enter YES to use average of 2 previous iterations, NO to use 1 previous iteration only
; Number of Zones 2553 Use 60 for subarea network, 2553 for NJRTM-E
; STEP 4: Toll Share: In this step, the toll vs non-toll share is computed using a logit model.
; First, we need to skim the network to find the shortest generalized cost path via I-78 and not via I-78
*erase C:\model2\Base\WithTolls\Model2\TOLLTEST5.PRN
*erase C:\model2\Base\WithTolls\Model2\TPPL*.PRN
*copy C:\model2\c2015\IITRUCK.TRP C:\model2\Base\WithTolls\Model2\IITRUCKS.TRP
*copy C:\model2\c2015\EETRFINAL.TRP C:\model2\Base\WithTolls\Model2\EETRUCKS.TRP
*copy C:\model2\c2015\EITRUCKOD.TRP C:\model2\Base\WithTolls\Model2\EIETRUCKS.TRP
*erase C:\model2\Base\WithTolls\Model2\TEMP.NET
; ITER 01
*erase C:\model2\Base\WithTolls\Model2\AMHWYLOAD01.NET
*erase C:\model2\Base\WithTolls\Model2\HWYSKMMAM01.MAT
*erase C:\model2\Base\WithTolls\Model2\AMTRIPS01.MAT
*erase C:\model2\Base\WithTolls\Model2\AMHWYLOAD01x.NET
RUN PGM=NETWORK MSG="AM ITERATION 01"
FILEI NETI[1] = "C:\model2\Base\WithTolls\Model2\AMHWYLOAD.NET""
FILEO NETO= "C:\model2\Base\WithTolls\Model2\TEMP.NET"
_VOT=0.3525 // Average Value of Time [$ /min] (per NJRTM-E)
_OPCOSTAUTO = 0.1 // Operating Cost - Auto [$ /mi] (per NJRTM-E)
_OPCOSTTRUCK = 0.31 // Operating Cost - Truck [$ /mi] (per NJRTM-E)
; We need to apply the toll scenario in this step. This is copies from the "A.s" script
; The definition of the I-78 Corridor (I78Check Field) is still done in the "A.s" script
COMP I78SOVTOLL=0.0 // SET AUTO TOLL ON I-78 or Zero
COMP I78HOVTOLL=0.0 // SET AUTO TOLL ON I-78 or Zero
COMP I78TRKTOLL=0.0 // SET TRUCK TOLL ON I-78 or Zero
COMP I78PATH_1=2.00*(LI.1.TIME_1 + _OPCOSTAUTO*LI.1.DISTANCE/_VOT + LI.1.SOVTOLL/_VOT) // THIS FIELD WILL BE
USED TO FIND THE MINIMUM Generalized Cost Path VIA I-78
COMP NOTI78PATH_1=0.5*(LI.1.TIME_1 + _OPCOSTAUTO*LI.1.DISTANCE/_VOT + LI.1.SOVTOLL/_VOT) // THIS FIELD WILL BE
USED TO FIND THE MINIMUM Generalized Cost Path NOT VIA I-78
; IF (SRI='00000078')
; List of I-78 links (A-Node and B-Nodes)
; Row 1 : I-78 EB - Pennsylvania state Line to NJ 31
; Row 2 : I-78 EB - NJ 31 to I-287
; Row 3 : I-78 EB - I-287 to NJ 24
; Row 4 : I-78 EB - NJ 24 to Garden State Parkway
; Row 5 : I-78 EB - Garden State Parkway to New Jersey Turnpike
; Row 6 : I-78 WB - New Jersey Turnpike to Garden State Parkway
; Row 6 : I-78 WB - Garden State Parkway to NJ 24
; Row 7 : I-78 WB - NJ 24 to I-287
; Row 8 : I-78 WB - I-287 to NJ 31

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; Row 9 : I-78 WB - NJ 31 to Pennsylvania state Line
IF
(A=38317,26059,26060,26078,26077,26061,26079,26080,26072,26062,26063,26379,26383,26064,26398,26396,26065,26401,2608
2,26405,26083,26408,26084,10470,26085,26938,26086,26955,26087,26956,26946,26955)
IF
(B=38317,26059,26060,26078,26077,26061,26079,26080,26072,26062,26063,26379,26383,26064,26398,26396,26065,26401,26082
,26405,26083,26408,26084,10470,26085,26938,26086,26955,26087,26956,26946,26955)
COMP I78SOVTOLL=0.1*LI.1.DISTANCE // SET SOV TOLL ON I-78 -- the toll needs to be expressed in dollars
COMP I78HOVTOLL=0.1*LI.1.DISTANCE // SET HOV TOLL ON I-78 -- the toll needs to be expressed in dollars
COMP I78TRKTOLL=0.6*LI.1.DISTANCE // SET HOV TOLL ON I-78 -- the toll needs to be expressed in dollars
COMP I78PATH_1=0.5*(LI.1.TIME_1 + _OPCOSTAUTO*LI.1.DISTANCE/_VOT + LI.1.SOVTOLL/_VOT) // THIS FIELD
WILL BE USED TO FIND THE MINIMUM Generalized Cost Path VIA I-78
COMP NOTI78PATH_1=2.00*(LI.1.TIME_1 + _OPCOSTAUTO*LI.1.DISTANCE/_VOT + LI.1.SOVTOLL/_VOT) // THIS
FIELD WILL BE USED TO FIND THE MINIMUM Generalized Cost Path NOT VIA I-78
ENDIF
ENDIF
IF
(A=26956,39522,27141,27142,26088,27151,26089,26929,26090,26932,26091,26439,26092,26351,26093,36319,26094,36324,2634
9)
IF
(B=26956,39522,27141,27142,26088,27151,26089,26929,26090,26932,26091,26439,26092,26351,26093,36319,26094,36324,26349
)
COMP I78SOVTOLL=0.1*LI.1.DISTANCE // SET SOV TOLL ON I-78 -- the toll needs to be expressed in dollars
COMP I78HOVTOLL=0.1*LI.1.DISTANCE // SET HOV TOLL ON I-78 -- the toll needs to be expressed in dollars
COMP I78TRKTOLL=0.6*LI.1.DISTANCE // SET HOV TOLL ON I-78 -- the toll needs to be expressed in dollars
COMP I78PATH_1=0.5*(LI.1.TIME_1 + _OPCOSTAUTO*LI.1.DISTANCE/_VOT + LI.1.SOVTOLL/_VOT) // THIS FIELD
WILL BE USED TO FIND THE MINIMUM Generalized Cost Path VIA I-78
COMP NOTI78PATH_1=2.00*(LI.1.TIME_1 + _OPCOSTAUTO*LI.1.DISTANCE/_VOT + LI.1.SOVTOLL/_VOT) // THIS
FIELD WILL BE USED TO FIND THE MINIMUM Generalized Cost Path NOT VIA I-78
ENDIF
ENDIF
IF
(A=36324,36322,26095,26364,26363,26096,26367,26421,26097,26423,36333,36334,26098,36335,6664,26425,26426,13507,10315,
36250,36254,36261,36262,36263,36251,26130,26131,26132,36268)
IF
(B=36324,36322,26095,26364,26363,26096,26367,26421,26097,26423,36333,36334,26098,36335,6664,26425,26426,13507,10315,
36250,36254,36261,36262,36263,36251,26130,26131,26132,36268)
COMP I78SOVTOLL=0.1*LI.1.DISTANCE // SET SOV TOLL ON I-78 -- the toll needs to be expressed in dollars
COMP I78HOVTOLL=0.1*LI.1.DISTANCE // SET HOV TOLL ON I-78 -- the toll needs to be expressed in dollars
COMP I78TRKTOLL=0.6*LI.1.DISTANCE // SET HOV TOLL ON I-78 -- the toll needs to be expressed in dollars
COMP I78PATH_1=0.5*(LI.1.TIME_1 + _OPCOSTAUTO*LI.1.DISTANCE/_VOT + LI.1.SOVTOLL/_VOT) // THIS FIELD
WILL BE USED TO FIND THE MINIMUM Generalized Cost Path VIA I-78
COMP NOTI78PATH_1=2.00*(LI.1.TIME_1 + _OPCOSTAUTO*LI.1.DISTANCE/_VOT + LI.1.SOVTOLL/_VOT) // THIS
FIELD WILL BE USED TO FIND THE MINIMUM Generalized Cost Path NOT VIA I-78
ENDIF
ENDIF
IF (A=36268,26133,26134,36271,26135,36291,36284,26136,36247,26137,36243)
IF (B=36268,26133,26134,36271,26135,36291,36284,26136,36247,26137,36243)
COMP I78SOVTOLL=0.1*LI.1.DISTANCE // SET SOV TOLL ON I-78 -- the toll needs to be expressed in dollars
COMP I78HOVTOLL=0.1*LI.1.DISTANCE // SET HOV TOLL ON I-78 -- the toll needs to be expressed in dollars
COMP I78TRKTOLL=0.6*LI.1.DISTANCE // SET HOV TOLL ON I-78 -- the toll needs to be expressed in dollars
COMP I78PATH_1=0.5*(LI.1.TIME_1 + _OPCOSTAUTO*LI.1.DISTANCE/_VOT + LI.1.SOVTOLL/_VOT) // THIS FIELD
WILL BE USED TO FIND THE MINIMUM Generalized Cost Path VIA I-78
COMP NOTI78PATH_1=2.00*(LI.1.TIME_1 + _OPCOSTAUTO*LI.1.DISTANCE/_VOT + LI.1.SOVTOLL/_VOT) // THIS
FIELD WILL BE USED TO FIND THE MINIMUM Generalized Cost Path NOT VIA I-78
ENDIF
ENDIF
IF (A=36243,26138,26139,26140,12021,26142,36159,26143,36169,26144,36164,36166,26145,36558,36531)
IF (B=36243,26138,26139,26140,12021,26142,36159,26143,36169,26144,36164,36166,26145,36558,36531)
COMP I78SOVTOLL=0.1*LI.1.DISTANCE // SET SOV TOLL ON I-78 -- the toll needs to be expressed in dollars
COMP I78HOVTOLL=0.1*LI.1.DISTANCE // SET HOV TOLL ON I-78 -- the toll needs to be expressed in dollars
COMP I78TRKTOLL=0.6*LI.1.DISTANCE // SET HOV TOLL ON I-78 -- the toll needs to be expressed in dollars
COMP I78PATH_1=0.5*(LI.1.TIME_1 + _OPCOSTAUTO*LI.1.DISTANCE/_VOT + LI.1.SOVTOLL/_VOT) // THIS FIELD
WILL BE USED TO FIND THE MINIMUM Generalized Cost Path VIA I-78
COMP NOTI78PATH_1=2.00*(LI.1.TIME_1 + _OPCOSTAUTO*LI.1.DISTANCE/_VOT + LI.1.SOVTOLL/_VOT) // THIS
FIELD WILL BE USED TO FIND THE MINIMUM Generalized Cost Path NOT VIA I-78
ENDIF
ENDIF

