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Incorporating Reliability Measures into the Freight Project Prioritization Decision Support System

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METRIC CONVERSION CHART

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or metric ton)	Mg (or t)
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F−32)/9 or (F−32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	pound force	4.45	newton	N
lbf/in^2	pound force per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or t)	mega grams (or metric ton)	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newton	0.225	pound force	lbf
kPa	kilopascals	0.145	pound force per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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16. Abstract

In this report, the detailed processes and methodologies required for implementation of the evaluation framework for the proposed Freight Project Prioritization Decision Support System are discussed. Research reports and guidelines at the federal level are referenced for the development of the methodologies. The evaluation framework produced a standard benefit-cost analysis (BCA) and metrics for the wider economic benefits (WEB) associated with travel time reliability, market accessibility, and intermodal connectivity. The BCA results of this framework were consistent with the guidance of USDOT for discretionary grant programs. The methodologies assessing the WEB were obtained from federally sponsored research programs.

Case studies were then conducted to demonstrate how the methodologies for the freight project prioritization decision support system can be implemented with real-world data. Three transportation projects in the State of Florida expected to generate wider economic benefits were selected for the case studies. The projects were selected based on their potential impacts on different aspects of wider economic benefits in reliability, connectivity, and productivity. The data used as well as the sources of data are included in the report.

With the data from the case studies, a spreadsheet tool was subsequently developed. The tool integrates standard Benefit-Cost Analysis (BCA) with analysis tools for Wider Economic Benefits, including reliability, market accessibility, and intermodal connectivity. A user guide is provided in this report to show users how to use the spreadsheet.

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EXECUTIVE SUMMARY

Over the last decade, financial constraints have led public leaders and agency decision makers to request more information from proposed transportation projects in terms of cost effectiveness and expected job and economic growth potentials of the projects. This is evidenced in the persistent demand from the U.S. Department of Transportation (USDOT) to have a Benefit-Cost Analysis (BCA) conducted for every project proposal requesting discretionary grant funds. Our review of existing studies for freight transportation project evaluation reveals that most of the existing BCA methodologies and analytical tools are not capable of capturing Wider Economic Benefits (WEB) of freight projects, such as improved travel time reliability, better accessibility to markets, and better connectivity to intermodal facilities. After a comprehensive examination of various research reports and guidelines at the federal levels, we identified valid methodologies for quantifying WEB of freight transportation projects. These methods can produce metrics for the project's long-term economic benefits and productivity beyond simple cost-effectiveness of a BCA.

Based on these methodologies, we developed a procedural analysis framework that integrates methods for estimating the WEB of freight transportation projects into a standard BCA process that is consistent with requirements from funding authorities such as USDOT and Federal Highway Administration (FHWA). The developed BCA process is consistent with FHWA recommendation in that it breaks down the direct benefits of transportation projects into travel time savings, operation cost savings, crash reduction benefits, and emission reduction benefits. The framework also recognizes the importance of EIA in complementing BCA in addressing a project's effects in regional job markets and on economic growth. The framework in essence is a strategic combination of these three elements: a standard BCA process, methods for quantifying WEBs, and integration with an EIA.

To demonstrate how the methodologies and the framework for the freight project prioritization decision support system can be implemented with real-world data, we conducted case studies with three transportation projects in the State of Florida that are expected to generate wider economic benefits. The projects were selected based on their potential impacts on different aspects of wider economic benefits in reliability, connectivity, and productivity.

1. The first project involves a new interchange on I-95 at Central Boulevard in Palm Beach County. The new interchange is expected to improve travel time reliability with congestion reduction and improve market accessibility, leading to productivity gain in the region.
2. The second project involves improvement to an existing interchange on I-95 at 45th Street, also in Palm Beach County. This project is expected to generate economic benefits via improved intermodal connectivity.

3. The third project is the Port of Miami Tunnel Project (FDOT, 2011), which provides direct access to the port from I-95. Productivity gain is expected through improved connectivity to the port for freight activities.

Results of the case studies showed that the analytic methods can be readily applied with publicly available data to generate metrics of BCA and WEB for improved reliability, market accessibility, and intermodal connectivity. With data and computational resources developed for the case studies, a spreadsheet tool integrating standard BCA with analysis tools for Wider Economic Benefits, including reliability, market accessibility, and intermodal connectivity was developed. A user guide for the tool was also developed and is included in this report for users to learn how to use the tool.

With findings of this project and the spreadsheet tool developed, the next step toward a better practice of freight project prioritization and selection is to begin implementing the developed project evaluation framework and conducting analyses using the spreadsheet tool in the project evaluation process. For projects that are expected to generate major direct and indirect economic benefits and costs, Economic Impact Analysis (EIA) and risk analyses should also be conducted to complement the results of BCA. Such a comprehensive approach can ensure that long-term economic benefits of the projects can be fully considered during the project prioritization and selection process.

In the future, integration of the spreadsheet tool with elements of EIA and risk analyses as an Internet application with GIS functionality can be pursued to further enhance the decision support process for project evaluation and prioritization. Another avenue for future research is to conduct before-and-after analyses of WEB and EIA of transportation investments in the State of Florida. It is expected that these analyses can generate evidence to support the incorporation of these higher order economic metrics in the process of project evaluation and prioritization.

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1. INTRODUCTION

Freight has long been a driving force for the prosperity of Florida's economy. The state's freight system moves 762 million tons of goods annually (FDOT 2013), and the freight industry employs over 500,000 Floridians (Florida Chamber Foundation 2013). To serve the increasing demand with limited funding, agencies are faced with the challenge to make strategic and prioritized investment decisions that lead to maximum outcomes in promoting efficient and reliable freight transportation. However, there lacks proper tools and methods to fully reflect freight reliability benefits in project prioritization and benefit /cost analysis. The main obstacles include the lack of consensus on the valuation of reliability for freight transportation and the challenge to estimate project outcomes of reliability improvement.

Current state-of-practice in project prioritization often does not specifically consider the benefits and impacts of reliability on the performance of the freight system. Even among the few studies that have developed performance-based approach for freight project prioritization, no effort has focused on methodologies to incorporate reliability into the project evaluation process.

Given increasing freight mobility needs and limited funding, there is a pressing need to prioritize public investments in freight systems with comprehensive and quantitative methods to analyze freight benefits of proposed projects. This project aims to address this need by proposing an approach to incorporating reliability measures into project prioritization and developing a decision-support system to facilitate the process.

Builds upon previous and on-going work, this project aims to develop a decision support tool to facilitate the project prioritization process and ensure full consideration of freight reliability benefits. To achieve this goal, the following objectives are developed for this research project:

- Develop the methodology to quantify reliability benefits associated with proposed highway and multimodal system improvements;
- Develop a data-driven freight project prioritization framework, with considerations of reliability measures; and
- Develop a decision support tool that account for reliability benefits to facilitate freight project prioritization process.

It has been well established that reliability plays a vital role in freight transportation and has broad impacts on the economy and quality of life. This research proposes an approach to capturing and reflecting freight reliability benefits in the project prioritization process. Better prioritization decisions in freight transportation investment and policy are essential to maximize the outcomes of public investments, enhance system performance, promote sustainable economic growth in the state and better quality of life for the communities.

2. LITERATURE REVIEW

A comprehensive literature review was conducted to provide a summary of current practices and methods of project prioritization and benefit-cost analysis (BCA). General practices for highway projects were also included with special focus on how the methods and framework might be different for freight considerations.

2.1 Benefit-Cost Analysis

2.1.1 Overview of Benefit-Cost Analysis

A BCA is a type of economic analysis that systematically evaluates the benefits and costs of a set of investment scenarios (FHWA, 2003). An economic analysis such as BCA compares the net benefits (i.e., benefits minus costs) of the scenarios in dollars adjusted with appropriate discount rates for effects of inflation over the investment's life cycle. The discounted net benefit value is termed the net present value (NPV). If the expected benefits exceed costs, NPV is positive and the project is worth pursuing from an economic point of view. BCAs and other types of economic analyses are often applied for the evaluation of public or private investment in the construction and/or maintenance of transportation facilities (FHWA, 2003). Typically, a baseline (i.e., the status quo) scenario is compared to one or more alternatives that are expected to generate benefits and incur costs while the facilities are in service. A BCA process first estimates the benefits and costs for the baseline and alternatives. The benefits and costs are then monetized with appropriate valuation factors (e.g., dollar per hour of travel time saving). The monetized net benefits of each alternative are then discounted with an appropriate rate to arrive at the NPV for comparison with the baseline and other alternatives.

A BCA is constructed to capture a project's benefits and costs accruing to the society as a whole (FHWA, 2003). There are usually more than one parties of the society that realize the benefits or costs, and the forms that these benefits and costs can take are not necessarily monetary in nature. For example, a project that improves freight movement may first benefit the freight industry. However, eventually the benefits will be passed down to the consumers in terms of shorter shipping time and lower shipping cost. Furthermore, a project that improves safety by reducing accident rates can generate benefits in multiple forms, including reduced repair cost, reduced injuries and mortalities, and reduced travel time delay owing to reduced accident occurrences. When constructed properly, a BCA identifies the economically efficient alternative that can realize the maximal net benefits to the public.

BCAs enable transportation agencies to identify and quantify the economic benefits and costs of transportation projects and programs over a multi-year horizon (FHWA, 2015a). The agencies can use this information to distribute resources for maximization of public benefits as well as for justification of the distribution. BCAs can provide information to support decision making in various phases of the transportation investment process. In the planning phase, BCAs can assist in the identification of transportation programs with the best return for the given budget. In both design and operation phases, BCAs can inform highway agencies as to which of the alternative designs and operational strategies can be implemented at the lowest life time cost with most benefits for the travelers. BCAs are also an effective tool for communication between the highway agencies and the general public as the monetized NPV of highway projects can highlight the rationale in the decision-making process to legislatures and the public.

2.1.2 BCA Process

Figure 1 shows the typical process of a BCA (FHWA, 2003). The process begins with defining the project's objectives and identifying the constraints (e.g., fiscal and natural) and analysis assumptions (e.g., expected regional traffic growth and vehicle mixes) over the expected service life of the project.

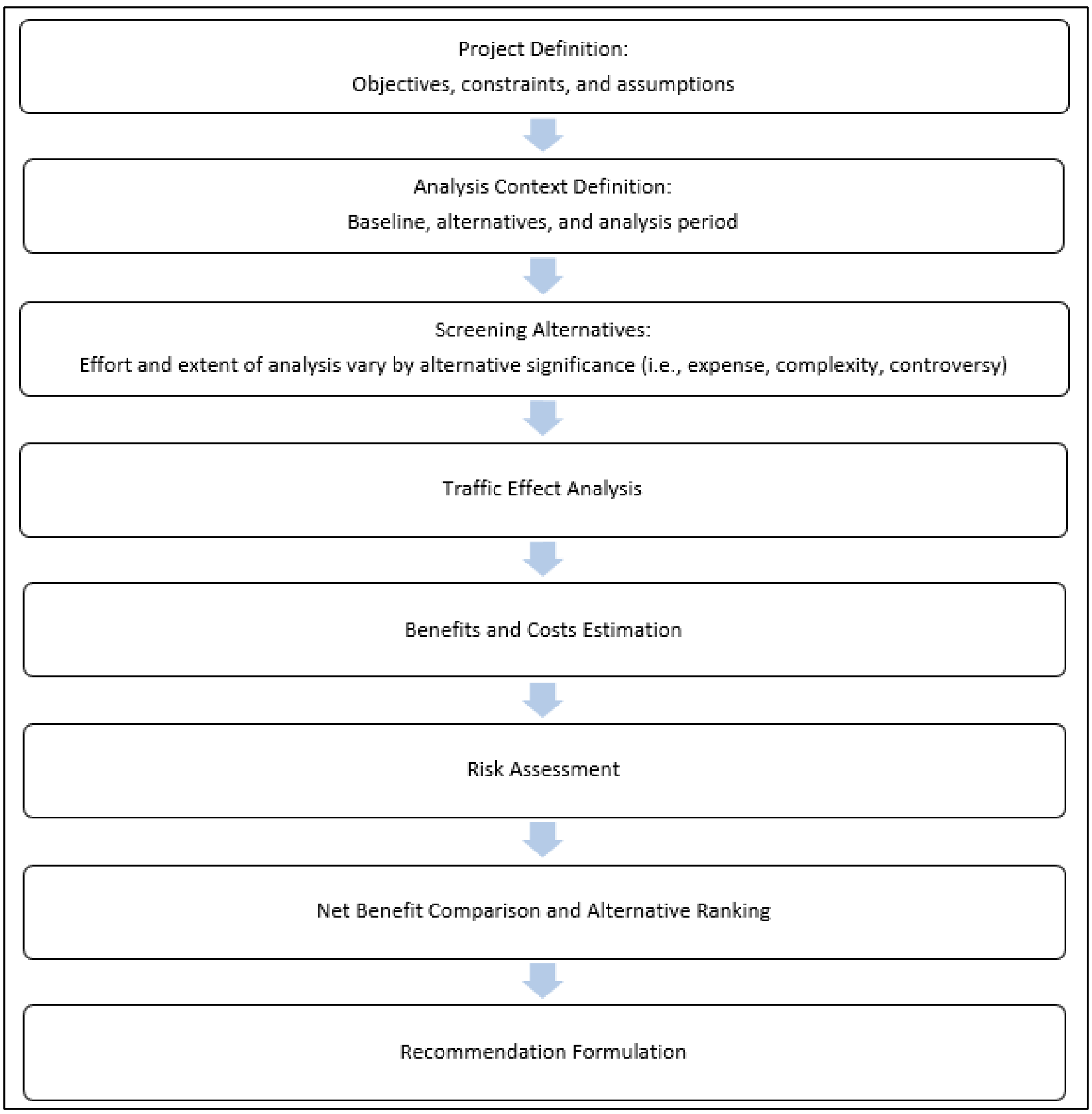

Figure 1 Major Steps in Benefit-Cost Analysis Process (Adapted from FHWA, 2003)

Guided by the assumptions, the baseline scenario and alternatives are then developed to meet the objectives within the boundary of the constraints. An appropriate analysis time period is chosen such that the period encompasses at least one major rehabilitation for each alternative (FHWA, 2015a). This ensures that the life-cycle benefits and costs of the baseline and all alternatives can be measured and compared fairly. Typically, the level of effort spent for quantifying the benefits and costs of an alternative is adjusted proportionally to the expense, complexity, and controversy of the alternative. Before quantitative analyses begin, the alternatives can be screened with this principle such that the greater share of analytical effort is given to the more promising alternatives.