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ENDIF
IF (A=36539,36568,37507,37912,9504,36170,9458,36163,36165,9425,36160,9393,36157,36158,8672,25125,5577,7163,7162)
IF (B=36539,36568,37507,37912,9504,36170,9458,36163,36165,9425,36160,9393,36157,36158,8672,25125,5577,7163,7162)
  COMP I78SOVTOLL=0.1*LI.1.DISTANCE // SET SOV TOLL ON I-78 -- the toll needs to be expressed in dollars
  COMP I78HOVTOLL=0.1*LI.1.DISTANCE // SET HOV TOLL ON I-78 -- the toll needs to be expressed in dollars
  COMP I78TRKTOLL=0.6*LI.1.DISTANCE // SET HOV TOLL ON I-78 -- the toll needs to be expressed in dollars
  COMP I78PATH_1=0.5*(LI.1.TIME_1 + _OPCOSTAUTO*LI.1.DISTANCE/_VOT + LI.1.SOVTOLL/_VOT) // THIS FIELD
WILL BE USED TO FIND THE MINIMUM Generalized Cost Path VIA I-78
  COMP NOTI78PATH_1=2.00*(LI.1.TIME_1 + _OPCOSTAUTO*LI.1.DISTANCE/_VOT + LI.1.SOVTOLL/_VOT) // THIS
FIELD WILL BE USED TO FIND THE MINIMUM Generalized Cost Path NOT VIA I-78
ENDIF
ENDIF
IF (A=7162,36245,36246,6981,36282,6963,36292,36273,6943) // This represents the links in subarea network
IF (B=7162,36245,36246,6981,36282,6963,36292,36273,6943) // This represents the links in subarea network
  COMP I78SOVTOLL=0.1*LI.1.DISTANCE // SET SOV TOLL ON I-78 -- the toll needs to be expressed in dollars
  COMP I78HOVTOLL=0.1*LI.1.DISTANCE // SET HOV TOLL ON I-78 -- the toll needs to be expressed in dollars
  COMP I78TRKTOLL=0.6*LI.1.DISTANCE // SET HOV TOLL ON I-78 -- the toll needs to be expressed in dollars
  COMP I78PATH_1=0.5*(LI.1.TIME_1 + _OPCOSTAUTO*LI.1.DISTANCE/_VOT + LI.1.SOVTOLL/_VOT) // THIS FIELD
WILL BE USED TO FIND THE MINIMUM Generalized Cost Path VIA I-78
  COMP NOTI78PATH_1=2.00*(LI.1.TIME_1 + _OPCOSTAUTO*LI.1.DISTANCE/_VOT + LI.1.SOVTOLL/_VOT) // THIS
FIELD WILL BE USED TO FIND THE MINIMUM Generalized Cost Path NOT VIA I-78
ENDIF
ENDIF
IF
(A=6930,36267,6915,36266,6904,6894,6865,36253,7106,36257,25147,8654,6663,36336,36337,6635,36332,26422,26424,6613,264
20,26366,26365,6583,26362,6547,36323,6537)
IF
(B=6930,36267,6915,36266,6904,6894,6865,36253,7106,36257,25147,8654,6663,36336,36337,6635,36332,26422,26424,6613,2642
0,26366,26365,6583,26362,6547,36323,6537)
  COMP I78SOVTOLL=0.1*LI.1.DISTANCE // SET SOV TOLL ON I-78 -- the toll needs to be expressed in dollars
  COMP I78HOVTOLL=0.1*LI.1.DISTANCE // SET HOV TOLL ON I-78 -- the toll needs to be expressed in dollars
  COMP I78TRKTOLL=0.6*LI.1.DISTANCE // SET HOV TOLL ON I-78 -- the toll needs to be expressed in dollars
  COMP I78PATH_1=0.5*(LI.1.TIME_1 + _OPCOSTAUTO*LI.1.DISTANCE/_VOT + LI.1.SOVTOLL/_VOT) // THIS FIELD
WILL BE USED TO FIND THE MINIMUM Generalized Cost Path VIA I-78
  COMP NOTI78PATH_1=2.00*(LI.1.TIME_1 + _OPCOSTAUTO*LI.1.DISTANCE/_VOT + LI.1.SOVTOLL/_VOT) // THIS
FIELD WILL BE USED TO FIND THE MINIMUM Generalized Cost Path NOT VIA I-78
ENDIF
ENDIF
IF
(A=6537,36318,6526,26350,6491,26438,25134,26348,26931,7356,26930,7238,39520,27152,7237,27140,27139,26957)
IF (B=6537,36318,6526,26350,6491,26438,25134,26348,26931,7356,26930,7238,39520,27152,7237,27140,27139,26957)
  COMP I78SOVTOLL=0.1*LI.1.DISTANCE // SET SOV TOLL ON I-78 -- the toll needs to be expressed in dollars
  COMP I78HOVTOLL=0.1*LI.1.DISTANCE // SET HOV TOLL ON I-78 -- the toll needs to be expressed in dollars
  COMP I78TRKTOLL=0.6*LI.1.DISTANCE // SET HOV TOLL ON I-78 -- the toll needs to be expressed in dollars
  COMP I78PATH_1=0.5*(LI.1.TIME_1 + _OPCOSTAUTO*LI.1.DISTANCE/_VOT + LI.1.SOVTOLL/_VOT) // THIS FIELD
WILL BE USED TO FIND THE MINIMUM Generalized Cost Path VIA I-78
  COMP NOTI78PATH_1=2.00*(LI.1.TIME_1 + _OPCOSTAUTO*LI.1.DISTANCE/_VOT + LI.1.SOVTOLL/_VOT) // THIS
FIELD WILL BE USED TO FIND THE MINIMUM Generalized Cost Path NOT VIA I-78
ENDIF
ENDIF
IF
(A=26957,7236,26958,26945,7318,26939,7235,10461,10471,7306,26407,7234,26406,7233,26402,7378,26397,26395,7232,26382,2
6378,7231,7230,26081,7229,7228,7353,25111,7316,26080,26076)
IF
(B=26957,7236,26958,26945,7318,26939,7235,10461,10471,7306,26407,7234,26406,7233,26402,7378,26397,26395,7232,26382,26
378,7231,7230,26081,7229,7228,7353,25111,7316,26080,26076)
  COMP I78SOVTOLL=0.1*LI.1.DISTANCE // SET SOV TOLL ON I-78 -- the toll needs to be expressed in dollars
  COMP I78HOVTOLL=0.1*LI.1.DISTANCE // SET HOV TOLL ON I-78 -- the toll needs to be expressed in dollars
  COMP I78TRKTOLL=0.6*LI.1.DISTANCE // SET HOV TOLL ON I-78 -- the toll needs to be expressed in dollars
  COMP I78PATH_1=0.5*(LI.1.TIME_1 + _OPCOSTAUTO*LI.1.DISTANCE/_VOT + LI.1.SOVTOLL/_VOT) // THIS FIELD
WILL BE USED TO FIND THE MINIMUM Generalized Cost Path VIA I-78
  COMP NOTI78PATH_1=2.00*(LI.1.TIME_1 + _OPCOSTAUTO*LI.1.DISTANCE/_VOT + LI.1.SOVTOLL/_VOT) // THIS
FIELD WILL BE USED TO FIND THE MINIMUM Generalized Cost Path NOT VIA I-78
ENDIF
ENDIF
; ;ENDRUN
; ;RUN PGM=NETWORK MSG="AM"
; ;FILEI NETI[1]= "C:\model2\Base\WithTolls\Model2\TEMP.NET"

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; FILEO NETO= "C:\model2\Base\WithTolls\Model2\TEMP2.NET"
_quescale = 0.75 ; parameter to scale queuing formula estimates
;----- SET DEBUG PATH, IF DESIRED -----
_init=0
array ptrc=12, pdfc=12
;----- SET POINTER FOR VDF INDEX -----
;----- SET FLAG FOR PROCESSING VDF (0=FIXED TIME) -----
ptrc[1]= 2
ptrc[2]= 2
ptrc[3]= 2
ptrc[4]= 2
ptrc[5]= 2
ptrc[6]= 2
ptrc[7]= 2
ptrc[8]= 2
ptrc[9]= 1
ptrc[10]=1
ptrc[11]=1
ptrc[12]=1
pdfc[1]= 1
pdfc[2]= 1
pdfc[3]= 1
pdfc[4]= 1
pdfc[5]= 1
pdfc[6]= 1
pdfc[7]= 1
pdfc[8]= 1
pdfc[9]= 1
pdfc[10]= 1
pdfc[11]= 1
pdfc[12]= 0
eetctf = 0 ; flag to indicate if region has exclusive ETC facilities
;----- SET POINTERS FOR LINKCLASS CODE -----
;----- SET LINKCLASS FOR VDF INDEX -----
linkclass=(ptrc[li.1.ft]-1)*20 + li.1.ft
;----- DO ANY OVERRIDE BASED ON SPECIFIC CONDITIONS UNDER VDF OPTION=4-----
if (ptrc[li.1.ft]=4 && li.1.tcd=5 ) linkclass=73
if (ptrc[li.1.ft]=4 && li.1.tcd=6 ) linkclass=74
if (ptrc[li.1.ft]=4 && li.1.tcd=7 )
linkclass=75
lw.arrtyp=0.40
endif
if (ptrc[li.1.ft]=4 && li.1.tcd=8 )
linkclass=75
lw.arrtyp=0.60
endif
if (ptrc[li.1.ft]=4 && li.1.tcd=9 )
linkclass=75
lw.arrtyp=0.80
endif
if (ptrc[li.1.ft]=4 && li.1.tcd=1 )
linkclass=78
endif
if (ptrc[li.1.ft]=4 && li.1.tcd=2 )
if (li.1.lanesAM=1) linkclass=79
if (li.1.lanesAM>1) linkclass=80
endif
if (ptrc[li.1.ft]=4 && li.1.tcd=3 ) linkclass=81
;----- BYPASS REVISED TRAVEL TIME CALCULATIONS IF LINKCLASS=99 -----
if (pdfc[li.1.ft]=0 || li.1.fixtime=1) linkclass=99
;----- BYPASS FLOOR SPEED FOR OPTION 2 BY SETTING LINKCLASS=98 -----
if (pdfc[li.1.ft]<>0 && ptrc[li.1.ft]=2 && li.1.fixcap=1) linkclass=98
;----- NOTE THAT BY FACTORING TRUCKS TO PCES, WE CAN'T DIRECTLY -----
;----- COMPARE "V" TO AADTs, WHICH HAVE BEEN ADJUSTED FOR AXLES -----
V=V1_1+V2_1+V3_1+V4_1+V5_1+V6_1+1.75*(V7_1+V8_1+V9_1)
C=li.1.LW_CAPACITY_1 ;1.75 is the PCE factor for trucks.
;----- OPTION 1 - STANDARD BPR FORMULA -----

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    if (linkclass=1-12 && li.1.lanesAM=1-9)
    timex =min(t0 *(1 + 0.15 * (v/c) ^4),li.1.TIME_1)
    endif
;----- OPTION 2 - HCM 2000 RECOMMENDED BPR PARAMETERS -----
;----- UNDER THIS OPTION RAMP ARE TREATED AS FOLLOWS:-----
;----- HIGH SPEED RAMP ( .25,9) -----
;----- MED. SPEED RAMP (1.00,9) CLASS 3 ARTERIAL -----
;----- LOW SPEED RAMP (1.11,9) CLASS 4 ARTERIAL -----
;----- EMPLOY SIMPLE QUEUING FORMULA FOR OVER CAPACITY LINKS -----
;----- FORMULA IS ENABLED FOR ALL LINKS WHERE "QUEFLG=1" -----
;----- FORMULA IS CAN BE SCALED WITH PARAMETER QUESCALE -----
;----- NOTE THAT FORMULA IS OPERABLE ONLY IF V/C >1.0 -----
    if (linkclass=21-29 && li.1.lanesAM=1-9 && li.1.lanesPM=1-9)
    timex = min(t0 *(1 + li.1.alcoeff * (v/c)^li.1.btcoeff) +
    MIN(1 ,10000*max(0,(v/c-1))) * li.1.queflg*(120/2)*(1-c/max(v,1))*_quescale,(li.1.distance/15.0)*60.0,li.1.TIME_1)
    endif
;----- IF TC=98 THEN DO NOT USE FLOOR SPEED TO LIMIT DELAY -----
if (linkclass=98 && li.1.lanesAM=1-9 && li.1.lanesPM=1-9)
    timex = t0 *(1 + li.1.alcoeff * (v/c)^li.1.btcoeff) + MIN(1 ,10000*max(0,(v/c-1))) * li.1.queflg*(120/2)*(1-
c/max(v,1))*_quescale
    endif
;----- OPTION 3 - AKCELIK FORMULA -----
if (linkclass=41-52 && li.1.lanesAM=1-9 && li.1.lanesPM=1-9)
    timex = (li.1.distance*((t0/60.0)/li.1.distance)+(0.25*(1.0*(v/c-1)+((v/c-1)^2+8.0*li.1.jfact*(v/c)/(c*1.0))^0.5)))*60.0
    endif
;----- OPTION 4 - HCM APPROXIMATION OF TCD-RELATED DELAY -----
;----- NOTE THAT THIS FORMULA ESTIMATES HOURS OF DELAY, SO MULTIPLY BY 60 TO CONVERT TO MINUTES -----
;----- NOTE ALSO THAT ZDELAY IS ALREADY INCLUDED IN THE FF TRAVEL TIME "TO" -----
if (linkclass=41-71 && li.1.lanesAM=1-9 && li.1.lanesPM=1-9)
    timex = t0 + (0.25*((v/c-1) + ((v/c-1)^2 + (16*li.1.jfact*(v/c)*(li.1.distance^2)))^0.5) ) * 60.0
    endif
if (linkclass=72 && li.1.lanesAM=1-9 && li.1.lanesPM=1-9)
    timex = t0 *(1 + 0.10 * (v/c) ^5)
    endif
;----- UNDER THIS OPTION, OVERLAY SPECIFIC FUNCTIONS FOR SIGNALIZED TCD -----
;----- NOTE THAT THESE EQUATIONS ARE IN SECONDS, SO DIVIDE BY 60.0 TO CONVERT TO MINUTES -----
if (linkclass=73 && li.1.lanesAM=1-9 && li.1.lanesPM=1-9)
    timex = t0 + ((1)*(0.5*li.1.sigcyc*(1-li.1.gc)^2)/(1-(min(1,v/c)*li.1.gc)) + 900*((v/c-1) + ((v/c-
1)^2+8*min(max(0.13,(0.13+(v/c-.50)*.75)),0.50)*(v/c)/c)^0.5))/60.0
    endif
if (linkclass=74 && li.1.lanesAM=1-9 && li.1.lanesPM=1-9)
    timex = t0 + ((1)*(0.5*li.1.sigcyc*(1-li.1.gc)^2)/(1-(min(1,v/c)*li.1.gc)) + 900*((v/c-1) + ((v/c-
1)^2+8*0.50*(v/c)/c)^0.5))/60.0
    endif
if (linkclass=75 && li.1.lanesAM=1-9 && li.1.lanesPM=1-9)
    timex = t0 + (((1-lw.arrtyp)/(1-li.1.gc))*(0.5*li.1.sigcyc*(1-li.1.gc)^2)/(1-(min(1,v/c)*li.1.gc)) + 900*((v/c-1) + ((v/c-
1)^2+8*0.50*(v/c)/c)^0.5))/60.0
    endif
;----- UNDER THIS OPTION, OVERLAY SPECIFIC FUNCTIONS FOR UNSIGNALIZED TCD (STOPS & YIELD ) ---
;----- 78= TWO-WAY STOP, 79=ALLWAY STOP 1 LANE, 80=ALLWAY STOP 2 LANE, 81=YIELD -----
if (linkclass=78 && li.1.lanesAM=1-9 && li.1.lanesPM=1-9)
    timex = t0 + ((3600*v/c / max(1,v)) + 900*((v/c-1) + ((v/c-1)^2+(8*v/c^2)/ max(1,v))^0.5))/60.0
    endif
if (linkclass=79 && li.1.lanesAM=1-9 && li.1.lanesPM=1-9)
    timex = t0 + ( 6358.4*(v/1000)^4- 5918.4*(v/1000)^3+2019.7*(v/1000)^2-261.49*(v/1000)+22)/60.0
    endif
if (linkclass=80 && li.1.lanesAM=1-9 && li.1.lanesPM=1-9)
    timex = t0 + ( 185.48*(v/1000)^4- 307.22*(v/1000)^3+184.37*(v/1000)^2-34.719*(v/1000)+12)/60.0
    endif
if (linkclass=81 && li.1.lanesAM=1-9 && li.1.lanesPM=1-9)
    timex = t0 * (1+ 1.75*(v/c)^6)
    endif
;----- THIS FUNCTION HOLDS TIME FIXED (APPROPRIATE FOR ZONAL CONNECTORS AND SPECIAL SITUATIONS -----
if (linkclass=99 && li.1.lanesAM=1-9 && li.1.lanesPM=1-9)
    timex = t0
    endif
if (li.1.lanesAM=0)

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        timex = t0
    endif
    if (li.1.lanesPM=0)
        timex = t0
    endif
ENDRUN
RUN PGM=HIGHWAY MSG="AM ITERATION 01"
; 01
FILEI NET1 = "C:\model2\Base\WithTolls\Model2\TEMP.NET"
FILEO MATO[1] = "C:\model2\Base\WithTolls\Model2\HWYSKMAM01.MAT",
    mo=1-33 dec=33*5 name=DIST1, I78PATH1, NOTI78PATH1, TIME1, SOVTOLL1, HOVTOLL1, TRKTOLL1, I78SOVTOLL1,
I78HOVTOLL1,I78TRKTOLL1, I78CHEK1,
    DIST2, I78PATH2, NOTI78PATH2, TIME2, SOVTOLL2, HOVTOLL2, TRKTOLL2, I78SOVTOLL2, I78HOVTOLL2,I78TRKTOLL2,
I78CHEK2,
    DIST3, I78PATH3, NOTI78PATH3, TIME3, SOVTOLL3, HOVTOLL3, TRKTOLL3, I78SOVTOLL3, I78HOVTOLL3,I78TRKTOLL3,
I78CHEK3
phase=iloop
    path=li.TIME_1, dec=1, ; Skim - Minimum Time Via All Routes
        mw[1]=pathtrace(li.DISTANCE), noaccess=0, ; DISTANCE - TOTAL
        mw[2]=pathtrace(li.I78PATH_1), noaccess=0, ; Generalized Cost - I-78
        mw[3]=pathtrace(li.NOTI78PATH_1), noaccess=0, ; Generalized Cost- NOT I-78
        mw[4]=pathtrace(li.TIME_1), noaccess=0, ; CONGESTED TIME
        mw[5]=pathtrace(li.SOVTOLL), noaccess=0, ; SOV TOLL
        mw[6]=pathtrace(li.HOVTOLL), noaccess=0, ; HOV TOLL
        mw[7]=pathtrace(li.TRKTOLL), noaccess=0, ; TRUCK TOLL
        mw[8]=pathtrace(li.I78SOVTOLL), noaccess=0, ; I-78 SOV TOLL
        mw[9]=pathtrace(li.I78HOVTOLL), noaccess=0, ; I-78 SOV TOLL
        mw[10]=pathtrace(li.I78TRKTOLL), noaccess=0, ; I-78 TRUCK TOLL
        mw[11]=pathtrace(li.I78CHECK), noaccess=0 ; I-78 CHECK
    path=li.I78PATH_1, dec=1, ; Skim - Minimum Time Via I-78
        mw[12]=pathtrace(li.DISTANCE), noaccess=0, ; DISTANCE - TOTAL
        mw[13]=pathtrace(li.I78PATH_1), noaccess=0, ; Generalized Cost - I-78
        mw[14]=pathtrace(li.NOTI78PATH_1), noaccess=0, ; Generalized Cost - NOT I-78
        mw[15]=pathtrace(li.TIMEX), noaccess=0, ; CONGESTED TIME
        mw[16]=pathtrace(li.SOVTOLL), noaccess=0, ; SOV TOLL
        mw[17]=pathtrace(li.HOVTOLL), noaccess=0, ; HOV TOLL
        mw[18]=pathtrace(li.TRKTOLL), noaccess=0, ; TRUCK TOLL
        mw[19]=pathtrace(li.I78SOVTOLL), noaccess=0, ; I-78 SOV TOLL
        mw[20]=pathtrace(li.I78HOVTOLL), noaccess=0, ; I-78 HOV TOLL
        mw[21]=pathtrace(li.I78TRKTOLL), noaccess=0, ; I-78 TRUCK TOLL
        mw[22]=pathtrace(li.I78CHECK), noaccess=0 ; I-78 CHECK
    path=li.NOTI78PATH_1, dec=1, ; Skim - Minimum Time Not Via I-78
        mw[23]=pathtrace(li.DISTANCE), noaccess=0, ; DISTANCE - TOTAL
        mw[24]=pathtrace(li.I78PATH_1), noaccess=0, ; Generalized Cost - I-78
        mw[25]=pathtrace(li.NOTI78PATH_1), noaccess=0, ; Generalized Cost - NOT I-78
        mw[26]=pathtrace(li.TIMEX), noaccess=0, ; CONGESTED TIME
        mw[27]=pathtrace(li.SOVTOLL), noaccess=0, ; SOV TOLL
        mw[28]=pathtrace(li.HOVTOLL), noaccess=0, ; HOV TOLL
        mw[29]=pathtrace(li.TRKTOLL), noaccess=0, ; TRUCK TOLL
        mw[30]=pathtrace(li.I78SOVTOLL), noaccess=0, ; I-78 SOV TOLL
        mw[31]=pathtrace(li.I78HOVTOLL), noaccess=0, ; I-78 HOV TOLL
        mw[32]=pathtrace(li.I78TRKTOLL), noaccess=0, ; I-78 TRUCK TOLL
        mw[33]=pathtrace(li.I78CHECK), noaccess=0 ; I-78 CHECK
endphase
ENDRUN
RUN PGM=MATRIX MSG="AM ITERATION 01"
ZONES = 2553
FILEI MATI[1] = "C:\model2\Base\WithTolls\Model2\HWYSKMAM01.MAT"
FILEI MATI[2] = "C:\model2\Base\WithTolls\Model2\AMPKALLV_I78ONLY.MAT"
FILEO MATO[3] = "C:\model2\Base\WithTolls\Model2\AMTRIPS01.MAT",
    mo=31-42, 77-79, 7-9, 80-84 dec=23*5 name=I78AUTOHBO, I78AUTOHBNW, I78AUTOHBO, I78AUTONHB, I78AUTOALL,
I78TRK, NonI78AUTOHBNW, NonI78AUTOHBNW,
    NonI78AUTOHBO, NonI78AUTONHB, NonI78AUTOALL, NonI78TRK, LigPT, MedPT, HvyPT, LigTrips, MedTrips,
HvyTrips, I78AGCost, NonI78AGCost, I78TGCost, NonI78TGCost, VARTKGCost
FILEI MATI[4] = "C:\model2\Base\WithTolls\Model2\IITRUCKS.TRP"
; Table 1: Medium; Table 2: Heavy; Table 3: Light
FILEI MATI[5] = "C:\model2\Base\WithTolls\Model2\EETRUCKS.TRP"