A particular step in the BCA process that is critical to the success of the analysis is analyzing and forecasting of future traffic for the baseline and all alternatives as many benefits and costs of the transportation projects vary by traffic volumes and characteristics. Table 1 shows typical elements of benefits and costs considered in a BCA (FHWA, 2015a). Benefits and costs specific to users of the project such as travel time, delay, crash rates, and vehicle operating cost depend on traffic volumes. Routine operation and maintenance cost for the agency as well as environmental impacts such as emissions and noise may also vary by traffic as higher traffic volumes on the facilities can trigger higher cost for operation and maintenance.

Table 1 Typical Benefits and Costs Considered in a BCA (Source: FHWA, 2015a)

Agency Benefits/Costs	User Benefits/Costs	Externalities
Design and engineering	Travel time and delay	Emissions
Land acquisition	Travel time reliability	Noise
Construction	Crashes	Other social impacts
Reconstruction/Rehabilitation	Vehicle operating cost	
Preservation		
Routine maintenance		
Mitigation		

After the traffic forecasts are developed for the baseline scenario and alternatives, statistic models are applied for the estimation of volume-dependent user benefits and costs. Valuation factors (e.g., dollar value per hour of travel time) are then applied to those non-monetary items such as travel time and delay. After monetization, all the benefits and costs are tallied and discounted for the NPV of each alternative. Risks associated with uncertainties also are assessed for the alternatives at this time. The alternatives with a positive NPV (i.e., discounted benefits exceed discounted costs) are worth pursuing from an economic standpoint. Finally, based on the selection criteria developed from the project objectives, results of the BCA and risk analysis are used to rank the alternatives and to form recommendations for best alternatives.

2.1.3 Current State of BCA Applications

In the last decades, increasingly constrained fiscal resources stipulate more regulations and requirements for highway investments, further strengthening the need to formalize the use of BCA for justification of highway investment decisions (NCHRP, 2014). FHWA had sponsored the development of the BCA.net (FHWA, 2007), an online application that assist decision makers at the Federal, State and local levels in evaluating the benefits and costs of highway projects. The United States Department of Transportation (USDOT) has also recognized the practicality of BCA in guiding public funding decisions as it requires a BCA to accompany all applications for the Transportation Investment Generating Economic Recovery (TIGER) Grants program (2010-2017) and the new Better Utilizing Investments to Leverage Development (BUILD) Transportation Discretionary Grants program (USDOT, 2018).

According to a report to the Congress from the USDOT (USDOT, 2017), there is a significant variation in the extent to which State DOTs use BCA. It is reported that only five to six State DOTs use BCA systematically to inform decision making. Many States use BCA only for certain project types or for situations where a BCA is required for external funding such as safety projects and significant projects for which funding decisions are under intense scrutiny. The report also notes that existing BCA conducted by State DOTs often exclude complex areas such as emissions and freight transportation. Technical challenges such as difficulties quantifying and monetizing benefits are the most frequently cited challenge by State DOTs for the exclusion. This is especially true for freight, multimodal, and non-motorized projects due to a relative lack of established methodologies and valuation methods.

2.1.4 Limitations of Current Practices for Freight Project Evaluation

Currently, most of the established analytical and valuation methods for economic analyses of transportation investment have focused on passenger traffic. It is noted that BCA methodologies developed for passenger travel cannot be readily applied to freight transportation because these methods do not give consideration to the economics of freight movement (FHWA, 2001). For example, for passenger travel, the dollar value of travel time saving is generally accepted to be the passengers' value of time multiplied by the amount of travel time saved. Early attempts at valuing travel time saving or delay for freight transportation used the hourly wage of the truck driver as the valuation factor (WSDOT, 2013). However, the driver's wage only reflects the benefits/costs of travel time changes to the carriers. It doesn't capture the true value of time in freight operation as the benefits/costs to the cargo owners (i.e., the shippers) are not considered in the valuation, especially in the case of perishable goods that can suffer significant value loss from unexpected delay in transit.

Moreover, the reliability in travel time (i.e., variation of transit time from shipment to shipment) is another benefit/cost factor in freight transportation that carry different valuation than passenger travel. Reliable transit time enables shippers to reduce business cost by operating with a more efficient inventory control and avoiding unnecessary warehouse cost. Such economic benefits stemming from the shippers' business reformation in response to improved travel time and reliability are called reorganization effects (FHWA, 2001), which are important contribution of freight transportation projects and need either special treatment in a BCA or a different type of economic analysis to quantify.

The benefits of a highway project measured by a BCA are often termed direct or first order benefits and represent immediate impacts of the transportation project on users and nonusers (NCHRP, 2014). Direct benefits consist of changes in travel time, crashes, vehicle operating costs, agency construction costs, and pollution. BCA typically do not measure how these direct benefits and costs are converted into indirect or higher order effects on the economy, such as improved logistic operation, better access to markets, changes in employment, wages, business sales, or land use. Collectively, these higher order benefits are often termed Wider Economic Benefits (WEB) in transportation economic literature (NCHRP, 2014).

Another class of economic analysis called Economic Impact Analysis (EIA) can be used to evaluate how the direct benefits and costs of a highway project (e.g., reduced vehicle operating cost) can turn into WEB and affect the local, regional, or national economy (FHWA, 2003). An EIA quantifies the multiple economic effects resulting from a change in the demand for a specific product or service. For example, improved transportation system can lead to reduced vehicle operating cost for average travelers. The money saved can then be used in shopping or other services, collectively leading to growth of multiple industries and the overall economy in the region.

The difference between BCA and EIA has been elaborated in NCHRP report 786: Assessing Productivity Impacts of Transportation Investments (NCHRP, 2014).

- Benefit-Cost Analysis (BCA) – focuses on the money value of all benefits associated with transportation system change, both traveler benefits and social benefits.
- Economic Impact Analysis (EIA) – focuses on the impact of a project on economic growth (jobs, income, investment, or value added).

Figure 2 illustrates the benefit and impact measures covered in BCA and EIA. WEB are reflected through productivity gains associated with agglomeration and logistics technology efficiencies that are enable by access, connectivity and reliability effects.

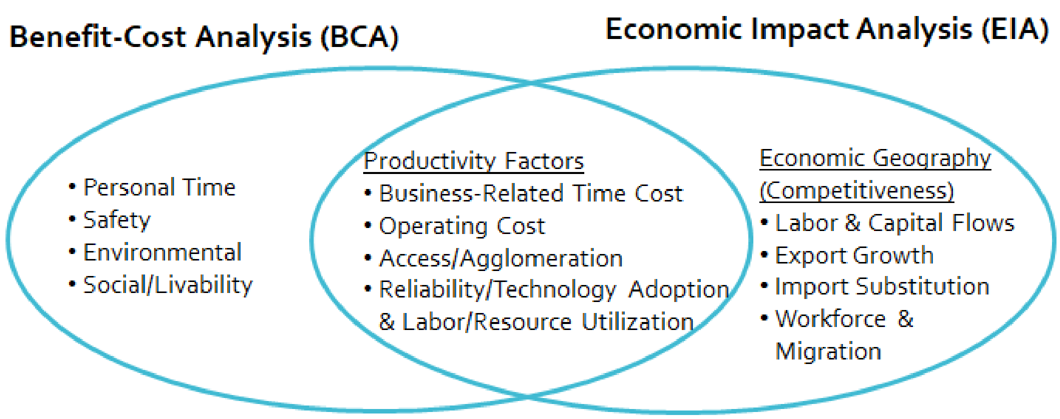

Figure 2 Relationship of Economic Impact and Benefit-Cost (Source: NCHRP, 2014)

For freight projects that are expected to generate significant higher order benefits, EIA results can be presented as complementary information to BCA (FHWA, 2003). BCA results show whether a project is worth the investment from the standpoint of public interest. EIA results can inform decision makers and the public about how the benefits and costs of the project will ultimately be distributed within the economy. Information from both analyses may be summarized in the final recommendations for project ranking and prioritization.

2.2 National Guidelines and Efforts

To identify relevant information and guidelines for development of the analytical framework for the proposed freight project priority decision support system, we reviewed a collection of research reports sponsored by the Federal and State level transportation agencies. We summarized our findings from seven of these reports. Each of the reports documented here offers some concepts and ideas relevant to our work. Table 2 offers a quick glance of these reports.

Table 2 Summary of National Reports

Sponsor	Year	Title	Major Contents
NCHRP	2007	Guidebook for Integrating Freight into Transportation Planning and Project Selection Processes	• Introduction of formal transportation programming and project development processes to freight planners • Step by step guidance on how to develop programs and secure funding for freight projects
FHWA	2008	Freight Benefit/Cost Study	• Introduction of economic theories and analytical methodologies to model the reorganization effects of freight transportation investments • Development of the Highway Freight Logistics Reorganization Benefits Estimation Tool
AASHTO	2010	User and Non-User Benefit Analysis for Highways, 3rd Edition	• Use of traffic performance data for quantification of user and non-user benefits of highway projects • Benefits/Costs valuation factors including values of time and operating costs for various vehicle classes, trip purposes, and occupancy rates, as well as accident cost parameters
NCFRP	2011	Framework and Tools for Estimating Benefits of Specific Freight Network Investments	• Development of a procedural framework for evaluating complex freight investment decisions facing both the public and private sectors of the freight industry • Review of available analytical tools for freight BCA

Table 2, continued

Sponsor	Year	Title	Major Contents
NCHRP	2014	Economic Productivity and Transportation Investment Priorities	• Introduction of productivity concept to capture the WEB in economic analyses of transportation projects • WEB considered including benefits attributable to improvements of travel time reliability, accessibility to markets, and connectivity to intermodal terminals • Concepts and methods implemented in commercial tool TREDIS
FHWA	2015b	Measuring the Impacts of Freight Transportation Improvements on the Economy and Competitiveness	• Review of approaches, methods, and tools used to assess how freight improvements contribute to economic competitiveness and the cost of goods
NCFRP	2017	Guide for Conducting Benefit-Cost Analyses of Multimodal, Multijurisdictional Freight	• Introduction of multimodal, multijurisdictional BCA for freight investment decision-making • Development of a procedural framework for conducting a multimodal, multijurisdictional BCA, accompanied by examples for illustration of concepts • Review of available analytical tools for multimodal, multijurisdictional BCA

2.2.1 FHWA Freight Benefit-Cost Study

Recognizing the importance and challenges of using BCA for evaluation of public investment in freight transportation, the Office of Freight Management and Operations of FHWA sponsored three phases of the Freight Benefit/Cost Study (FHWA, 2008). Phase I of the study focuses on formulating the economic theories of reorganization effects in freight transportation. Phase II identifies the long-term economic benefits of freight improvement projects by examining the dynamic interactions between the supply/demand of freight transportation and the performance of the highway systems at the national level. Phase III establishes the analytical approach, sensitivities and data inputs required to quantify long-term economic benefits of freight transportation investment on a regional level. Concluded in 2008, the three phases of the Freight Benefit/Cost Study represent an important step forward in formalizing economic analysis for freight transportation. The study introduces theories and analytical methodologies that are more capable of reflecting the true benefits of freight transportation than the conventional BCA methods. The overall methodology allows for the quantification of the effects of freight transportation improvements with respect to:

a) immediate cost reduction to carriers and shippers
b) the benefits of improved logistics while the output remain fixed, and

c) additional gains from reorganization such as increased demand and supply.

The benefits identified with items (b) and (c) are collectively termed wider transportation impacts or Wider Economic Benefits (WEB) in subsequent freight studies to distinguish them from the benefits in item (a), which are readily captured in traditional BCA approach.

2.2.2 AASHTO Redbook

The American Association of State Highway and Transportation Officials (AASHTO) is also involved in promoting BCA for highway projects by publishing and continuously updating the manual User and Non-User Benefit Analysis for Highways (AASHTO, 2010). Professionally known as the Redbook for its red cover, the manual endorses the use of traffic performance data (e.g., traffic volume, speed, and travel time) and their future forecasts based on the baseline and alternative scenarios for quantification of user benefits of the project. The manual also contains benefits and costs valuation factors such as values of time and operating cost for various vehicle classes, trip purposes, and occupancy rates, as well as accident cost parameters. These factors are applied with the obtained traffic performance data to determine various user and non-user benefits and costs. The Redbook generally follows the conventional highway BCA approach in that only direct benefits and costs from travel time and other traffic performance improvement are considered. The manual does not provide coverage on regional economic benefits generated by the aforementioned reorganization effects of improved freight transportation.

2.2.3 NCHRP Report 594

The National Cooperative Highway Research Program (NCHRP) is another major sponsor in studies involving highway freight transportation. Published in 2007, the NCHRP Report 594, Guidebook for Integrating Freight into Transportation Planning and Project Selection Processes (NCHRP, 2007), introduces the formal transportation programming and project development processes to freight planners with step by step guidance on how to develop programs and secure funding for freight projects. Although no technical details are provided, the guidebook recognizes the importance of performing economic impact evaluation and BCA for freight project programming. These analyses can increase the chance for successful approval and funding of freight projects by showcasing the magnitude and nature of economic benefits that are either directly or indirectly generated by the projects.

2.2.4 NCFRP Report 12

The NCFRP Report 12, Framework and Tools for Estimating Benefits of Specific Freight Network Investments (NCFRP, 2011), describes the development of a procedural framework (see Figure 3) that can be followed when evaluating complex freight investment decisions facing both the public and private sectors of the freight industry.

The framework is developed through identification of best practices, interviews with public and private stakeholders, and assessment of existing data and methods for freight investments evaluation. In addition to the framework, this report also compiles a list of existing tools and supporting data necessary for evaluation of freight project benefits and costs. Essentially, the framework produced with this research study is a structured procedure, with which analyses utilizing existing tools and data can be conducted. The report does not provide much guidance on how the analyses should be performed for the framework to work. Another shortcoming of this study is that the framework does not appropriately address the WEB that are critical to the benefits of a freight project.

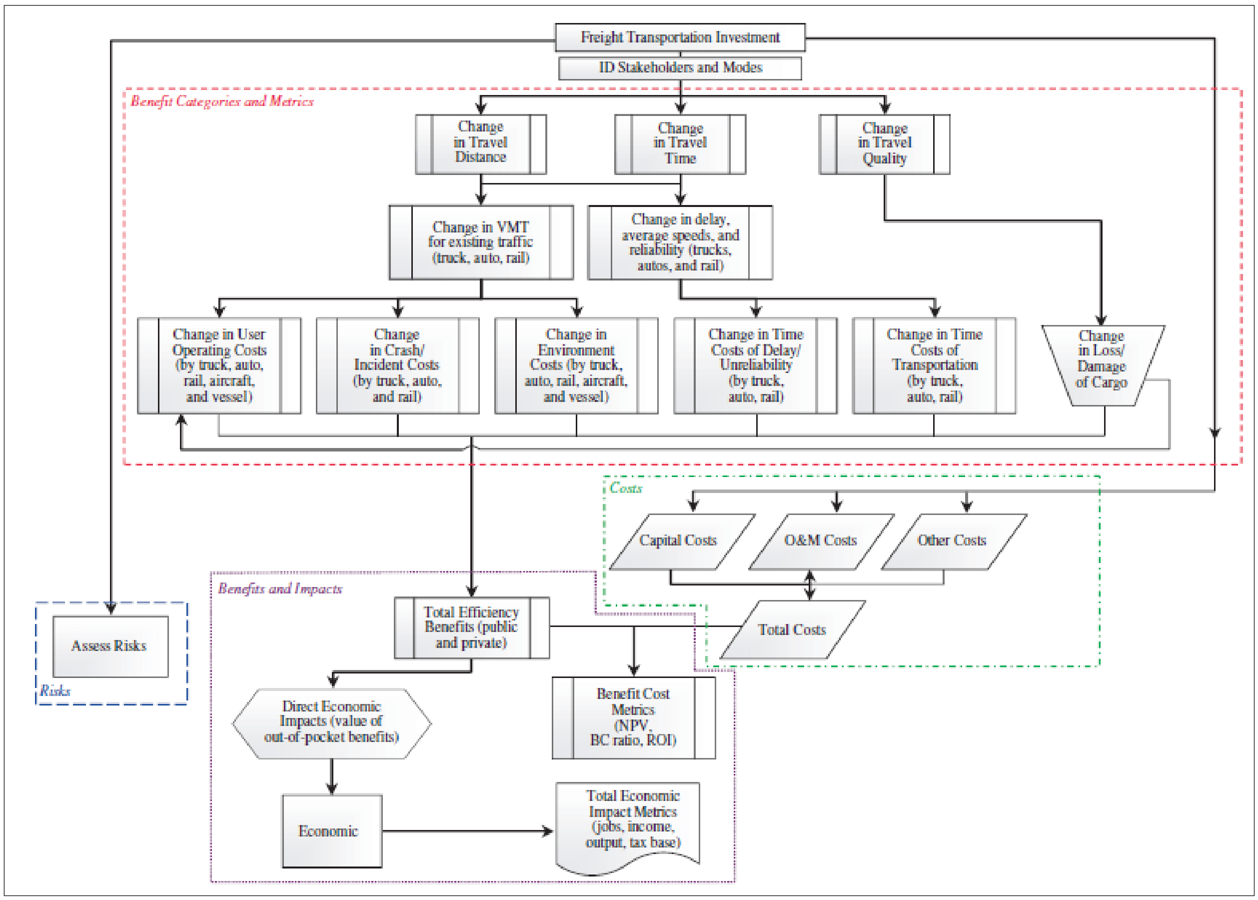

Figure 3 Freight Evaluation Framework (Source: NCFRP, 2011)

2.2.5 NCHRP Report 786

NCHRP project 02-24, Economic Productivity and Transportation Investment Priorities, marks the first research effort that directly tackles the issue of WEB involving freight transportation (NCHRP, 2014). The study recognizes that WEB associated with enhancement of reliability of movements, accessibility to markets, and connectivity to intermodal terminals from highway transportation improvement are not being fully captured in current benefit-cost analysis methods. This study introduces the concept of productivity to capture the WEB in economic analyses of transportation projects. Productivity is defined as the measurement of how much economic output is generated from a given amount of input (e.g., dollars invested in the transportation projects). The three elements of enhancement in reliability, accessibility and connectivity can each contribute to productivity gain through reorganization and agglomeration effects. For example, reliability improvement empowers productivity gain through logistics and operational reorganization. Enhanced accessibility and connectivity can increase the effective density, range, and size of a firm's markets for labors and customers (i.e., agglomeration), resulting in growth in economies at the local and regional scales.

The research team formulated a procedure (see Figure 4) for analyzing the productivity effects of transportation system improvements. The procedure begins with screening projects to eliminate those that are not expected to significantly change transportation reliability, accessibility, and connectivity in the region. Projects expected to have significant economic impacts are applied with specific analysis tools depending on the specific benefits (i.e., reliability, accessibility, and/or connectivity) expected. Standard travel benefits in travel time and travel cost are first analyzed, followed by wider transportation impacts from reliability, accessibility, and/or connectivity enhancement. Productivity gain from all expected benefit elements are tallied and the total productivity is included with results of a BCA or Economic Impact Analysis (EIA) for decision support of project selection. The research team also prepared a step by step guidance for incorporating productivity gains into analysis for prioritizing transportation investment projects. The final report of this study, NCHRP Report 786 Assessing Productivity Impacts of Transportation Investments (NCHRP, 2014), is meant to be used by DOT, MPO staff and others responsible for evaluating projects and making recommendations to decision makers.

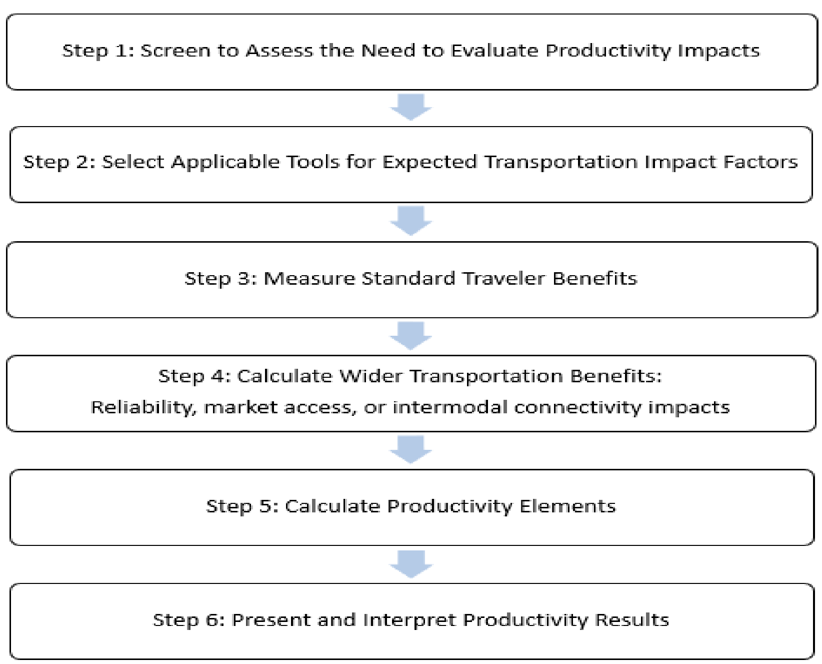

Figure 4 Six Steps Required to Assess Productivity Impacts of Transportation Projects (Adapted from NCHRP, 2014)

2.2.6 FHWA Measuring the Impacts of Freight Transportation Improvements

In 2015, FHWA released the report, Measuring the Impacts of Freight Transportation Improvements on the Economy and Competitiveness (FHWA, 2015b), which provides a review of approaches, methods, and tools that can be used to assess how freight improvements contribute to economic competitiveness and the cost of goods. This document is intended to be used as a resource by practitioners, particularly state and regional transportation decision makers, when faced with investment decisions regarding freight. Although no new method or data are discussed, this report recognizes the viewpoint that productivity and competitiveness are intrinsically related as productivity is viewed as the ratio of economic output per unit of input and cost competitiveness is measured by the ratio of input cost per unit of output produced. Productivity can thus be viewed as an indicator of net national economic impact. This viewpoint essentially supports the use of expected productivity gain as benefit measurement of freight transportation projects.

2.2.7 NCFRP Report 38

The NCFRP Report 38, Guide for Conducting Benefit-Cost Analyses of Multimodal, Multijurisdictional Freight (NCFRP, 2017), explains how to conduct multimodal, multijurisdictional benefit-cost analyses (BCAs) for freight investment decision-making. The content of this report mirrors that in the aforementioned NCHRP Report 786, except that this NCFRP report addresses decisions involving all modes and across jurisdictional boundaries such as state and metropolitan planning organization (MPO) lines. This guidebook presents a process framework (Figure 5) for conducting a multimodal, multijurisdictional BCA, accompanied by examples for illustration of concepts. The framework is divided into three stages with a total of 11 steps.