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; Table 1: Medium; Table 2: Heavy
FILEI MATI[6] = "C:\model2\Base\WithTolls\Model2\EIETRUCKS.TRP"
; Table 1: Medium; Table 2: Heavy, Table 3: Medium (Intermodal); Table 4: Heavy (Intermodal), Table 5: Medium
(EIE); Table 6: Heavy (EIE)
;ZDATA[1]="c:\jobs\NJIT\NJRTME\SEDATA.DBF", ZONE=#1, INCOME=#12
OPCOSTAUTO = 0.1 // Operating Cost - Auto (per NJRTM-E)
OPCOSTTRUCK = 0.31 // Operating Cost - Truck (per NJRTM-E)
PCTSOVETC = 0.67 // Percent of vehicles with ETC - SOV - (NJRTME was set for 0.65 based on 2000 data)
PCTHOVETC = 0.67 // Percent of vehicles with ETC - SOV - (NJRTME was set for 0.65 based on 2000 data)
PCTTRKETC = 0.87 // Percent of vehicles with ETC - SOV - (NJRTME was set for 0.65 based on 2000 data)
; USE FILE INTRUCK.TRP to SPLIT TRUCK TRIPS AMONG LIGHT, MEDIUM AND HEAVY TRUCKS
JLOOP
mw[1]=(mi.2.1+mi.2.2+mi.2.3+mi.2.4+mi.2.5+mi.2.6+mi.2.7+mi.2.8+mi.2.9+mi.2.10+mi.2.11+mi.2.12+mi.2.13+mi.2.14+mi.2.15)
// Check whether best i-78 path includes any I-78 links
; (1=HBW SOV, 2=HBS SOV, 3=HBO SOV, 4=NHB SOV, 8=TRUCK, 9=HBW HOV, 10=HBS HOV, 11=HBO HOV, 12=NHB HOV)
mw[3]=mi.2.1*1.0/10.0 // Auto Trips - SOV - HBW
mw[4]=mi.2.2*1.0/10.0 // Auto Trips - SOV - HBS
mw[5]=mi.2.3*1.0/10.0 // Auto Trips - SOV - HBO
mw[6]=mi.2.4*1.0/10.0 // Auto Trips - SOV - NHB
mw[13]=mi.2.9*1.0/10.0 // Auto Trips - HOV - HBW
mw[14]=mi.2.10*1.0/10.0 // Auto Trips - HOV - HBS
mw[15]=mi.2.11*1.0/10.0 // Auto Trips - HOV - HBO
mw[16]=mi.2.12*1.0/10.0 // Auto Trips - HOV - NHB
mw[86]=(mw[3]+mw[13])*0.1642/0.4324+(mw[4]+mw[14])*0.1182/0.364+(mw[5]+mw[15])*0.0888/0.2971+
(mw[6]+mw[16])*0.1468/0.361)/max(0.01,(mw[3]+mw[4]+mw[5]+mw[6]+mw[13]+mw[14]+mw[15]+mw[16]))
; Divide truck trips into Light, Medium and Heavy categories. Add Internal and External Truck Trips Together // Weighted
value of time
IF (mi.4.3+mi.4.1+mi.4.2+mi.5.1+mi.5.2+mi.6.1+mi.6.2+mi.6.3+mi.6.4+mi.6.5+mi.6.6==0)
mw[7]=mi.2.8*0.33*1.0/10.0 // Light Truck Trips
mw[8]=mi.2.8*0.33*1.0/10.0 // Medium Truck Trips
mw[9]=mi.2.8*0.33*1.0/10.0 // Heavy Truck Trips
ELSE mw[7]=mi.2.8*1.0/10.0*(mi.4.3/(mi.4.3+mi.4.1+mi.4.2+mi.5.1+mi.5.2+mi.6.1+mi.6.2+mi.6.3+mi.6.4+mi.6.5+mi.6.6)) //
Light Truck
mw[8]=mi.2.8*1.0/10.0*((mi.4.1+mi.5.1+mi.6.1+mi.6.3+mi.6.5)/(mi.4.3+mi.4.1+mi.4.2+mi.5.1+mi.5.2+mi.6.1+mi.6.2+mi.6.3+mi.6.4+
mi.6.5+mi.6.6)) // Medium Truck Trips
mw[9]=mi.2.8*1.0/10.0*((mi.4.2+mi.5.2+mi.6.2+mi.6.4+mi.6.6)/(mi.4.3+mi.4.1+mi.4.2+mi.5.1+mi.5.2+mi.6.1+mi.6.2+mi.6.3+mi.6.4+
mi.6.5+mi.6.6)) // Heavy Truck Trips
ENDIF
mw[21]=mi.1.12-mi.1.23 // Distance Differential - Toll Route vs Non Toll Route
mw[22]=mi.1.15-mi.1.26 // Time Differential - Toll Route vs Non Toll Route
mw[23]=mi.1.16+mi.1.19-mi.1.27-mi.1.30 // SOV Toll Cost Differential - Toll Route vs Non Toll Route
mw[24]=mi.1.17+mi.1.20-mi.1.28-mi.1.31 // HOV Toll Cost Differential - Toll Route vs Non Toll Route
mw[25]=mi.1.18+mi.1.21-mi.1.29-mi.1.32 // Truck Toll Cost Differential - Toll Route vs Non Toll Route
mw[26]=OPCOSTAUTO*mw[21]+mw[23] // Total SOV Cost Differential - Toll Route vs Non Toll Route ($)
mw[27]=OPCOSTAUTO*mw[21]+mw[24] // Total HOV Cost Differential - Toll Route vs Non Toll Route ($)
mw[28]=(OPCOSTTRUCK*mw[21]+mw[25])*(2.0/6.0) // Total Light Truck Cost Differential - Toll Route vs Non Toll Route ($)
mw[29]=(OPCOSTTRUCK*mw[21]+mw[25])*(4.0/6.0) // Total Medium Truck Cost Differential - Toll Route vs Non Toll Route ($)
mw[30]=(OPCOSTTRUCK*mw[21]+mw[25])*(6.0/6.0) // Total Heavy Truck Cost Differential - Toll Route vs Non Toll Route ($)
IF (mw[1]==0.0) // IF the I-78 and Non-I78 paths do not include any I-78 links then set the I-78 and non-I78
trips to zero
mw[31]=0 // I78 AUTO TRIPS - HBW
mw[32]=0 // I78 AUTO TRIPS - HBNW
mw[33]=0 // I78 AUTO TRIPS - HBO
mw[34]=0 // I78 AUTO TRIPS - NHB
mw[35]=0 // I78 AUTO TRIPS - All
mw[36]=0 // I78 TRUCK TRIPS
mw[37]=0 // Non-I78 AUTO TRIPS - HBW
mw[38]=0 // Non-I78 AUTO TRIPS - HBS
mw[39]=0 // Non-I78 AUTO TRIPS - HBO
mw[40]=0 // Non-I78 AUTO TRIPS - NHB
mw[41]=0 // Non-I78 AUTO TRIPS - All
mw[42]=0 // Non-I78 TRUCK TRIPS
mw[80]=OPCOSTAUTO*mi.1.1+mw[86]*mi.1.4+mi.1.5+mi.1.8 // SOV GENERALIZED COST VIA I-78
mw[81]=OPCOSTAUTO*mi.1.1+mw[86]*mi.1.4+mi.1.5+mi.1.8 // SOV GENERALIZED COST VIA non I-78
mw[82]=OPCOSTTRUCK*mi.1.1+0.1/0.068*mi.1.4+ mi.1.7+mi.1.10 // Truck Generalized Cost via I-78
mw[83]=OPCOSTTRUCK*mi.1.1+0.1/0.068*mi.1.4+ mi.1.7+mi.1.10 // Truck Generalized Cost via non I-78
ENDIF

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; If the I-78 and NonI78 trip lengths are not the same, then we need to compute the new trips
; Toll Share = 1.0 / (1 + exp( ALPHA * DELTAT + BETA * COST/INCOME + TOLLBIASc + ETCBIAS))
; Generalized Cost = f (Travel Distance, Travel Time and Toll)
mw[80]=OPCOSTAUTO*mi.1.12+mw[86]*mi.1.15+mi.1.16+mi.1.19 // SOV GENERALIZED COST VIA I78
mw[81]=OPCOSTAUTO*mi.1.23+mw[86]*mi.1.26+mi.1.27+mi.1.30 // SOV GENERALIZED COST VIA non I78
mw[82]=OPCOSTTRUCK*mi.1.12+0.1/0.068*mi.1.15+ mi.1.18+mi.1.21 // Truck Generalized Cost via I-78
mw[83]=OPCOSTTRUCK*mi.1.23+0.1/0.068*mi.1.26+ mi.1.29+mi.1.32 // Truck Generalized Cost via non I-78
mw[84]=OPCOSTTRUCK*mi.1.1+0.1/0.068*mi.1.4+ mi.1.7+mi.1.10 // Truck Generalized Cost via I-78 at iteration zero
IF (mw[1]>0.0) // IF the I-78 path includes I-78 links
ALPHAHBW = 0.1642
ALPHAHBS = 0.1182
ALPHAHBO = 0.0888
ALPHANHB = 0.1468
ALPHATRK = 0.1
BETAHBW = 0.4324
BETAHBS = 0.364
BETAHBO = 0.2971
BETANHB = 0.361
BETATRK = 0.068
TOLLBIASHBW = -1
TOLLBIASHBS = -1
TOLLBIASHBO = -1
TOLLBIASNHB = -1
TOLLBIASTRK = -1.9
ETCBIASHBW = 0
ETCBIASHBS = 0
ETCBIASHBO = 0
ETCBIASNHB = 0
ETCBIASTRK = 0
IF (mw[3]==0)
mw[31]=0
mw[37]=0
ENDIF
IF (mw[4]==0)
mw[32]=0
mw[38]=0
ENDIF
IF (mw[5]==0)
mw[33]=0
mw[39]=0
ENDIF
IF (mw[6]==0)
mw[34]=0
mw[40]=0
ENDIF
IF (mw[7]==0)
mw[36]=0
mw[42]=0
ENDIF
; The logit model is applied to each of the auto trip purposes HBW, HBS, HBO and NHB. Auto trips are broken out by SOV and
HOV trips
; The logit model is also applied separately to vehicles with and without EZPass
IF (mw[3]+mw[13]>0)
; I78 AUTO TRIPS - HBW - SOV AND HOV
mw[31]=PCTSOVETC * mw[3] * ( 1.0 / (1.0 + EXP (ALPHAHBW * mw[22] + BETAHBW * mw[26] + TOLLBIASHBW +
ETCBIASHBW ) ) ) +
(1.0-PCTSOVETC) * mw[3] * ( 1.0 / (1.0 + EXP (ALPHAHBW * mw[22] + BETAHBW * mw[26] + TOLLBIASHBW + 0.00 ) ) )
+
PCTHOVETC * mw[13] * ( 1.0 / (1.0 + EXP (ALPHAHBW * mw[22] + BETAHBW * mw[27] + TOLLBIASHBW + ETCBIASHBW )
) ) +
(1.0-PCTHOVETC) * mw[13] * ( 1.0 / (1.0 + EXP (ALPHAHBW * mw[22] + BETAHBW * mw[27] + TOLLBIASHBW + 0.00 ) ) )
; NON I78 AUTO TRIPS - HBW
mw[37]=mw[3]+mw[13]-mw[31]
ENDIF
IF (mw[4]+mw[14]>0)
; I78 AUTO TRIPS - HBS - SOV AND HOV