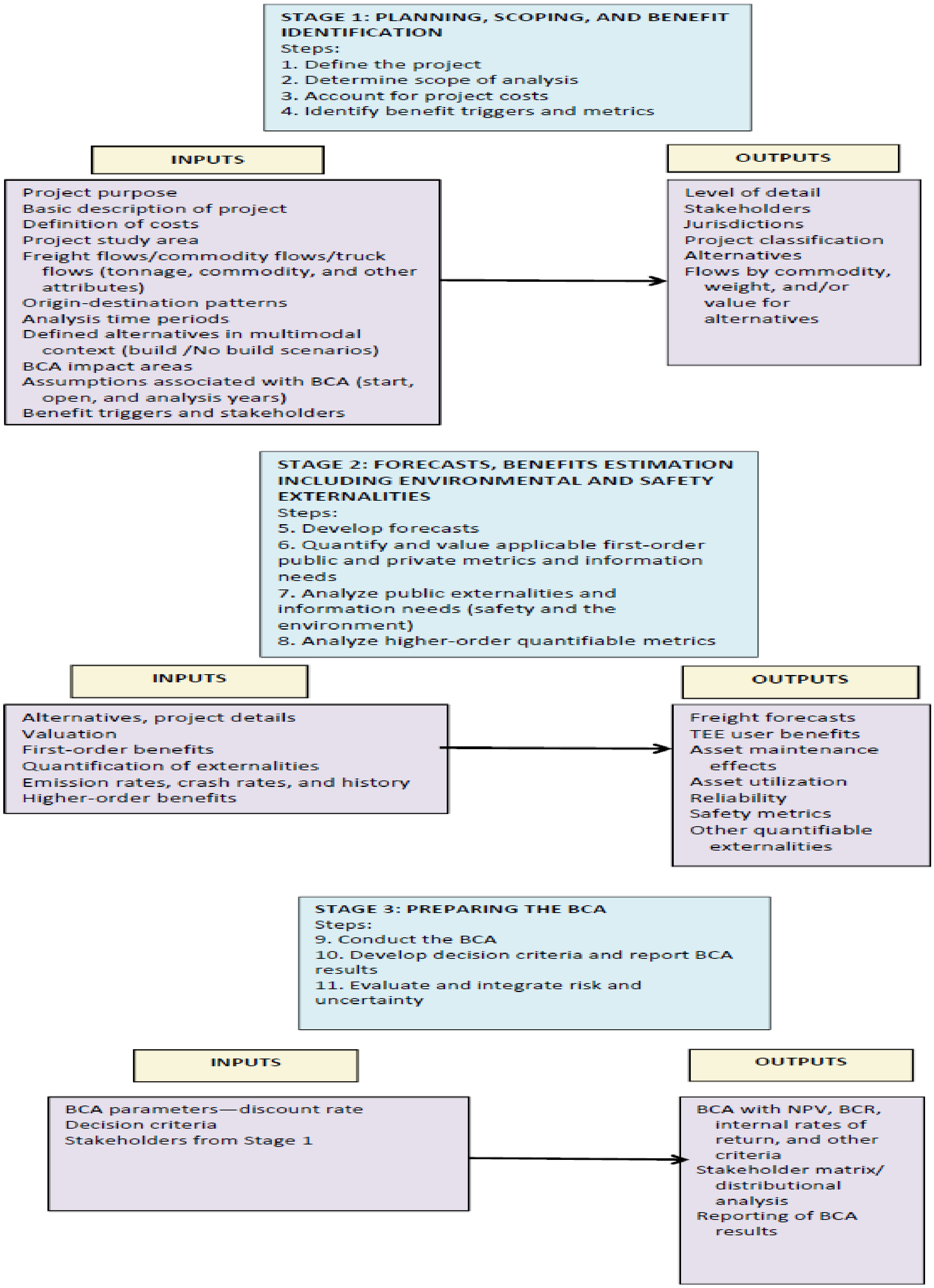

Figure 5 Framework for Multimodal, Multijurisdictional BCA (Source: NCFRP, 2017)

This framework in Figure 5 represents an elaboration of those in Figure 1 and Figure 4 with specific considerations given to multimodal and multi-jurisdictional aspects of freight projects. This guidebook also touches on the issues of higher-order benefits (i.e., the Wider Economic Benefits) of freight transportation. However, readers of the report are referred to NCHRP Report 786 and the FHWA Benefit/Cost Study for suggestions on capturing the higher order benefits in the BCA.

2.3 Major Tools

We identified and reviewed seven existing BCA tools that are relevant to our work. These tools have been extensively reviewed in FHWA's Report Measuring the Impacts of Freight Transportation Improvements on the Economy and Competitiveness (FHWA, 2015b). We provide a summary of the tools in Table 3, followed by a brief description of the tools' features.

2.3.1 MicroBENCOST

First released in 1993 and later updated in 1997 as a deliverable of a NCHRP project (NCHRP, 1999), MicroBENCOST implements the earliest edition of AASHTO's Redbook for BCA of highway projects. The program is capable of analyzing seven categories of highway projects: added capacity, bypass, intersection/interchange, pavement rehabilitation, bridge, safety, and highway-railroad grade crossing. Vehicle delays and operating costs may be estimated for up to nine passenger vehicle types and up to nine truck types. In addition to Annual Average Daily Traffic (AADT) data, the tool requires users to input estimated truck percent and vehicle fleet composition of the project corridor to perform BCA.

Three groups of benefits are considered with MicroBENCOST: user travel times, vehicle operating costs, and accidents. Cost categories include total initial cost, salvage value at the end of the evaluation period, and rehabilitation and maintenance costs throughout the analysis period. Benefit/cost metrics produced at the end of analysis include NPV, Benefits/Costs ratio, and internal rate of return, which is the estimated rate of return, or discount rate, that would equate the present value of total benefits to total costs. MicroBENCOST is available via the McTrans Center of University of Florida (https://mctrans.ce.ufl.edu/mct/). MicroBENCOST gives users the option of updating the valuation parameters built in with the program, making the tool applicable for current practice.

2.3.2 STEAM

The Surface Transportation Efficiency Model (STEAM) was developed for FHWA (Cambridge Systematics, 2000) to estimate user benefits, costs, and externalities of transportation projects using data from regional four-step travel demand models. STEAM can be used to evaluate projects involving multi-modal transportation systems incorporating seven different modes including auto, carpool, truck, local bus, express bus, light rail, and heavy rail. Project impacts are modeled at the corridor or regional levels.

Project benefit metrics considered by STEAM includes travel times, vehicle operating costs, accidents, emissions (i.e., CO, NO_x, PM_{10}, volatile organic compounds, with cold-start component), energy consumption, and noise. Infrastructure investments and operating costs are the cost metrics considered. The model produces economic performance metrics in NPV and Benefit/Cost ratio, access to jobs, revenues and transfers from fares, tolls, and fuel taxes. For the model results, STEAM provides probability distributions for the outputs as an estimation of risk involved.

Currently, STEAM is no longer available from FHWA. However, the product catalog of the McTrans Center of the University of Florida contains the listing of STEAM for purchase as a limited support product.

2.3.3 HERS-ST

The Highway Economic Requirements System – State Version (HERS-ST) was developed by FHWA to perform highway engineering/economic analyses that reflect both the current condition of the highway system and the estimated costs and benefits of improvement alternatives to the system (FHWA, 2005). The program was designed to work with the Highway Performance Monitoring System (HPMS) data (FHWA, 2018a).

For a particular highway under consideration for improvement, HERS-ST obtains information about the current condition of the highway from HPMS data, then it generates a set of standard improvement alternatives. Users can specify additional alternatives to this set. The application then searches for the best combination of improvements for which the economic benefits exceed the costs. Up to six different investment alternatives are considered for each highway segment by combining possible improvements to pavement, lane width, and alignment.

HERS-ST considers user and agency benefits in travel times, vehicle operating costs (i.e., fuel, oil, tires, maintenance, and depreciation), collisions, emissions (i.e., CO, NO_X, PM_{10}, volatile organic compounds, SO_X, and road dust), highway maintenance and operation cost, and highway residual values. Cost elements considered include initial right-of-way acquisition and construction costs. The final economic metrics produced by HERS-ST is incremental benefit-cost ratios.

As of today, HERS-ST is no longer available for download from the FHWA's Asset Management program. It cannot be found in the catalog of the McTrans Center either. It is reported that four state DOTs (i.e., Washington, Oregon, Kentucky, and Iowa) still actively use HERS-ST for project evaluation (WSDOT, 2018). Agencies interested in implementing HERS-ST may contact these four DOTs for available resources.

2.3.4 CAL-B/C

The California Life-Cycle Benefit/Cost Analysis Model (CAL-B/C) is a spreadsheet model developed by Caltrans for BCA of projects involving highway capacity improvement, passenger rail/transit capacity improvement, highway operation improvement (e.g., HOV lanes), and Transportation Management Systems/Intelligent Transportation Systems (e.g., ramp metering) (Caltrans, 2017a). After entering data to define the type, scope, cost, and traffic volumes of the project, the model produces benefit/cost metrics including life-cycle costs, life-cycle benefits, net present values, benefit-cost ratios, internal rates of return, and payback periods. Variations of the model have also been released for BCA involving different project types, including corridor, park and ride, active transportation, and intermodal freight.

The California Intermodal Freight Benefit/Cost Analysis Model (Cal-B/C IF) is a new variation of the Cal-B/C model designed to run BCA for intermodal freight projects (Caltrans, 2017b). Three major types of freight projects can be modeled, including freight network improvements (i.e., truck and/or rail corridors), modal diversion (i.e., facilities diverting cargo between trucks and rail), and terminal efficiency and transload operation improvements (e.g., new terminals, terminal capacity improvement, or new technologies improving load transfer or drayage operation). Three major groups of benefits are considered: shipper cost savings, accident cost savings, and emissions cost savings.

Freight network improvement projects generate benefits through cost savings owing to faster travel time or shorter travel distance. Modal diversion benefits occur after loads are transferred from trucks to rail for long distance travel, resulting in cheaper overall shipping cost, reduced truck emissions on highways, and reduced truck accidents on highways. Terminal efficiency and transload operation improvements create saving in shipper cost.

The Cal-B/C model family utilizes standard economic valuations for application in the BCA. The economic values represent California statewide averages. Users interested in using Cal-B/C for BCA in a different state need to use values specific for their state. For projects applying for the USDOT BUILD grants, the new 2018 Cal-B/C BUILD Model can be used. This model use economic valuation values contain in USDOT's Benefit-Cost Analysis Guidance for Discretionary Grant Programs (USDOT, 2018).

2.3.5 BCA.Net

BCA.Net is FHWA's web-based tool for conducting formal BCA for highway projects (FHWA, 2007). BCA.Net's underlying methodology is consistent with the current benefit-cost methodologies employed by the FHWA. The tool can evaluate a variety of highway improvement projects including preservation, lane-widening, lane additions, new alignments, addition of traffic control devices, and intersection upgrades). It facilitates the evaluation of multiyear, full-lifecycle investment and maintenance strategies. The model allows inputs for time-of-day distribution of traffic (e.g., peak, peak shoulder, off-peak) and traffic mix by vehicle type (e.g., auto, truck, bus). User and non-user benefits include time savings, vehicle operating cost savings, accident reductions, air emissions reductions, and the project residual value. Cost elements considered include project construction and maintenance costs. BCA.Net also models specific cost involving traffic disruption during construction of the project.

The final economic performance metrics produced by BCA.net included NPV, Benefit/Cost ratios, and rate of return. BCA.NET allows the user to use risk analysis techniques to estimate probabilities associated with the results.

BCA.Net contains a unique feature of "Non-Transportation Benefits" for users to incorporate specific benefits and costs of the project that are not captured in the built in standard traveler benefit categories. This feature can be used when users want to include the wider economic benefits from the project into the BCA. However, values of the non-transportation benefits need to be estimated by the users separately then manually entered into BCA.Net in constant dollar amount by year. The application will include the values of this user-specified benefit in the tallying of the final economic performance metrics.

By 2007, FHWA no longer officially supports the BCA.Net (FHWA, 2007). BCA.Net is now available as a commercial Internet application (https://hwbca.net/BaseLogin/LoginReg3.aspx).

2.3.6 Highway Freight Logistics Reorganization Benefits Estimation Tool

FHWA's Highway Freight Logistics Reorganization Benefits Estimation Tool (HFLRBET) is the product of the FHWA Freight Benefit/Cost Study (FHWA, 2001). The tool was designed to analyze the WEB resulting from the reorganization effects of transportation projects. HFLRBET takes the data and results from a traditional BCA as inputs and estimates WEB triggered by the project such as reduction of shipping and sourcing costs, replacement of inventory on-hand with just-in-time delivery of inputs, and wholesale reformation of the supply chain. HFLRBET also considers the long-run economic benefits from expansion of markets and the outward shift in the demand curve for freight transportation. Essentially, the tool captures the benefits that accrue to businesses and the economy as lower freight transportation costs facilitate reorganization of the supply chain in terms of better efficiency and economic outputs.

The key inputs to the HFLRBET are data pertaining to the baseline initial conditions of the project, including the project location, project length, baseline truck traffic, average speed, value of time, vehicle operating costs, and travel time reliability. In addition, users are required to enter the typical output data of a BCA into HFLRBET such as changes in vehicle operating costs, travel time, and reliability. Based on these inputs, the tool estimates the reorganization benefits. This tool enables the analysts of a traditional BCA to expand the scope of analysis by incorporating the benefits and productivity that accrue from supply chain reorganization. HFLRBET is implemented as a spreadsheet tool available for download from FHWA's Freight Benefit/Cost Analysis web site (https://ops.fhwa.dot.gov/freight/freight_analysis/cba/index.htm).

2.3.7 TREDIS

TREDIS® was created by the Economic Development Research Group (EDRG) as an online application accessible by paid subscriptions (EDRG, 2018). TREDIS integrates BCA with elements of EIA (see Figure 6) for evaluation of a wide range of impacts associated with transportation projects including the assessment of benefits, costs, finance and macroeconomic impacts. It is noted that EDRG is one of the investigators of the aforementioned NCHRP Report 786 (NCHRP, 2014) that introduces the concept of productivity for quantification of WEB involving freight projects. The assessment of productivity impacts from improved travel time reliability, accessibility to markets, and connectivity to intermodal terminals mentioned in the report can be performed with TREDIS.

Figure 6 shows the analysis process of TREDIS, which operates as a set of interconnected modules, including: Travel Costs, Market Access, Economic Adjustment, Benefit/Cost, Finance, and Freight.

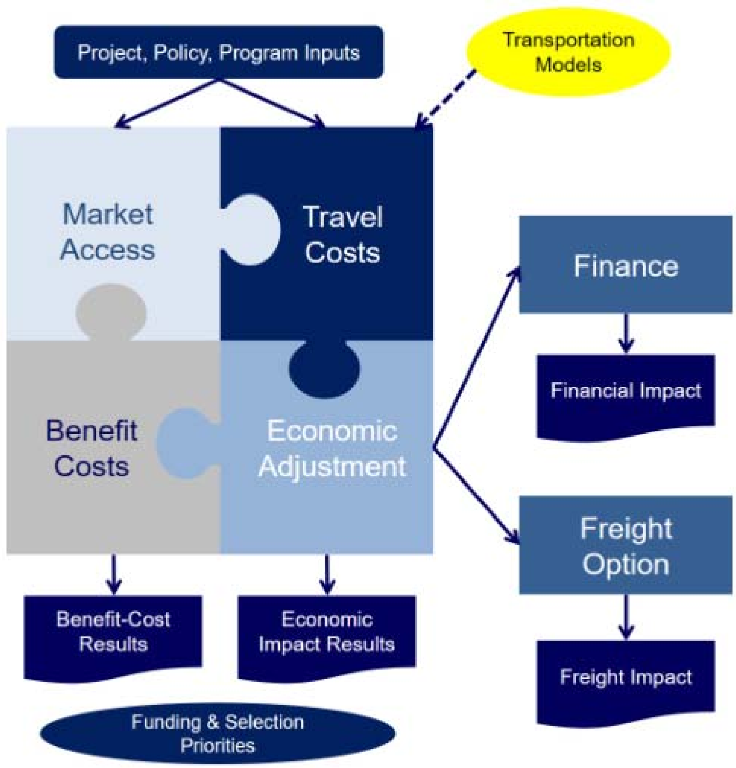

Figure 6 TREDIS Analysis Process and Modules (Source: EDRG, 2018)

The Travel Cost module receives data from a regional travel demand model and assess how changes in travel characteristics translate into user and nonuser benefits, as well as direct economic impacts. The Market Access module models how changes to market accessibility improve conditions for business growth and productivity. These two modules combined evaluate the direct impacts of a transportation project or policy. These direct impacts are then processed in the Economic Adjustment module to estimate secondary economic effects (i.e., productivity gain), and also to the Benefit-Cost module, to itemize and discount costs, benefits, and impacts for the project's service life. The Freight and Finance modules take results from the Economic Adjustment coupled with additional data sources to indicate a project's impacts on the financial gain and freight operation in the region. For example, the Finance module shows additional tax receipts credited to the project impacts, and the Freight module shows how commodity flows are affected.

The Travel Cost module considers nine different passenger and freight modes, including passenger car, passenger bus, passenger rail, passenger air, passenger ferry, freight truck, freight rail, freight air, and freight marine. Figure 6 shows the input and output data of the Travel Cost Module. Input data to the Travel Cost Module typically come from regional travel demand models, including number of trips, Vehicle Miles Traveled (VMT), Vehicle Hours Traveled (VHT), and passenger car and freight occupancy. Travel benefit/cost is reflected in terms of congestion, safety, and tolls. TREDIS model the reliability cost using the buffer time concept, which refers to the amount of time travelers add to their travel time budget in order to avoid unpredictable delay. The total cost of buffer time is estimated by multiplying the total number of trips by the average buffer hours per trip and the average cost per hour of buffer time.

The Market Access module of TREDIS estimates how a region's economy improves if businesses have better access to labor, customers, and suppliers from improved transportation. The statistical relationships applied by this module were estimated using a database of accessibility and connectivity factors in the US. Population reached within a 40–minute drive and employment covered within a 3-hour drive are two critical factors used to measure market accessibility. The 40 minutes driving time represents as an average travel time for commute trips in the U.S. The 3-hour driving time reflects the market accessibility of domestic supply chains as it approximates the average time required for the same-day deliveries (Alstadt et al., 2012). Calculation of connectivity to intermodal terminals involves variables in airport activity level (i.e., annual operations), average drive time to domestic airport, average drive time to rail intermodal facility, average drive time to seaport facility, average drive time to international airport, and average drive time to international land border.

The TREDIS Market Access Module uses regression models to assess how accessibility to markets and connectivity to intermodal terminals affect the business productivity, international exports, and business relocation (i.e., for better access of labor and markets) of an industry in a county with certain population and skilled labor force. These three outcomes (i.e., productivity, exports, and relocation) combined measure the area's economic development brought upon by improved accessibility and connectivity.

The results of Travel Cost and Market Access Module are then transferred to the Economic Adjustment Module, which incorporates a regional economic model to estimate impacts on employment and income growth over time. TREDIS uses the IMPLAN – CRIO (FHWA, 2015b), an economic input-output model, to converts the various cost savings and business productivity to economic development impact indicators (e.g., employment and income).

The Benefit Costs Module receives results from the Traffic Cost Module, Market Access Module, and Economic Adjustment Module. It then itemizes and discounts the economic benefits of the projects to produce NPV and Benefits/Costs ratios. In calculating the metrics, the Module avoids double-counting and follows the benefit-cost guidance of USDOT Grant rules.

This Finance module calculates the economic changes on revenues, expenditures and cash flow for both private and public sectors. It calculates the effects of changes in tolls, taxes and pricing of transportation services, together with local, state and federal tax revenues resulting from the transportation projects.

This Freight Module estimates the volume and types of freight movements of a given region triggered by the project's impacts on the economy. It relates changes in a region's economic growth into freight tonnage flows and changes in volume of trucks. The TREDIS Freight Module can estimate commodity being shipped by mode (i.e., air, marine, truck, rail) and by origin and destination within the US and abroad.

Table 3 presents a summary of the major features of the BCA tools reviewed.

2.4 Summary

Over the last decade, financial constraints have led public leaders and agency decision makers to request more information from proposed transportation projects in terms of cost effectiveness and expected job and economic growth potentials of the projects (NCHRP, 2014). This is evidenced in the persistent demand from the USDOT to have a BCA conducted for every project proposal requesting the TIGER grand (terminated after 2017) and the new BUILD grant (USDOT, 2018). It can be expected that requirements of conducting BCAs and/or other types of economic analyses are going to be increasing for proposals requesting public funding, especially for investment involving freight transportation that has great potentials in stimulating regional job market and economic growth.

Our review of existing studies involving BCA for freight transportation project reveals that most of the existing BCA methodologies and analytical tools are not capable of capturing the higher order benefits of freight projects such as improved logistic operation, better access to markets, changes in employment, wages, business sales, and the overall regional economy. We identify two particular studies: FHWA's Freight Benefit/Cost Study (FHWA, 2008) and NCHRP Project 02-24 (NCHRP, 2014), that offer valid analytical methods and associated tools (e.g., Highway Freight Logistics Reorganization Benefits Estimation Tool and TREDIS) for quantifying the WEB of freight projects. The task at hand now is to develop a procedural analysis framework that integrate these WEB methods into a standard BCA process that is consistent with requirements from funding authorities such as USDOT and FHWA.

Table 3 Summary of BCA Tools Reviewed

Sponsor	Year	Title	Application context	Input Data	Benefits Considered	Costs Considered	Economic Metrics Produced
NCHRP	1999	MicroBENCOST (NCHRP, 1999)	Highway improvement projects in a corridor	• Project information • Project design data • AADT	• User travel times • Vehicle operating costs • Accidents • Residual value	• Total initial cost • Rehabilitation and maintenance costs	• Net present value • Benefits/Costs ratios • Internal rate of return
FHWA	2000	STEAM (Cambridge Systematics, 2000)	Highway investments at the regional and corridor levels	• Project information • Travel demand model	• Travel times • Vehicle operating costs • Accidents • Emissions • Energy consumption • Noise • Access to jobs	• Infrastructure investments • Operating costs	• Net present value • Benefits/Costs ratios • Level of risks associated with the estimated results
FHWA	2001	Highway Freight Logistics Reorganization Benefits Estimation Tool (FHWA, 2001)	Reorganization effects of transportation projects	• Project information • Results of a BCA of the project	• Reduction of shipping and sourcing costs • Replacement of inventory on-hand with just-in-time delivery • Wholesale reformation of the supply chain. • Long-run economic benefits from expansion of markets • Increased demand for freight transportation	• N/A	• N/A
FHWA	2005	HERS-ST (FHWA, 2005)	Projects on nine major functional classes of highways	• Highway Performance Monitoring System (HPMS), data • User-specified project data	• Travel times • Vehicle operating costs • Accidents • Emissions • Highway maintenance and operations • Highway residual values	• Initial right-of-way acquisition • Construction costs	• Benefits/Costs ratios

Table 3, continued

Sponsor	Year	Title	Application context	Input Data	Benefits Considered	Costs Considered	Economic Metrics Produced
FHWA	2007	BCA.Net (FHWA, 2007)	Highway improvement projects	• Project information • Traffic volume data	• Travel times • Vehicle operating costs • Accidents • Emissions • Residual value	• Project construction and maintenance costs. • Work zone traffic disruption during construction	• NPV • Benefit/Cost ratios • Rate of return • Level of risks associated with the estimated results
Caltrans	2017	CAL-B/C (Caltrans, 2017a)	Highway capacity improvement; Passenger rail/ transit capacity improvement; Highway operation improvement; Transportation Management Systems/ITS; Corridor; Park and ride; Active transportation; Intermodal freight	• Project information • AADT	• Travel time • Vehicle operating costs • Accidents • Emissions	• Total life cycle investment • Annual operating and rehabilitation costs	• Net present value • Benefit-cost ratio • Internal rate of return • Payback period
EDRG	2018	TREDIS (EDRG, 2018)	Transportation projects of all modes (highway, freight, rail, air, and marine)	• Project information • Travel demand model	• Direct benefits (e.g., travel time, cost, accident) • Productivity of the WEB resulting from improved reliability, accessibility, and connectivity	• Infrastructure investments • Operating and maintenance costs	• Net present value • Benefit-cost ratio •

3. FRAMEWORK DEVELOPMENT

This section describes a procedural analysis framework that integrate methods for estimating the WEB of freight transportation projects into a standard BCA process that is consistent with requirements from funding authorities such as USDOT and FHWA.

We reviewed relevant reports from FHWA, AASHTO, NCHRP, and NCFRP and identified a BCA process in FHWA's Economic Analysis Primer (FHWA, 2003) that is comprehensive and practical for quantifying the direct benefits of projects at the State or regional level. Two particular studies: FHWA's Freight Benefit/Cost Study (FHWA, 2008) and NCHRP Project 02-24 (NCHRP, 2014) demonstrated valid approaches and analytical methods for quantifying the WEB of freight projects. We also recognized the importance of EIA in complementing BCA in addressing a project's effects in regional job market and economic growth. The framework we develop is a strategic combination of these three elements: a standard BCA process, methods for quantifying WEBs, and integration with an EIA.

Figure 7 shows the framework developed for the proposed freight project prioritization decision support system. To this structure, we embed the steps involving in calculation of WEB and productivity from Figure 3 and integrate the process of EIA after benefit/cost aggregation and discounting.