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mw[32]=PCTSOVETC * mw[4] * ( 1.0 / (1.0 + EXP (ALPHAHBS * mw[22] + BETAHBS * mw[26] + TOLLBIASHBS + ETCBIASHBS )
)) +
(1.0-PCTSOVETC) * mw[4] * ( 1.0 / (1.0 + EXP (ALPHAHBS * mw[22] + BETAHBS * mw[26] + TOLLBIASHBS + 0.00 ) ) ) +
PCTHOVETC * mw[14] * ( 1.0 / (1.0 + EXP (ALPHAHBS * mw[22] + BETAHBS * mw[27] + TOLLBIASHBS + ETCBIASHBS ) ) ) +
(1.0-PCTHOVETC) * mw[14] * ( 1.0 / (1.0 + EXP (ALPHAHBS * mw[22] + BETAHBS * mw[27] + TOLLBIASHBS + 0.00 ) ) )
; NON I78 AUTO TRIPS - HBS
mw[38]=mw[4]+mw[14]-mw[32]
ENDIF
IF (mw[5]+mw[15]>0)
; I78 AUTO TRIPS - HBO - SOV AND HOV
mw[33]=PCTSOVETC * mw[5] * ( 1.0 / (1.0 + EXP (ALPHAHBO * mw[22] + BETAHBO * mw[26] + TOLLBIASHBO + ETCBIASHBO
)) +
(1.0-PCTSOVETC) * mw[5] * ( 1.0 / (1.0 + EXP (ALPHAHBO * mw[22] + BETAHBO * mw[26] + TOLLBIASHBO + 0.00 ) ) ) +
PCTHOVETC * mw[15] * ( 1.0 / (1.0 + EXP (ALPHAHBO * mw[22] + BETAHBO * mw[26] + TOLLBIASHBO + ETCBIASHBO ) ) )
+
(1.0-PCTHOVETC) * mw[15] * ( 1.0 / (1.0 + EXP (ALPHAHBO * mw[22] + BETAHBO * mw[26] + TOLLBIASHBO + 0.00 ) ) )
; NON I78 AUTO TRIPS - HBO
mw[39]=mw[5]+mw[15]-mw[33]
ENDIF
IF (mw[6]+mw[16]>0)
; I78 AUTO TRIPS - NHB - SOV AND HOV
mw[34]=PCTSOVETC * mw[6] * ( 1.0 / (1.0 + EXP (ALPHANHB * mw[22] + BETANHB * mw[26] + TOLLBIASNHB + ETCBIASNHB
)) +
(1.0-PCTSOVETC) * mw[6] * ( 1.0 / (1.0 + EXP (ALPHANHB * mw[22] + BETANHB * mw[26] + TOLLBIASNHB + 0.00 ) ) ) +
PCTHOVETC * mw[16] * ( 1.0 / (1.0 + EXP (ALPHANHB * mw[22] + BETANHB * mw[26] + TOLLBIASNHB + ETCBIASNHB ) ) )
+
(1.0-PCTHOVETC) * mw[16] * ( 1.0 / (1.0 + EXP (ALPHANHB * mw[22] + BETANHB * mw[26] + TOLLBIASNHB + 0.00 ) ) )
; NON I78 AUTO TRIPS - NHB
mw[40]=mw[6]+mw[16]-mw[34]
ENDIF
; I78 TRUCK TRIPS - NHB - LIGHT, MEDIUM, HEAVY
; Apply the Freight vs Rail Model for select OD pairs before applying the Toll Route vs Free Route Model
; Set constants per Spasovic Mode Choice Model - need to confirm specific OD-pairs as well as Truck and Rail Times and Rates
mw[77]=1.0
mw[78]=1.0
mw[79]=1.0
ALPHARAIL=-2.1
ALPHATRUK=0
BETA1=-0.009
BETA2=-0.007
RAILRATE=100
TRUKRATE=100
RAILTIME=120
; TRUKTIME=min(mi.1.15, mi.1.26)
IF (mw[7]+mw[8]+mw[9]>0)
; Spasovic Rail Diversion Model
IF (I==570,571,1800,2256,2272,2280,2287,2288,2354,2362,2374,2380,2502,2507,2511,2517) // Newark Airport,
Port Newark, Port Elizabeth
IF (J==570,571,1800,2256,2272,2280,2287,2288,2354,2362,2374,2380,2502,2507,2511,2517) // Pennsylvania
External Zones
; Compute Percent Truck Trips by Light, Medium and Heavy Trucks: mw[77], mw[78],mw[79]
mw[77]=1.0
mw[78]=exp(ALPHATRUK+BETA1*TRUKRATE+BETA2*((MIN(mi.1.15,mi.1.26)*0.1/0.068)+mw[25]))/(exp(ALPHATRUK+BETA1*TRUKR
ATE+BETA2*((MIN(mi.1.15,mi.1.26)*0.1/0.068)+mw[25]))+exp(ALPHARAIL+BETA1*RAILRATE+BETA2*RAILTIME))
mw[79]=exp(ALPHATRUK+BETA1*TRUKRATE+BETA2*((MIN(mi.1.15,mi.1.26)*0.1/0.068)+mw[25]))/(exp(ALPHATRUK+BETA1*TRUKR
ATE+BETA2*((MIN(mi.1.15,mi.1.26)*0.1/0.068)+mw[25]))+exp(ALPHARAIL+BETA1*RAILRATE+BETA2*RAILTIME))
ENDIF
ENDIF
; Vairable Demand Model
; Alpha=0.0036 ; needs to be adjusted according to the time period
; Beta=-0.7279
; IF (I==570,571,1800,5,23,117,176,206,215,304,444,571,580,666,691,1652,1654,1696,1800,1836,1854,1855,2096,2097,
2108,2127,2129,2149,2173,2213,2216,2219,2224,2228,2255,2256,2272,2280,2287,2288,2338,2354,2362,2374,2380,2502,2507,251
1,2517) // Newark Airport, Port Newark, Port Elizabeth
; IF (J==570,571,1800,5,23,117,176,206,215,304,444,571,580,666,691,1652,1654,1696,1800,1836,1854,1855,2096,2097,
2108,2127,2129,2149,2173,2213,2216,2219,2224,2228,2255,2256,2272,2280,2287,2288,2338,2354,2362,2374,2380,2502,2507,251
1,2517) // Newark Airport, Port Newark, Port Elizabeth

```

```

; ; Compute Percent Truck Trips by Light, Medium and Heavy Trucks: mw[77],mw[78],mw[79]
;   mw[77]=1.0
;   mw[78]=1-((2*Alpha*mw[82]+Beta)*((mw[82]-mw[84])/max(mw[84],0.01)))
;   mw[79]=1-((2*Alpha*mw[82]+Beta)*((mw[82]-mw[84])/max(mw[84],0.01)))
;   ENDIF
;   ENDIF
mw[36]=mw[77]*PCTTRKETC * mw[7] * ( 1.0 / (1.0 + EXP (ALPHATRK * mw[22] + BETATRK * mw[28] + TOLLBIASRTRK +
ETCBIASRTRK ) ) ) +
mw[78]*PCTTRKETC * mw[8] * ( 1.0 / (1.0 + EXP (ALPHATRK * mw[22] + BETATRK * mw[29] + TOLLBIASRTRK + ETCBIASRTRK
))) +
mw[79]*PCTTRKETC * mw[9] * ( 1.0 / (1.0 + EXP (ALPHATRK * mw[22] + BETATRK * mw[30] + TOLLBIASRTRK + ETCBIASRTRK
))) +
mw[77]*(1.0-PCTTRKETC) * mw[7] * ( 1.0 / (1.0 + EXP (ALPHATRK * mw[22] + BETATRK * mw[28] + TOLLBIASRTRK + 0.00 )
)) +
mw[78]*(1.0-PCTTRKETC) * mw[8] * ( 1.0 / (1.0 + EXP (ALPHATRK * mw[22] + BETATRK * mw[29] + TOLLBIASRTRK + 0.00 )
)) +
mw[79]*(1.0-PCTTRKETC) * mw[9] * ( 1.0 / (1.0 + EXP (ALPHATRK * mw[22] + BETATRK * mw[30] + TOLLBIASRTRK + 0.00 ) ) )
; NON I-78 TRUCK TRIPS
mw[42]=(mw[77]*mw[7]+mw[78]*mw[8]+mw[79]*mw[9])-mw[36]
ENDIF
ENDIF
; Add the auto trip purposes together for the output trip table
mw[35]=mw[31]+mw[32]+mw[33]+mw[34] // I-78 Trips - All Autos - All Trip Purposes
mw[41]=mw[37]+mw[38]+mw[39]+mw[40] // Not I-78 Trips - All Autos - All Trip Purposes
ENDJLOOP
ENDRUN
; Add a step to run the assignment with a PRELOAD of trips from the NJRTME
RUN PGM=MATRIX MSG="GENERATE MATRIX WITH AND WITHOUT I-78 ITERATION 01"
ZONES = 2553
FILEI MATI[1] = "C:\model2\Base\WithTolls\Model2\AMTRIPS01.MAT"
FILEI MATI[2] = "C:\model2\Base\WithTolls\Model2\AMTOLLANDFREE.MAT"
FILEO MATO = "C:\model2\Base\WithTolls\Model2\AMTRIPS01x.MAT", MO=101-119, DEC=5
comp
mw[1]=max(0.00000001,(mi.2.1+mi.2.2+mi.2.3+mi.2.4+mi.2.5+mi.2.6+mi.2.11+mi.2.12+mi.2.13+mi.2.14+mi.2.15+mi.2.16))
comp mw[2]=max(0.00000001,(mi.2.7+mi.2.8+mi.2.9+mi.2.17+mi.2.18+mi.2.19))
; ----- autos via I-78 -----
comp mw[101]=1.*MI.1.5*(MI.2.1+MI.2.11)/MW[1]
comp mw[102]=1.*MI.1.5*(MI.2.2+MI.2.12)/MW[1]
comp mw[103]=1.*MI.1.5*(MI.2.3+MI.2.13)/MW[1]
comp mw[104]=1.*MI.1.5*(MI.2.4+MI.2.14)/MW[1]
comp mw[105]=1.*MI.1.5*(MI.2.5+MI.2.15)/MW[1]
comp mw[106]=1.*MI.1.5*(MI.2.6+MI.2.16)/MW[1]
; ----- trucks via I-78 -----
comp mw[107]=1.*MI.1.6*(MI.2.7+MI.2.17)/MW[2]
comp mw[108]=1.*MI.1.6*(MI.2.8+MI.2.18)/MW[2]
comp mw[109]=1.*MI.1.6*(MI.2.9+MI.2.19)/MW[2]
; ----- autos via non I-78 -----
comp mw[111]=1.*MI.1.11*(MI.2.1+MI.2.11)/MW[1]
comp mw[112]=1.*MI.1.11*(MI.2.2+MI.2.12)/MW[1]
comp mw[113]=1.*MI.1.11*(MI.2.3+MI.2.13)/MW[1]
comp mw[114]=1.*MI.1.11*(MI.2.4+MI.2.14)/MW[1]
comp mw[115]=1.*MI.1.11*(MI.2.5+MI.2.15)/MW[1]
comp mw[116]=1.*MI.1.11*(MI.2.6+MI.2.16)/MW[1]
; ----- via I-78 -----
comp mw[117]=1.*MI.1.12*(MI.2.7+MI.2.17)/MW[2]
comp mw[118]=1.*MI.1.12*(MI.2.8+MI.2.18)/MW[2]
comp mw[119]=1.*MI.1.12*(MI.2.9+MI.2.19)/MW[2]
ENDRUN
RUN PGM=HIGHWAY MSG="AM ITERATION 01"
; 01
FILEI MATI[1] = "C:\model2\Base\WithTolls\Model2\AMTRIPS01x.MAT"
FILEI NETI = "C:\model2\Base\WithTolls\Model2\TEMP.NET"
FILEI TURNPENI = "C:\model2\c2015\15VAN\HWAMTP.CRD",
missinglink=1
FILEI MATI[2] = "C:\model2\Base\WithTolls\Model2\AMTOLLANDFREE.MAT"
FILEO NETO = "C:\model2\Base\WithTolls\Model2\AMHWYLOAD01x.NET"
;----- NOW LOAD TRIPS TO SPECIFIC PATHS -----

```