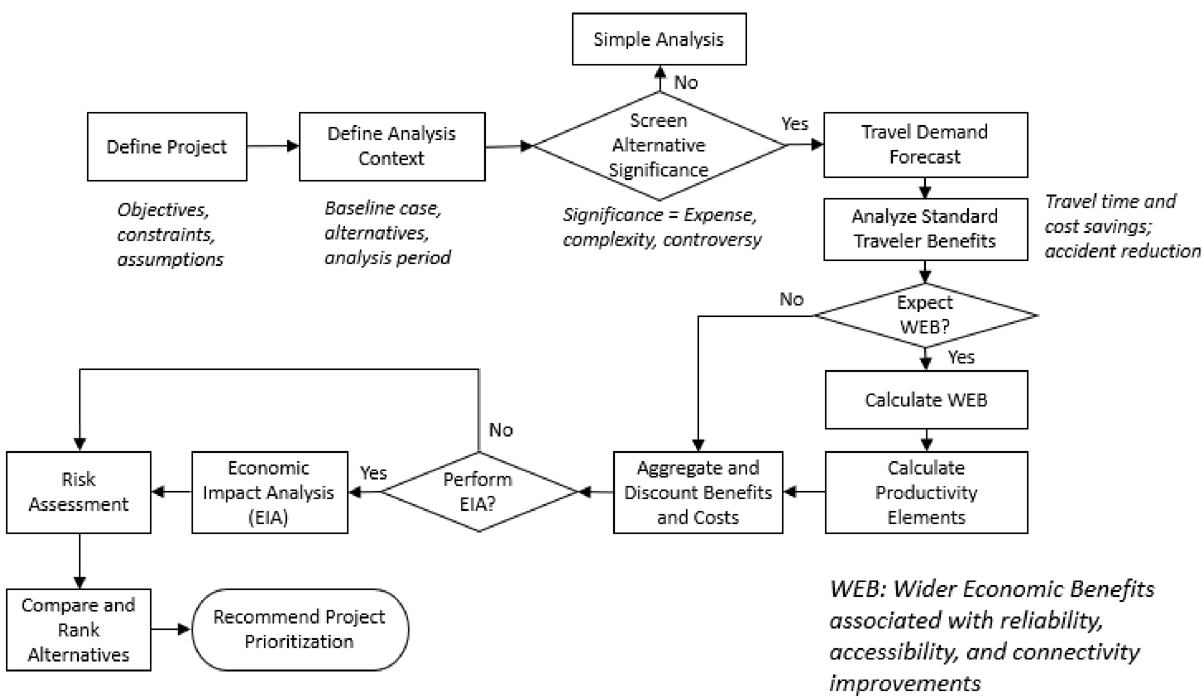

Figure 7 Analysis Framework for Freight Project Prioritization

The first three steps of the framework follow the standard BCA process of FHWA (FHWA, 2003). The framework begins with defining the project in terms of objectives, constraints, and assumptions, followed by defining the analysis context regarding the baseline scenario, alternatives and an appropriate analysis time period that covers at least one major rehabilitation for each alternative (FHWA, 2015a). The decision made in the third step is to allocate the greater share of analytical effort to the more promising alternatives. Detailed analysis of all alternatives is usually not necessary.

The next two steps, travel demand forecast and standard traveler benefits analysis, quantify metrics of direct benefits of the project such as travel time saving, savings in vehicle operating cost, and reduced accident occurrence. Depending on the resources available for travel demand forecasting, estimation and projection of travel data such as vehicle miles traveled (VMT) and vehicle hours traveled (VHT) can be calculated by either sketch planning methods or a demand forecasting model. For alternatives that are expected to generate only direct benefits, the analysis proceeds directly to summarizing and discounting of benefits and costs. For alternatives expected to generate WEB such as improvements in travel time reliability, accessibility to markets, or connectivity to intermodal terminals, the framework proceeds to calculate the WEB and the corresponding productivity. Analytical methods and tools discussed in NCHRP Report 786 (NCHRP, 2014) and FHWA's Freight Benefit-Cost Study (FHWA, 2008) are implemented here.

For most freight projects, calculation of WEB and an EIA are usually needed to fully address the potential economic impacts of the projects (NCHRP, 2014). EIAs may also be of major interest to decision makers and the public for large projects that are expected to generate significant direct benefits and costs (FHWA, 2003). However, it is also likely that some projects or alternatives are not expected to generate impacts that warrant an EIA, or an EIA is not required for grant application purposes. In these cases, the analysis can proceed to risk assessment for identification and evaluation of risks associated with the alternatives.

Based on the results of the BCA, risk analysis, and EIA, ranking of the alternatives and/or projects can be performed based on the project objectives and other selection criteria, leading to recommendations for project prioritization.

We developed this framework with highway freight projects being our focus. With all the guidelines and existing works that we have reviewed, this framework was designed to work with highway projects and projects serving as access to intermodal terminals. However, this framework was flexible to incorporate future enhancements that are capable of considering investments involving other modes such as rail, air, and marine.

4. METHODOLOGY DEVELOPMENT

This section presents the detailed processes and methodologies required for implementation of the conceptual framework. **Figure 8** shows the methodological flowchart, with two major evaluation processes: Standard Traveler Benefits (STB) and Wider Economic Benefits (WEB).

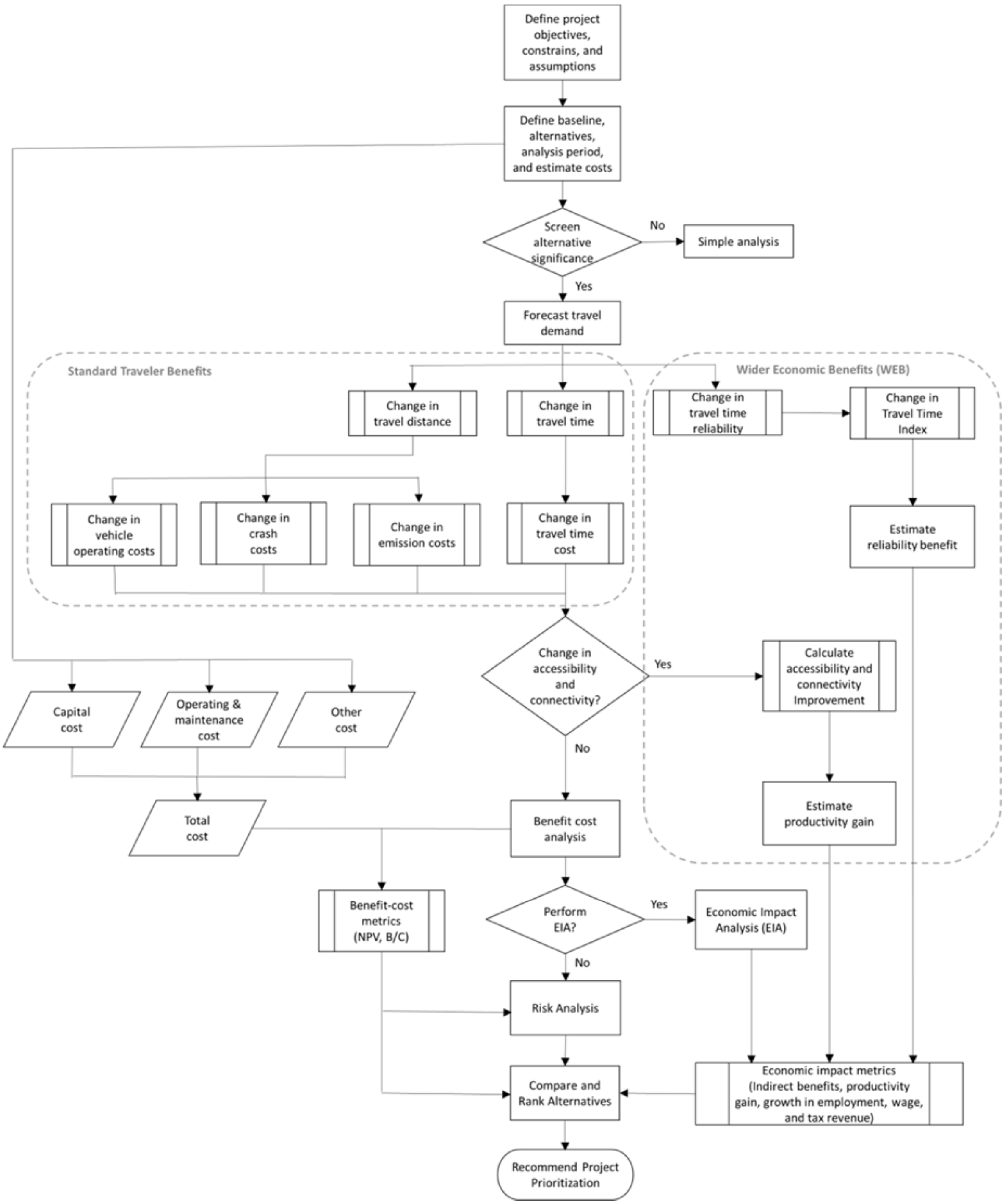

Figure 8 Detailed Methodological Flowchart of the Decision Support System

The STB process follows the requirements and guidelines found in FHWA's Economic Analysis Primer (FHWA, 2003) and the latest USDOT Benefit-Cost Analysis Guidance for Discretionary Grant Programs (USDOT, 2018). The STB process conforms to the BCA requirements of USDOT. The WEB process draws its methodologies from research performed for the Strategic Highway Research Program 2 (SHRP2), specifically the SHRP2 project C11 (SHRP2, 2014) that developed tools for assessment of WEB from transportation projects. It is important to note that the results of STB and WEB are presented separately per guidance from USDOT, which views WEB as economic impacts to a region that may or may not be distributed to the society equally (USDOT, 2018). Thus, the USDOT recommend that the monetary value assessed for the WEB of the project not be aggregated with the direct benefits of STB in a BCA.

The following sections describes the approach and method for each component in the flowchart. Specifically, the components and processes involved in each major step in the conceptual framework are specified. Various reports and guidelines referenced for the development of the methodologies are also discussed. With the methodologies presented in this report, the complete evaluation framework can be implemented in a computerized tool for the Freight Project Prioritization Decision Support System.

4.1 Define Project Objectives, Constraints, and Assumptions

The first step in the evaluation process is to establish objectives of the project (FHWA, 2003) as the benefits and costs expected of the project depend on its objectives. The NCHRP Report 786 (NCHRP, 2014) lists 12 common objectives of freight-related transportation projects. These objects are categorized into three broad categories of mobility-related, access-related, and social goal:

Mobility-related objectives:

- Relieve congestion and improve reliability
- Increase capacity for anticipated future demand growth
- Reduce travel time between areas
- Increase service frequency for non-highway modes, such as transit, aviation, or passenger rail
- Reduce closure and detour due to sporadic delays at rail crossings and in areas prone to flooding, landslides, or snow slides

Access-related objectives:

- Increase market access by enlarging effective population and labor markets
- Improve access roads and interchanges to existing business parks and centers
- Enhance rural community access
- Improve intermodal connectivity by reducing time to access intermodal passenger or freight terminals, and/or by improving the transfer efficiency at the terminals

Social goal objectives:

- Promote safety by reducing collision and injury rates
- Preserve or rehabilitate existing transportation infrastructure
- Improve quality of life by creating transportation choices, livable communities, and pedestrian friendly environments

Table 4 below shows a list of project information that needs to be collected.

Table 4 Project Information

Process	Variables	Description
Project Info	Project Name	Name of the project
	Project Types	Highways/roads, rails, intermodal terminals
	Terminal types	Rail stations, airports, marine
	Use orientation	Freight, passenger, both
	Primary objectives	Congestion/Reliability, capacity/future growth, travel time, intermodal connectivity, market access, safety
	Impact areas	Urban, suburban, rural, intercity connection, interstate, international gateway

The next step is to identify constraints of developing the project, which may be financial, political, legal, or environmental. There will also be assumptions that need to be made for the subsequent BCA process. The most critical assumptions are about factors that can influence future traffic growth and the likely composition of the future vehicle fleet over the life of the project. For freight projects in particular, assumptions about future socioeconomic development in the region are also important.

4.2 Define Baseline, Alternatives, Analysis Period, and Screening Alternatives

A baseline scenario is often referred to as the do-nothing or no-build alternative, which is analyzed with the assumption that traffic volume and other relevant sociodemographic factors would continue to grow at the existing pace. If the project is to be implemented on an existing facility, regularly scheduled operation and maintenance costs still need to be accounted for in the baseline scenario. The alternatives need to be viable options for the agency to improve over the baseline scenario and meet the objectives, while observing the constraints and assumptions defined in the previous step. Such alternatives do not necessarily involve major infrastructural construction. Options that employ new technologies to improve highway operations or manage travel demand are suitable for consideration as well.

Typical variables related to the baseline and alternative scenarios of highway projects include highway types, number of lanes, free flow speed, and length of the project. These variables are required for analyses of the project's capacity and average running speed, which are critical for all analyses involving benefits from reduced travel time and distance.

Table 5 below shows a list of project data that needs to be specified.

Table 5 Project Input Data

Process	Variable	Unit	Description	Comments
Define Analysis Period	Analysis period	Years	Number of years into the future for which the analysis applies	Based on expected project life cycle, typically 20 to 30 years
	Expected years in construction	Years	Number of years before the project opens	
Define Baseline & Alternatives	Highway types		Freeways, multilane highways, signalized corridors, or two-lane highways	
	Number of lanes			
	Free flow speed	MPH		
	Project length	Miles	Ending milepost - beginning milepost	

Because an investment in the transportation system is expected to be in service for many years, a BCA needs to account for the streams of benefits and costs that are expected of the baseline and alternatives over the project's life cycle. The selection of an appropriate analysis period is an important consideration in a BCA. The analysis period for a BCA typically covers the initial development and construction of the project, and an operational period during which recurring benefits and costs manifest. The operational period is generally set to cover at least one major rehabilitation activity for each alternative (FHWA, 2003).

USDOT recommends that the analysis period should cover the full development and construction of the project, plus at least 20 years after the opening of the project (USDOT, 2018). If the project's service life is expected to be less than 20 years, the operational period can then be set to the expected service life. On the other hand, if a project is expected to continuously generate significant benefits and/or costs after 20 years, a longer analysis period may be justified, although USDOT recommend that 30 years be the limit for the length of an analysis period due to increasing uncertainties involved in forecasting for such a long term future.

The level of effort involved in a BCA depends on the expense, complexity, and controversy of the project. To reduce effort, the alternatives can be screened initially to ensure that resources are dedicated to thoroughly analyze the benefits and costs of the most promising ones. Detailed analysis is usually not needed for every alternative (FHWA, 2003).

4.3 Estimate Costs

Project costs consist of all economic resources required to develop and maintain a new or improved transportation facility over its service life. Cost data used in the BCA should account for the full cost of the project required to achieve the benefits described in the BCA. All costs items need to be included regardless of which organizations (e.g., State, local, and private partners or the Federal government) cover the specific items. The costs of constructing a new facility or improving an existing facility include three main items: the initial capital costs, subsequent operation and maintenance costs, and additional cost associated with mitigation (e.g., sound walls). Table 6 summarizes the cost variables to be provided by the user.

Table 6 Project Cost Estimation Variables

Process	Variable	Unit	Description
Estimate Capital Costs	Project support cost	$	Cost for planning and designing of the project
	Right of way acquisition cost	$	
	Construction cost	$	
Estimate Operation & Maintenance Costs	Operation and Maintenance cost	$	
	Rehabilitation cost	$	
Estimate Other Costs	Mitigation cost	$	Mitigation for environmental and/or traffic impacts
	Other cost not accounted for	$	

4.3.1 Capital Costs

The capital cost of a project is the sum of the monetary resources needed to build the project. Capital costs generally include the cost for right of way acquisition and the cost for construction including labor, material, and equipment. In addition to direct construction costs, capital costs may also include costs for project support such as planning and design, environmental reviews, land acquisition, utility relocation, or transaction costs for securing financing.

Project capital costs may be incurred over multiple years. Costs should be recorded in the year in which they are expected to be incurred rather than when payment is made for those costs. All costs and benefits described in a BCA need to be stated in constant dollars using a common base year. Any future year constant dollar costs also need to be appropriately discounted to present value of the baseline analysis year to allow for comparisons with other BCA elements.

4.3.2 Operating and Maintenance Costs

Operating and maintenance (O&M) costs cover expenses required to continuously support the functions of the facility throughout the project lifecycle. O&M costs are typically incurred by increments and cover monetary resources required for operation, maintenance, and periodic rehabilitation incurred after the opening of the project. O&M costs should be projected for both the no-build baseline and with proposed improvement alternatives. Note that the relevant O&M costs are only those required to provide the service levels used in the BCA benefits calculations. Reasonable assumptions need to be made about the timing and costs of O&M activities in accordance with standard agency or industry practices. If the estimated O&M costs are provided in year of expenditure dollars, they should also be adjusted to the present value of the base year dollars prior to being included in the BCA.

4.3.3 Other Costs

In addition to the capital and O & M costs, there may be other costs that need to be accounted for in a BCA. Such costs are often termed externalities in economic analysis. One of the most frequently incurred externalities is for mitigation of environmental impacts from the project. Where adverse impacts are identified in the environmental impact study of the project, mitigation is required to minimize or compensate for them. Without mitigation measures, the project cannot be approved on the ground of environmental regulations.

4.3.4 Residual Value and Remaining Service Life

Many transportation infrastructures such as bridges and tunnels are designed for a very long service life that usually exceeds the analysis period of a BCA. In such cases, a residual value may be calculated for the project at the end of the analysis period. One way of estimating the residual value is to assume that its initial value depreciates linearly over its service life. For example, a facility with an expected service life of 60 years would retain half of its value after 30 years in service.

4.4 Forecast Travel Demand

Estimates and forecasts of highway performance measures under baseline and alternative scenarios are required for the evaluation of benefits and costs associated with each scenario. Generally, highway performance of a particular scenario is described by data such as Average Daily Traffic (ADT), Vehicle Miles Traveled (VMT), and Vehicle Hours Traveled (VHT). Reduced VMT is a result of shorter average distance by the travelers in the region, leading to benefits in reduced vehicle operating cost, reduced vehicle accidents and emissions for the entire region. Reduced VHT results from shorter average travel time, a benefit enjoyed by the regional travelers directly.

Estimates and forecasts of VMT, VHT, and the number of trips by modes for each scenario can be derived from the regional travel demand models. For projects involving a highway segment, VMT can be derived by multiplying the number of vehicles using the segment with length of the segment. VHT can be derived similarly by multiplying the number of vehicles with the average time required to traverse the segment, which is essentially the length of the segment divided by the estimated running speed on the segment. If a travel demand model is not available, sketch planning methods utilizing historic traffic data such as those from FHWA's Highway Performance Monitoring System (HPMS) data. ADT and percent trucks in traffic data are used to estimate baseline VMT and VHT by passenger cars and trucks. A growth rate can also be estimated from historic traffic data to forecast future VMT and VHT data. Table 7 presents the travel demand information to be compiled for the evaluation process.

Table 7 Travel Demand Variables

Process	Variable	Unit	Description	Comments
Forecast Travel Demand	Average Daily Traffic (ADT)	Vehicles	Current year ADT	Available from regional travel demand model or FHWA's Highway Performance Monitoring System data
	Annual traffic growth rate	%	Used to forecast future traffic growth	Derived from the regional travel demand model or estimated by the users from historic traffic data
	Percent truck in traffic	%		Available from regional travel demand model or FHWA's Highway Performance Monitoring System data
	Average speeds by modes	MPH	Average speed of passenger cars and trucks	Available from regional travel demand model or estimated by the users from historic traffic data

Benefits resulting from change in VMT and VHT are the direct benefits of the project. These benefits are often termed Standard Traveler Benefits (STB) for the fact that these benefits come from travel time or distance changes and they are typically captured in standard BCA methodologies. For projects that reduce congestion and/or improve safety on the highways, an additional benefit of improved travel time reliability may be expected. Travel time reliability can be defined as the variance around average travel time. Improvement in travel time reliability can come from reduction of unexpected delays caused by non-recurring congestion (e.g., due to traffic incidences). The benefits associated with improved travel time reliability are often categorized as one of the Wider Economic Benefits (WEB) that manifest via the project's effects on improved logistic operation, better access to markets, and improved connectivity to intermodal terminals. The WEB is typically not accounted for in standard BCA methods, but for freight projects such as expansion or improvement of an intermodal terminal, the productivity gain at the regional or national scale associated with increased connectivity from the improvement can be a significant economic consideration that cannot be overlooked.

4.5 Standard Traveler Benefits

For evaluation of standard traveler benefits, the USDOT published the Benefit-Cost Analysis Guide for Discretionary Grant Programs (USDOT, 2018) that contains guidance and valuation factors for most of the benefits resulting from changes in travel distance and travel time. These values are recommended for projects applying for the Better Utilizing Investments to Leverage Development (BUILD) Transportation Discretionary Grants program (USDOT, 2018).

4.5.1 Benefits from Changes in VHT

Changes in travel time as measured by VHT is a direct benefit/cost for the travelers. The monetary value of VHT change is estimated with Equation 1:

$$\textit{Travel Time Benefit or Cost} = \textit{VHT Change} * \textit{Vehicle Occupancy} * \textit{Hourly Value of Travel Time Savings} \quad \text{(Eq. 1)}$$

Table 8 shows the USDOT recommended values of travel time savings in dollars per person-hour. This table includes values for travel by both private vehicle and commercial vehicle operators. For highway freight crew time cost, the commercial truck drivers' hourly value is applied. Private vehicle travel can be made for personal, business purposes, or a mix of personal and business travel, which is used when the purpose is unknown (i.e., all purposes). For non-vehicle personal travel time such as waiting or transfer time, it is recommended that such time values should be valued at twice the in-vehicle rates (USDOT, 2018).

Table 8 Recommended Travel Time Values

Recommended Hourly Values of Travel Time Savings (2017 U.S. $ per person-hour)	
Category	**Hourly Value**
In-vehicle travel	
Personal	$14.20
Business	$26.50
All Purposes	$14.80
Commercial Vehicle Operators	
Truck Drivers	$28.60
Bus Drivers	$30.00
Transit Rail Operators	$48.90
Locomotive Engineers	$44.90

Source: Benefit-Cost Analysis Guide for Discretionary Grant Programs (USDOT, 2018)

USDOT recommends that vehicle occupancy data be based on local traffic data or model estimates that are specific to the project facilities (USDOT, 2018). In the absence of such data, national-level vehicle occupancy factors in Table 9 may be used. When the project purpose is to reduce peak hour travel delay, vehicle occupancy factors by time of day should be applied if available.

Table 9 Generic Vehicle Occupancy Rates Based on US Nationwide Data

Vehicle Type	Occupancy
Passenger vehicles	1.39
Trucks	1.00

Source: Benefit-Cost Analysis Guide for Discretionary Grant Programs (USDOT, 2018)

4.5.2 Benefits from Changes in VMT

Benefits resulting from changes in regional VMT captured in standard BCA methods include:

- Vehicle operating costs
- Accident costs
- Emissions

Vehicle Operating Cost

Freight projects that improve highways, rails, and intermodal terminals can generate cost savings to carriers (e.g., reduced fuel consumption and other operating costs). Projects targeting improvement of passenger vehicles may also reduce vehicle operating or dispatching costs for freight service providers due to the effects of reduced congestion and VMT on the highways.

Vehicle operating cost change from VMT change can be divided into two parts: fuel consumption change and non-fuel cost change. The overall vehicle operating cost change can be estimated with Equation 2:

*Vehicle Operating Cost Change = (VMT Change * Fuel Consumption in gallon per VMT * Average Fuel Price per gallon) + (VMT Change * Non-Fuel Operating Cost per VMT)* (Eq. 2)

Fuel consumption per VMT varies by estimate average running speed on the project highway. Data on fuel economy at various running speed and average fuel prices are available from the US Department of Energy (US DOE, 2019). For non-fuel operating cost, USDOT recommends the use of local data on vehicle operating costs if available, provided that the data sources and assumptions be appropriately documented. For analyses where such data is not available, standard national-level data on vehicle operating costs can be used. The American Automobile Association (AAA) publishes data on various costs of owning and operating a vehicle (AAA, 2015). These data can provide data on non-fuel operating cost per mile for passenger vehicle. Non-fuel operating cost for commercial trucks can be obtain from data on the costs of operating commercial trucks published by the American Transportation Research Institute (ATRI) (ATRI, 2018).

For projects in parts of Florida where toll facilities are present, vehicle operating cost from tolls need to be included in the analysis. The cost for tolls does not vary by VMT, but by total number of vehicle trips accessing the toll facilities:

*Toll Cost=Total Number of Vehicle Trips*Average Toll Cost per Vehicle Trip* (Eq. 3)

Total number of vehicle trips accessing the toll facilities can be obtained from historic traffic data or from the regional travel demand model. Average toll cost per vehicle trip depends on the costs of the toll facilities in the area where projects are being evaluated. The toll costs data are readily available from toll authorities.

Safety Benefits

Safety benefits from highway projects come from reduced number of vehicle crashes involving fatalities, injuries, and/or property damage. There are different methods for estimating safety benefits of transportation projects. For projects with features that address crash reduction, estimating the change in the number of fatalities, injuries, and amount of property damage of the project can be done using crash modification factors (CMFs), which relate different types of safety improvements to crash outcomes (FHWA, 2018b).

CMFs are estimated by relating crash types, injury severities, and property damages to different types of transportation project. FHWA sponsored extensive research on CMFs for various types of transportation projects and the results are available from the online database CMF Clearinghouse (FHWA, 2018b). Each type of project has a corresponding CMF that identifies the potential for the project to reduce crashes involving injuries of specific severity levels. For example, the CMF of installing an additional lane on a highway is 0.76. That is, if a particular stretch of highway has an average of 100 crashes per year, the number of crashes with installation of an additional lane can be reduced to 76. The CMF of the additional lane is applicable to all types of crashes with injury severities of minor, serious, and fatal (FHWA, 2018b).