```

quescale = 0.75          ; parameter to scale queuing formula estimates
;----- SET DEBUG PATH, IF DESIRED -----
_init=0
array ptrc=12, pdfc=12
;----- SET POINTER FOR VDF INDEX -----
;----- SET FLAG FOR PROCESSING VDF (0=FIXED TIME) -----
ptrc[1]= 2
ptrc[2]= 2
ptrc[3]= 2
ptrc[4]= 2
ptrc[5]= 2
ptrc[6]= 2
ptrc[7]= 2
ptrc[8]= 2
ptrc[9]= 1
ptrc[10]=1
ptrc[11]=1
ptrc[12]=1
pdfc[1]= 1
pdfc[2]= 1
pdfc[3]= 1
pdfc[4]= 1
pdfc[5]= 1
pdfc[6]= 1
pdfc[7]= 1
pdfc[8]= 1
pdfc[9]= 1
pdfc[10]= 1
pdfc[11]= 1
pdfc[12]= 0
etcft = 0                ; flag to indicate if region has exclusive ETC facilities
phase=linkread
spdminfct=3.5
  if (li.ft=1 && li.AT=1) MINSPEED=60.0/spdminfct
  if (li.ft=1 && li.AT=2) MINSPEED=65.0/spdminfct
  if (li.ft=1 && li.AT=3) MINSPEED=70.0/spdminfct
  if (li.ft=1 && li.AT=4) MINSPEED=70.0/spdminfct
  if (li.ft=2 && li.AT=1) MINSPEED=50.0/spdminfct
  if (li.ft=2 && li.AT=2) MINSPEED=60.0/spdminfct
  if (li.ft=2 && li.AT=3) MINSPEED=60.0/spdminfct
  if (li.ft=2 && li.AT=4) MINSPEED=60.0/spdminfct
  if (li.ft=3-4 && li.AT=1) MINSPEED=45.0/spdminfct
  if (li.ft=3-4 && li.AT=2) MINSPEED=50.0/spdminfct
  if (li.ft=3-4 && li.AT=3) MINSPEED=55.0/spdminfct
  if (li.ft=3-4 && li.AT=4) MINSPEED=55.0/spdminfct
  if (li.ft=5-6 && li.AT=1) MINSPEED=35.0/spdminfct
  if (li.ft=5-6 && li.AT=2) MINSPEED=45.0/spdminfct
  if (li.ft=5-6 && li.AT=3) MINSPEED=52.5/spdminfct
  if (li.ft=5-6 && li.AT=4) MINSPEED=50.0/spdminfct
  if (li.ft=7 && li.AT=1) MINSPEED=30.0/spdminfct
  if (li.ft=7 && li.AT=2) MINSPEED=35.0/spdminfct
  if (li.ft=7 && li.AT=3) MINSPEED=45.0/spdminfct
  if (li.ft=7 && li.AT=4) MINSPEED=45.0/spdminfct
  if (li.ft=8 && li.AT=1) MINSPEED=20.0/spdminfct
  if (li.ft=8 && li.AT=2) MINSPEED=25.0/spdminfct
  if (li.ft=8 && li.AT=3) MINSPEED=35.0/spdminfct
  if (li.ft=8 && li.AT=4) MINSPEED=35.0/spdminfct
  if (li.ft=9 && li.AT=1-4) MINSPEED=55.0/spdminfct
  if (li.ft=10 && li.AT=1-4) MINSPEED=40.0/spdminfct
  if (li.ft=11 && li.AT=1-4) MINSPEED=25.0/spdminfct
;----- SET POINTERS FOR LINKCLASS CODE -----
;----- SET LINKCLASS FOR VDF INDEX -----
  linkclass=(ptrc[li.ft]-1)*20 + li.ft
;----- DO ANY OVERRIDE BASED ON SPECIFIC CONDITIONS UNDER VDF OPTION=4-----
  if (ptrc[li.ft]=4 && li.tcd=5 ) linkclass=73
  if (ptrc[li.ft]=4 && li.tcd=6 ) linkclass=74
  if (ptrc[li.ft]=4 && li.tcd=7 )

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```

linkclass=75
lw.arrtyp=0.40
endif
if (ptrc[li.ft]=4 && li.tcd=8 )
linkclass=75
lw.arrtyp=0.60
endif
if (ptrc[li.ft]=4 && li.tcd=9 )
linkclass=75
lw.arrtyp=0.80
endif
if (ptrc[li.ft]=4 && li.tcd=1 )
linkclass=78
endif
if (ptrc[li.ft]=4 && li.tcd=2 )
if (li.lanesAM=1) linkclass=79
if (li.lanesAM>1) linkclass=80
endif
if (ptrc[li.ft]=4 && li.tcd=3 ) linkclass=81
;----- BYPASS REVISED TRAVEL TIME CALCULATIONS IF LINKCLASS=99 -----
if (pdfc[li.ft]=0 || li.fixtime=1) linkclass=99
;----- BYPASS FLOOR SPEED FOR OPTION 2 BY SETTING LINKCLASS=98 -----
if (pdfc[li.ft]<>0 && ptrc[li.ft]=2 && li.fixcap=1) linkclass=98
;----- NOTE THAT BY FACTORING TRUCKS TO PCES, WE CAN'T DIRECTLY -----
;----- COMPARE "V" TO AADTs, WHICH HAVE BEEN ADJUSTED FOR AXLES -----
C=li.LW_CAPACITY_1
;----- SET WORKING VARIABLE FOR TOLL -----
if (li.linktype==1) addtogroup=1 ; free auto & truck links
if (li.linktype==2) addtogroup=2 ; free auto only links
if (li.linktype==3) addtogroup=3 ; free truck only links
if (li.linktype==4) addtogroup=4 ; urban toll auto & truck links
if (li.linktype==5) addtogroup=5 ; urban toll auto only links
if (li.linktype==6) addtogroup=6 ; urban toll truck only links
if (li.linktype==7) addtogroup=7 ; rural toll auto & truck links
if (li.linktype==8) addtogroup=8 ; rural toll auto only links
if (li.linktype==9) addtogroup=9 ; rural toll truck only links
if (li.linktype==10) addtogroup=10 ; urban free HOV only links
if (li.linktype==11) addtogroup=11 ; urban toll HOV only links
if (li.linktype==12) addtogroup=12 ; urban toll SOV, Free HOV links
if (li.linktype==13) addtogroup=13 ; urban toll, Free HOV links
if (li.linktype==14) addtogroup=14 ; ETC only toll links
if (li.linktype==15) addtogroup=15 ; ETC only, auto only toll links
if (li.linktype==16) addtogroup=16 ; ETC only, SOV toll, Free HOV links
if (li.tcodeam>8 ) addtogroup=32 ; This group excludes all transit only links
if (li.I78CHECK=1) addtogroup=17 ; This group represent only I78 links
lw.prevol=(li.V1_1+li.V2_1+li.V3_1+li.V4_1+li.V5_1+li.V6_1)+(li.V7_1+li.V8_1+li.V9_1)*1.75
endphase
phase=iloop
function
v=vol[2]+vol[3]+vol[4]+vol[5]+vol[6]+vol[7]+vol[8]*1.75+vol[9]*1.75+vol[10]*1.75+vol[11]+vol[12]+vol[13]+vol[14]+vol[15]+vol[16]+
vol[17]*1.75+vol[18]*1.75+vol[19]*1.75+lw.prevol
path=LI.TIMEX, peni=1,excludegrp=3-16,32,
trace=(i=1 && j=10),
vol[2]=mi.1.1/1. ; SOV, Free via I-78
path=LI.TIMEX, peni=1,excludegrp=3,6,9-11,14-16,32,
trace=(i=1 && j=10),
vol[3]=mi.1.2/1. ; SOV, Cash via I-78
path=LI.TIMEX, peni=1,excludegrp=3,6,9-11,32,
trace=(i=1 && j=10),
vol[4]=mi.1.3/1. ; SOV, ETC via I-78
path=LI.TIMEX, peni=1,excludegrp=3-9,11,14-16,32,
trace=(i=1 && j=10),
vol[5]=mi.1.4/1. ; HOV, Free via I-78
path=LI.TIMEX, peni=1,excludegrp=3,6,9,14-16,32,
trace=(i=1 && j=10),
vol[6]=mi.1.5/1. ; HOV, Cash via I-78
path=LI.TIMEX, peni=1,excludegrp=3,6,9,32,

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```

    trace=(i=1 && j=10),
    vol[7]=mi.1.6/1.                                ; HOV, ETC via I-78
path=LI.TIMEX, peni=1-2,excludegrp=2,4-16,32,
    trace=(i=1 && j=10),
    vol[8]=mi.1.7/1.                                ; Trucks FREE via I-78
path=LI.TIMEX, peni=1-2,excludegrp=2,5,8,10-12,14-16,32,
    trace=(i=1 && j=10),
    vol[9]=mi.1.8/1.                                ; Trucks CASH via I-78
path=LI.TIMEX, peni=1-2,excludegrp=2,5,8,10-12,15-16,32,
    trace=(i=1 && j=10),
    vol[10]=mi.1.9/1.                               ; Trucks ETC via I-78
;----- NOT VIA I-78 -----
path=LI.TIMEX, peni=1,excludegrp=3-16,32,17,
    trace=(i=1 && j=10),
    vol[11]=mi.1.11/1.                              ; SOV, Free via NOT I-78
path=LI.TIMEX, peni=1,excludegrp=3,6,9-11,14-16,32,17,
    trace=(i=1 && j=10),
    vol[12]=mi.1.12/1.                              ; SOV, Cash via NOT I-78
path=LI.TIMEX, peni=1,excludegrp=3,6,9-11,32,17,
    trace=(i=1 && j=10),
    vol[13]=mi.1.13/1.                              ; SOV, ETC via NOT I-78
path=LI.TIMEX, peni=1,excludegrp=3-9,11,14-16,32,17,
    trace=(i=1 && j=10),
    vol[14]=mi.1.14/1.                              ; HOV, Free via NOT I-78
path=LI.TIMEX, peni=1,excludegrp=3,6,9,14-16,32,17,
    trace=(i=1 && j=10),
    vol[15]=mi.1.15/1.                              ; HOV, Cash via NOT I-78
path=LI.TIMEX, peni=1,excludegrp=3,6,9,32,17,
    trace=(i=1 && j=10),
    vol[16]=mi.1.16/1.                              ; HOV, ETC via NOT I-78
path=LI.TIMEX, peni=1-2,excludegrp=2,4-16,32,17,
    trace=(i=1 && j=10),
    vol[17]=mi.1.17/1.                              ; Trucks FREE via NOT I-78
path=LI.TIMEX, peni=1-2,excludegrp=2,5,8,10-12,14-16,32,17,
    trace=(i=1 && j=10),
    vol[18]=mi.1.18/1.                              ; Trucks CASH via NOT I-78
path=LI.TIMEX, peni=1-2,excludegrp=2,5,8,10-12,15-16,32,17,
    trace=(i=1 && j=10),
    vol[19]=mi.1.19/1.                              ; Trucks ETC via NOT I-78
endphase
phase=ADJUST
;----- NOTE THAT BY FACTORING TRUCKS TO PCES, WE CAN'T DIRECTLY -----
;----- COMPARE "V" TO AADTs, WHICH HAVE BEEN ADJUSTED FOR AXLES -----
;----- OPTION 1 - STANDARD BPR FORMULA -----
function {
    tc[1 ] =min(t0 *(1 + 0.15 * (v/c) ^4),(li.distance/minspeed)*60.0)
    tc[2 ] =min(t0 *(1 + 0.15 * (v/c) ^4),(li.distance/minspeed)*60.0)
    tc[3 ] =min(t0 *(1 + 0.15 * (v/c) ^4),(li.distance/minspeed)*60.0)
    tc[4 ] =min(t0 *(1 + 0.15 * (v/c) ^4),(li.distance/minspeed)*60.0)
    tc[5 ] =min(t0 *(1 + 0.15 * (v/c) ^4),(li.distance/minspeed)*60.0)
    tc[6 ] =min(t0 *(1 + 0.15 * (v/c) ^4),(li.distance/minspeed)*60.0)
    tc[7 ] =min(t0 *(1 + 0.15 * (v/c) ^4),(li.distance/minspeed)*60.0)
    tc[8 ] =min(t0 *(1 + 0.15 * (v/c) ^4),(li.distance/minspeed)*60.0)
    tc[9 ] =min(t0 *(1 + 0.15 * (v/c) ^4),(li.distance/minspeed)*60.0)
    tc[10 ] =min(t0 *(1 + 0.15 * (v/c) ^4),(li.distance/minspeed)*60.0)
    tc[11 ] =min(t0 *(1 + 0.15 * (v/c) ^4),(li.distance/minspeed)*60.0)
    tc[12 ] =t0 *(1 + 0.15 * (v/c) ^4)
;----- OPTION 2 - HCM 2000 RECOMMENDED BPR PARAMETERS -----
;----- UNDER THIS OPTION RAMPS ARE TREATED AS FOLLOWS:-----
;----- HIGH SPEED RAMP ( .25,9) -----
;----- MED. SPEED RAMP (1.00,9) CLASS 3 ARTERIAL -----
;----- LOW SPEED RAMP (1.11,9) CLASS 4 ARTERIAL -----
;----- EMPLOY SIMPLE QUEUING FORMULA FOR OVER CAPACITY LINKS -----
;----- FORMULA IS ENABLED FOR ALL LINKS WHERE "QUEFLG=1" -----
;----- FORMULA IS CAN BE SCALED WITH PARAMETER QUESCALE -----
;----- NOTE THAT FORMULA IS OPERABLE ONLY IF V/C >1.0 -----

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tc[21]=min(t0*(1+li.alcoeff*(v/c)^li.btcoeff)+MIN(1,10000*max(0,(v/c-1)))*li.queflg*(120/2)*(1-
c/max(v,1))*quescale,(li.distance/minspeed)*60.0)
tc[22]=min(t0*(1+li.alcoeff*(v/c)^li.btcoeff)+MIN(1,10000*max(0,(v/c-1)))*li.queflg*(120/2)*(1-
c/max(v,1))*quescale,(li.distance/minspeed)*60.0)
tc[23]=min(t0*(1+li.alcoeff*(v/c)^li.btcoeff)+MIN(1,10000*max(0,(v/c-1)))*li.queflg*(120/2)*(1-
c/max(v,1))*quescale,(li.distance/minspeed)*60.0)
tc[24]=min(t0*(1+li.alcoeff*(v/c)^li.btcoeff)+MIN(1,10000*max(0,(v/c-1)))*li.queflg*(120/2)*(1-
c/max(v,1))*quescale,(li.distance/minspeed)*60.0)
tc[25]=min(t0*(1+li.alcoeff*(v/c)^li.btcoeff)+MIN(1,10000*max(0,(v/c-1)))*li.queflg*(120/2)*(1-
c/max(v,1))*quescale,(li.distance/minspeed)*60.0)
tc[26]=min(t0*(1+li.alcoeff*(v/c)^li.btcoeff)+MIN(1,10000*max(0,(v/c-1)))*li.queflg*(120/2)*(1-
c/max(v,1))*quescale,(li.distance/minspeed)*60.0)
tc[27]=min(t0*(1+li.alcoeff*(v/c)^li.btcoeff)+MIN(1,10000*max(0,(v/c-1)))*li.queflg*(120/2)*(1-
c/max(v,1))*quescale,(li.distance/minspeed)*60.0)
tc[28]=min(t0*(1+li.alcoeff*(v/c)^li.btcoeff)+MIN(1,10000*max(0,(v/c-1)))*li.queflg*(120/2)*(1-
c/max(v,1))*quescale,(li.distance/minspeed)*60.0)
tc[29]=min(t0*(1+li.alcoeff*(v/c)^li.btcoeff)+MIN(1,10000*max(0,(v/c-1)))*li.queflg*(120/2)*(1-
c/max(v,1))*quescale,(li.distance/minspeed)*60.0)
tc[30]=min(t0*(1+li.alcoeff*(v/c)^li.btcoeff)+MIN(1,10000*max(0,(v/c-1)))*li.queflg*(120/2)*(1-
c/max(v,1))*quescale,(li.distance/minspeed)*60.0)
tc[31]=min(t0*(1+li.alcoeff*(v/c)^li.btcoeff)+MIN(1,10000*max(0,(v/c-1)))*li.queflg*(120/2)*(1-
c/max(v,1))*quescale,(li.distance/minspeed)*60.0)
tc[32]=min(t0*(1+li.alcoeff*(v/c)^li.btcoeff)+MIN(1,10000*max(0,(v/c-1)))*li.queflg*(120/2)*(1-
c/max(v,1))*quescale,(li.distance/minspeed)*60.0)
;----- IF TC=98 THEN DO NOT USE FLOOR SPEED TO LIMIT DELAY -----
tc[98]=t0*(1+li.alcoeff*(v/c)^li.btcoeff)+MIN(1,10000*max(0,(v/c-1)))*li.queflg*(120/2)*(1-c/max(v,1))*quescale
;----- OPTION 3 - AKCELIK FORMULA -----
tc[41]=(li.distance*((t0/60.0)/li.distance)+(0.25*(1.0*(v/c-1)+((v/c-1)^2+8.0*li.jfact*(v/c)/(c*1.0)^0.5))))*60.0
tc[42]=(li.distance*((t0/60.0)/li.distance)+(0.25*(1.0*(v/c-1)+((v/c-1)^2+8.0*li.jfact*(v/c)/(c*1.0)^0.5))))*60.0
tc[43]=(li.distance*((t0/60.0)/li.distance)+(0.25*(1.0*(v/c-1)+((v/c-1)^2+8.0*li.jfact*(v/c)/(c*1.0)^0.5))))*60.0
tc[44]=(li.distance*((t0/60.0)/li.distance)+(0.25*(1.0*(v/c-1)+((v/c-1)^2+8.0*li.jfact*(v/c)/(c*1.0)^0.5))))*60.0
tc[45]=(li.distance*((t0/60.0)/li.distance)+(0.25*(1.0*(v/c-1)+((v/c-1)^2+8.0*li.jfact*(v/c)/(c*1.0)^0.5))))*60.0
tc[46]=(li.distance*((t0/60.0)/li.distance)+(0.25*(1.0*(v/c-1)+((v/c-1)^2+8.0*li.jfact*(v/c)/(c*1.0)^0.5))))*60.0
tc[47]=(li.distance*((t0/60.0)/li.distance)+(0.25*(1.0*(v/c-1)+((v/c-1)^2+8.0*li.jfact*(v/c)/(c*1.0)^0.5))))*60.0
tc[48]=(li.distance*((t0/60.0)/li.distance)+(0.25*(1.0*(v/c-1)+((v/c-1)^2+8.0*li.jfact*(v/c)/(c*1.0)^0.5))))*60.0
tc[49]=(li.distance*((t0/60.0)/li.distance)+(0.25*(1.0*(v/c-1)+((v/c-1)^2+8.0*li.jfact*(v/c)/(c*1.0)^0.5))))*60.0
tc[50]=(li.distance*((t0/60.0)/li.distance)+(0.25*(1.0*(v/c-1)+((v/c-1)^2+8.0*li.jfact*(v/c)/(c*1.0)^0.5))))*60.0
tc[51]=(li.distance*((t0/60.0)/li.distance)+(0.25*(1.0*(v/c-1)+((v/c-1)^2+8.0*li.jfact*(v/c)/(c*1.0)^0.5))))*60.0
tc[52]=(li.distance*((t0/60.0)/li.distance)+(0.25*(1.0*(v/c-1)+((v/c-1)^2+8.0*li.jfact*(v/c)/(c*1.0)^0.5))))*60.0
}
function {
;----- OPTION 4 - HCM APPROXIMATION OF TCD-RELATED DELAY -----
;----- NOTE THAT THIS FORMULA ESTIMATES HOURS OF DELAY, SO MULTIPLY BY 60 TO CONVERT TO MINUTES -----
;----- NOTE ALSO THAT ZDELAY IS ALREADY INCLUDED IN THE FF TRAVEL TIME "T0" -----
tc[61]=t0+(0.25*((v/c-1)+((v/c-1)^2+(16*li.jfact*(v/c)*(li.distance^2))^0.5))*60.0
tc[62]=t0+(0.25*((v/c-1)+((v/c-1)^2+(16*li.jfact*(v/c)*(li.distance^2))^0.5))*60.0
tc[63]=t0+(0.25*((v/c-1)+((v/c-1)^2+(16*li.jfact*(v/c)*(li.distance^2))^0.5))*60.0
tc[64]=t0+(0.25*((v/c-1)+((v/c-1)^2+(16*li.jfact*(v/c)*(li.distance^2))^0.5))*60.0
tc[65]=t0+(0.25*((v/c-1)+((v/c-1)^2+(16*li.jfact*(v/c)*(li.distance^2))^0.5))*60.0
tc[66]=t0+(0.25*((v/c-1)+((v/c-1)^2+(16*li.jfact*(v/c)*(li.distance^2))^0.5))*60.0
tc[67]=t0+(0.25*((v/c-1)+((v/c-1)^2+(16*li.jfact*(v/c)*(li.distance^2))^0.5))*60.0
tc[68]=t0+(0.25*((v/c-1)+((v/c-1)^2+(16*li.jfact*(v/c)*(li.distance^2))^0.5))*60.0
tc[69]=t0+(0.25*((v/c-1)+((v/c-1)^2+(16*li.jfact*(v/c)*(li.distance^2))^0.5))*60.0
tc[70]=t0+(0.25*((v/c-1)+((v/c-1)^2+(16*li.jfact*(v/c)*(li.distance^2))^0.5))*60.0
tc[71]=t0+(0.25*((v/c-1)+((v/c-1)^2+(16*li.jfact*(v/c)*(li.distance^2))^0.5))*60.0
tc[72]=t0*(1+0.10*(v/c)^5)
;----- UNDER THIS OPTION, OVERLAY SPECIFIC FUNCTIONS FOR SIGNALIZED TCD -----
;----- NOTE THAT THESE EQUATIONS ARE IN SECONDS, SO DIVIDE BY 60.0 TO CONVERT TO MINUTES -----
tc[73]=t0+((1*(0.5*li.sigcyc*(1-li.gc)^2)/(1-(min(1,v/c)*li.gc))+900*((v/c-1)+((v/c-1)^2+8*min(max(0.13,(0.13+(v/c-
.50)*.75)),0.50)*(v/c)/c^0.5)))/60.0
tc[74]=t0+((1*(0.5*li.sigcyc*(1-li.gc)^2)/(1-(min(1,v/c)*li.gc))+900*((v/c-1)+((v/c-1)^2+8*0.50*(v/c)/c^0.5)))/60.0
tc[75]=t0+((1-lw.arrtyp)/(1-li.gc))*(0.5*li.sigcyc*(1-li.gc)^2)/(1-(min(1,v/c)*li.gc))+900*((v/c-1)+((v/c-
1)^2+8*0.50*(v/c)/c^0.5)))/60.0
;----- UNDER THIS OPTION, OVERLAY SPECIFIC FUNCTIONS FOR UNSIGNALIZED TCD (STOPS & YIELD) -----
;----- 78= TWO-WAY STOP, 79=ALLWAY STOP 1 LANE, 80=ALLWAY STOP 2 LANE, 81=YIELD -----
tc[78]=t0+((3600*v/c/max(1,v))+900*((v/c-1)+((v/c-1)^2+(8*v/c^2)/max(1,v))^0.5))/60.0
tc[79]=t0+(6358.4*(v/1000)^4-5918.4*(v/1000)^3+2019.7*(v/1000)^2-261.49*(v/1000)+22)/60.0

```

```

tc[80] =t0 + ( 185.48*(v/1000)^4- 307.22*(v/1000)^3+184.37*(v/1000)^2-34.719*(v/1000)+12)/60.0
tc[81] =t0 * (1+ 1.75*(v/c)^6)
;----- THIS FUNCTION HOLDS TIME FIXED (APPROPRIATE FOR ZONAL CONNECTORS AND SPECIAL SITUATIONS-
tc[99] =t0
} ,*****
;----- DYNAMIC REVISION SECTION - (TOLLS AND CAPACITY OPTIONS) -----
;----- REVISE TOLLS BASED ON VC RATIO & FIXTOLL CODE -----
if (li.fixtoll<>1) lw.sovtoll=min(max(li.sovtoll, 0.143*exp(v/li.capacity*4.48155)),8)
if (li.fixtoll<>1 && li.tollapc<>1) lw.hovtoll=min(max(li.hovtoll, 0.143*exp(v/li.capacity*4.48155)),8)
if (li.fixtoll<>1 && li.tollapc<>2) lw.trktoll=min(max(li.trktoll, 0.143*exp(v/li.capacity*4.48155)),8)
;----- REVISE PERIOD SPECIFIC CAPACITY - RELEASE PEAK HR CONSTRAINT -----
;----- BASED ON 3-HOUR PERIOD SCALE FOR AM PEAK (SCALE TOWARD MAX IF V/C > 0.90) -----
if (c >0)
if (v/li.capacity>0.90) lw.capacity=li.capacity+(li.capacity*(3/2.63-1)*min((v/li.capacity-0.9)/0.1,1.0))
if (li.fixcap=1) lw.capacity=li.capacity
endif
endphase
ENDRUN
RUN PGM=NETWORK MSG="FIX TRAVEL TIME FOR NO CHANGES 01"
FILEI NETI[1] = "C:\model2\Base\WithTolls\Model2\AMHWYLOAD01x.NET"
FILEO NETO = "C:\model2\Base\WithTolls\Model2\AMHWYLOAD01.NET"
; ITER 1
COMP
_VoLall=LI.1.V2_2+LI.1.V3_2+LI.1.V4_2+LI.1.V5_2+LI.1.V6_2+LI.1.V7_2+LI.1.V8_2+LI.1.V9_2+LI.1.V10_2+LI.1.V11_2+LI.1.V12_2+LI.1.
V13_2+LI.1.V14_2+LI.1.V15_2+LI.1.V16_2+LI.1.V17_2+LI.1.V18_2+LI.1.V19_2
IF (_VoLall = 0.0)
COMP TIME_2=LI.1.TIMEX
ENDIF
ENDRUN

```

APPENDIX E

COMPARISON OF O-D STUDY WITHIN PORT AUTHORITY OF NY & NJ

At the direction of the Port Authority of New York and New Jersey, maritime container terminal survey of truck origin and destination was conducted 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 Port Authority Terminal, one in Jersey City and one in Staten Island, New York. The New York ports were surveyed for two days and ports in New Jersey were surveyed for one day. The data was collected at the city/state or zip code level and was aggregated at the county level.

The study previously mentioned was compared to the origin-destination data from the NJTPA which is being used in the dissertation. Figure 5.8 shows the comparison of the truck trips percentage by county level. Even though both data represent the same region, there were significant differences observed. One of the reasons could 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 NJTPA's data represents data generated outside of New Jersey in the form of external zones to account for background traffic.

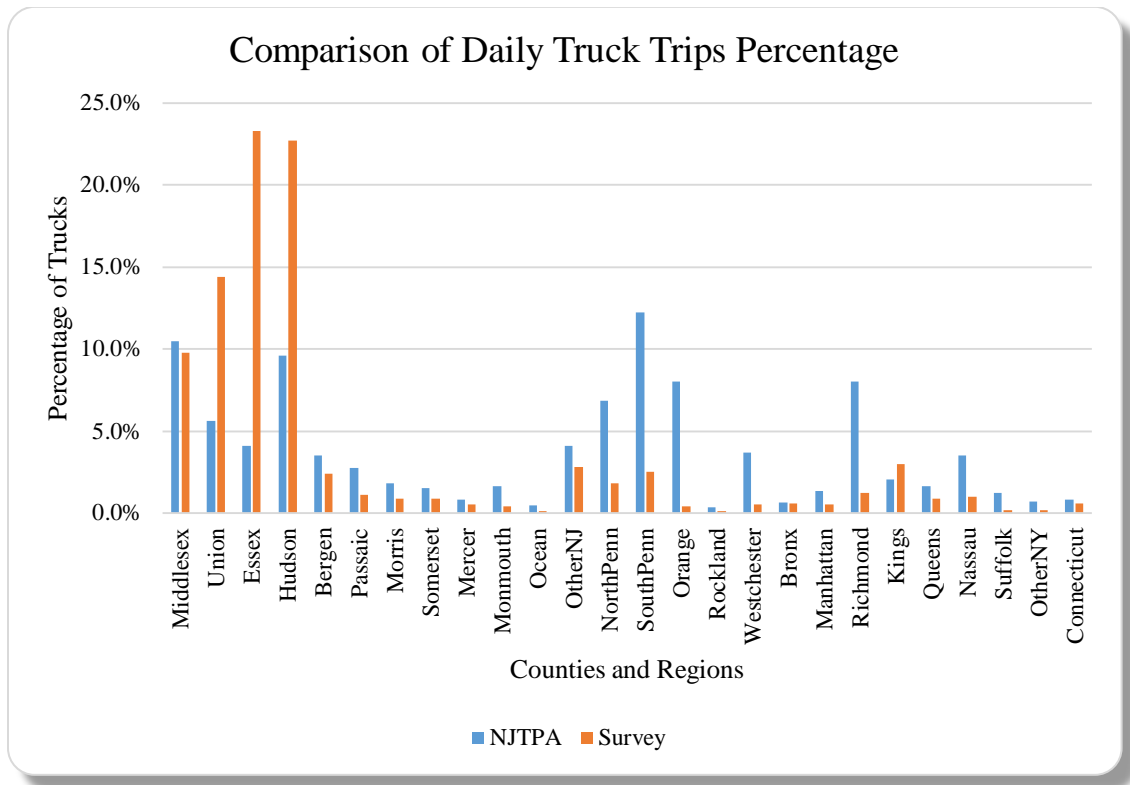


Figure E.1 Comparison of daily truck trips percentage between NJTPA and survey data by county.

The truck trip tables, therefore, could be obtained by either actual measurement via origin-destination surveys as done in the case on 2005 study or through the synthesis of the demand models as in case of NJTPA. These models are estimated and calibrated using origin-destination surveys however in practice 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 the macroscopic analysis.

The results of the case study examine the nature of travel response to the change in policy scenarios and measure its impact on the region in monetary terms. It shows that the change in generalized cost may result in the change in route choice or may opt for another mode of the origin and destination. These changes can affect the planning decisions and

are therefore important to support the development of balanced and efficient transportation systems.

The results of the case study show that the developed framework is capable of quantifying the impact of the change in truck traffic with implications concerning policy measures. It is also evident that multiple policy scenarios can be evaluated in a controlled environment using macroscopic simulation modeling keeping time and budget constraints the agencies face.

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