To estimate safety benefits from the projects with CMFs, Equation 4 can be applied (USDOT, 2018):

*Benefits of Reduced Number of Crashes = VMT in million miles * Baseline Annual Crash Rate per million VMT * (1-CMF) * Expected Consequences* (Eq. 4)

The CMF of the proposed project is first applied to baseline annual crash rate, which is typically drawn from historic crash data on the facility that is being improved. The crash data should cover a period of 3-7 years, over which millions of VMT had typically accumulated. Thus, the baseline crash rates are often measured in crashes per million VMT and the number of VMT are also measured in million miles correspondingly.

The Expected Consequences refer to the monetary values associated with the expected crash severity levels and/or property damages that can be prevented by the proposed improvement. The USDOT-recommended values for monetizing reductions in injuries and property damages are based on the Maximum Abbreviated Injury Scale (MAIS), which categorizes injuries with a six-point scale from Minor to Not Survivable (USDOT, 2018). To estimate the cost associated with each scale of injury, the U.S. DOT's Value of Statistical Life (VSL) data are used (USDOT, 2016). VSL provides fractional values for use when assessing the benefit of preventing an injury crash based on different levels of MAIS (see Table 10). In 2016, the U.S. Office of the Secretary of Transportation (OST) issued a memorandum updating the cost to avert a fatality (i.e., VSL = 1.0) to $9.6 million (USDOT, 2016). Table 11 shows the most recent VSL fraction and monetary cost for each level of MAIS (USDOT, 2018).

Table 10 Values of Reduced Fatalities and Injuries for MAIS Levels

Recommended Monetized Value(s)			
MAIS Level	**Severity**	**VSL**	**Unit Value ($2017)**
MAIS 1	Minor	0.003	$28,800
MAIS 2	Moderate	0.047	$451,200
MAIS 3	Serious	0.105	$1,008,000
MAIS 4	Severe	0.266	$2,553,600
MAIS 5	Critical	0.593	$5,692,800
Fatal	Not Survivable	1.000	$9,600,000

Source: Benefit-Cost Analysis Guide for Discretionary Grant Programs (USDOT, 2018)

In practice, traffic-related injury data obtained from the law enforcement are often reported in the KABCO scale (FHWA, 2017). The Benefit-Cost Analysis Guide for Discretionary Grant Programs (USDOT, 2018) also contains monetization factors for injuries reported on the KABCO scales (see Table 11).

Table 11 Values of Reduced Fatalities and Injuries for KABCO Levels

KABCO Level	Monetized Value ($2017)
O - No injury	$3,200
C - Possible injury	$63,900
B - Non incapacitating	$125,000
A - Incapacitating	$459,100
K - Killed	$9,600,000
U – Injured (severity unknown)	$174,000
Accident reported but unknown if injury or not	$132,200

Source: Benefit-Cost Analysis Guide for Discretionary Grant Programs (USDOT, 2018)

To illustrate how benefits can be estimated with CMFs, assume that a centerline rumble strip with a CMF of 0.91 is proposed for a stretch of a freeway that has 20 crashes per one million VMT in the last 5 years, resulting in 5 fatalities, 10 non-incapacitating injuries, and 10 incapacitating injuries. This translates to an annual rate of 4 crashes, 1 fatality, 2 non-incapacitating injuries, and 2 incapacitating injuries per million VMT per year. The annual VMT of the project is expected to be 20 million. Applying these values to Equation 4:

*Benefits of Reduced Number of Crashes = VMT in millions * Baseline Annual Crash Rate per million VMT * (1-CMF) * Expected Consequences* = 20 * 4 * (1-0.91) * (1* $9,600,000+ 2* $125,000 + 2* $459,100) = $77,531,040 per year.

For projects that are expected to reduce VMT without crash modification features, the benefits of reduced number of crashes of the build scenario can be estimated by Equation 5:

*Benefits of Reduced Number of Crashes = VMT change in millions (between build and no build) * Baseline Annual Crash Rate per million VMT * *Expected Consequences* (Eq. 5)

Emissions Reduction Benefits

Transportation projects that reduce regional VMT and VHT can decrease overall vehicle emissions and thus produce environmental benefits for the region. The most common local air pollutants generated by transportation activities are carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NO_X), fine particulate matter (PM), and volatile organic compounds (VOC). If specific emission factors (i.e., grams of vehicle emissions per VMT by pollutant) by vehicle running speeds are available, the emission cost associated with a build or no build scenario can be precisely modeled based on expected average speed of the scenario. Moreover, emissions can be further divided into running emissions and starting emissions to improve the accuracy of emission modeling. The cost associated running emissions of a scenario is estimated by Equation 6:

$$Running\ Emission\ Cost = \sum^{All\ m} \sum^{All\ p} VMT_m * EF_{m,p} * Health\ Cost_p \quad \text{(Eq. 6)}$$

where

m = modes (i.e., passenger car, truck, and bus)
p = pollutants (i.e., CO, SO_2, NO_X, PM, and VOC)
VMT_m = Vehicle Miles Traveled by mode m
$EF_{m,p}$ = Emission Factor (gram/mile) of pollutant p by mode m
$Health\ Cost_p$ = Health cost (dollars/ton) associated with pollutant p

The emission factor of a pollutant by mode depends on the expected running speed of the build or no build scenario. The EMFAC data published by the California Air Resources Board (CARB) provide example emission factors by running speeds and modes. McCubbin and Delucchi (1999) contains estimates of health cost in dollars per ton of vehicular emissions of CO, SO_2, NO_X, PM, and VOC.

Starting emissions are produced by vehicles at the time when engines are started. The modeling of starting emission is similar to running emissions except that VMT is replaced by the number of vehicles (i.e., traffic volume) associated with the scenario and the emission factor corresponds to the grams of pollutants produced at running speed zero.

Note that previous BCA guidance from USDOT included consideration for benefits from reductions in carbon dioxide (CO_2) emissions and other greenhouse gases (GHGs). However, the current Benefit-Cost Analysis Guide for Discretionary Grant Programs for BUILD grant program (USDOT, 2018) does not contain valuation factors for either CO_2 or GHGs. Any such estimates provided in a BCA should be based on the domestic data rather than using global values.

Table 12 presents a summary of variables involved in estimating STB.

Table 12 Standard Transportation Benefit Variables

Process	Variable	Unit	Description	Comments
Estimate Travel Time Benefits	Vehicle Hours Traveled by modes	Vehicle-hours	VHT by passenger cars and trucks	Available from regional travel demand model or using sketch planning methods with ADT data
	Average vehicle occupancy by modes	Persons		Based on regional data or national averages available from USDOT
	Hourly values of travel time saving by modes	$/Person-hour	Values for travel by private vehicle and commercial vehicle operators	Based on regional data or national averages available from USDOT
Estimate Travel Distance Benefits	Vehicle Miles Traveled (VMT) by modes	Vehicle-miles	VMT by passenger cars and trucks	Available from regional travel demand model or using sketch planning methods with ADT data
	Project area		Urban, suburban, or rural	Relevant for accident costs and emission costs analyses
	Fuel consumption per VMT by average speed by modes	Gallons/VMT	Gallon/VMT by average running speed lookup tables for passenger cars and trucks	Data available from USEPA
	Fuel price per gallon	$/Gallon		Data available from US Department of Energy
	Non-fuel cost per VMT by modes	$/VMT	Maintenance, repair and other operating cost per VMT for passenger cars and trucks	Data available from American Automobile Association
	Number of vehicles accessing toll facilities	Vehicles	For projects in areas with toll facilities	Available from regional travel demand model or data from toll authorities
	Average toll cost	$/vehicle	For projects in areas with toll facilities	Available from toll authorities
	Baseline annual crash rate	Crashes/year	Number of crashes, fatalities, injuries, and property damages per year	Estimated by users based on relevant crash data from the past 3 to 5 years
	Crash Modification Factors (CMF) of the project		CMF corresponding to the safety improvement being evaluated	Available from FHWA Crash Modification Factors Clearinghouse
	Expected crash consequences	$	Monetary cost involved in crashes expected to be prevented by the project	Estimated by users based on baseline crash data and USDOT Values of Statistical Life
	Emission production per VMT by average speed by modes	Gram/VMT	Vehicular emissions per VMT by average speed of passenger car and trucks	Data available from USEPA
	Health cost of emission by source types	$/VMT	Health cost of per ton CO, NO_x, PM_{10}, SO_x, and VOC emissions	Example values available from McCubbin and Delucchi, 1996

4.6 Wider Economic Benefits

4.6.1 Travel Time Reliability Benefits

Travel time reliability is defined as the variation in travel time for the same trip from day to day (NCHRP, 2014). Most congestions on highways and/or arterial streets during peak hours consists of two distinct effects: a recurring congestion that often occur on bottlenecks regularly and a non-recurring congestion in which the frequency of traffic incidents and the length of vehicle queues both exceed beyond the expected regularity (SHRP2, 2013a).

To model the benefits or costs of travel time reliability changes, we follow the methodologies of the reliability analysis tool developed by the SHRP2 Project C11 (SHRP2, 2014). The C11 tool is a spreadsheet designed to function as a sketch planning tool for highway projects that are designed to benefit on both travel time and reliability. The tool estimates total delay costs and separates them into recurring delay and non-recurring delay. Costs associated with the non-recurring delay are referred to as reliability-related costs.

The foundation of the C11 reliability tool is the use of travel time distribution functions estimated in SHRP2 Project L03 (SHRP2, 2013a). These travel time distribution functions are used to derive distribution of Travel Time Index (TTI), which is the ratio of average travel time under congested conditions divided by average travel time under free-flow conditions. TTI and various derivations of TTI are found to be effective metrics of travel time reliability (SHRP2, 2013a).

The calculations of reliability benefits or costs begin by estimating the capacity of the project roadway segment with Highway Capacity Manual equations (TRB, 2016). Congested travel time due to recurring delay is estimated with the use of a speed-flow-capacity relationship (NCHRP, 1998) in Equation 7. Recurring delay can be estimated by subtracting free flow travel time per mile from the congested travel time (see Equation 8).

$$t = (1 + (0.1225 * (v/c)^8))/\text{Free Flow Speed, for } v/c \leq 1.4 \qquad \text{(Eq. 7)}$$

where

t = travel time (hours/mile)
v = hourly volume (vehicles/hour)
c = capacity (vehicles/hour)

$$\text{Recurring Delay} = t - (1/\text{ Free Flow Speed}) \qquad \text{Eq. 8)}$$

where

Recurring delay in hours/mile
t = travel time (hours/mile)
1/Free Flow Speed (miles/hour) = Travel time (hours/mile) required to travel one mile under free flow condition

Delay in travel time due to incidents is estimated with values in the lookup tables developed for the ITS Deployment Analysis System (IDAS) (Cambridge Systematics, 2003). The incident delay (hours/mile) is related to the v/c ratio, number of lanes, and length (e.g., one to four hour peak periods) and type of the period (e.g., peak vs. off-peak) being analyzed. Table 13 shows the incident delay look up table for one-hour peak period.

Table 13 Travel Time Reliability: Rate for 1-H Peak – Vehicle-Hours of Incident Delay per Vehicle-Mile

Volume/1-hour level of service capacity	Number of lanes		
	2	**3**	4+
0.05	3.44×10^{-8}	1.44×10^{-9}	4.39×10^{-12}
0.1	5.24×10^{-7}	4.63×10^{-8}	5.82×10^{-10}
0.15	2.58×10^{-6}	3.53×10^{-7}	1.01×10^{-8}
0.2	7.99×10^{-6}	1.49×10^{-6}	7.71×10^{-8}
0.25	1.92×10^{-5}	4.57×10^{-6}	3.72×10^{-7}
0.3	3.93×10^{-5}	1.14×10^{-5}	1.34×10^{-6}
0.35	7.20×10^{-5}	2.46×10^{-5}	3.99×10^{-6}
0.4	0.000122	4.81×10^{-5}	1.02×10^{-5}
0.45	0.000193	8.68×10^{-5}	2.34×10^{-5}
0.5	0.000293	0.000147	4.93×10^{-5}
0.55	0.000426	0.000237	9.65×10^{-5}
0.6	0.0006	0.000367	0.000178
0.65	0.000825	0.000548	0.000313
0.7	0.001117	0.000798	0.000528
0.75	0.001511	0.001142	0.00086
0.8	0.002093	0.001637	0.00136
0.85	0.003092	0.002438	0.002115
0.9	0.005095	0.004008	0.003348
0.95	0.009547	0.007712	0.005922
1.0	0.01986	0.01744	0.01368

Source: IDAS User Manual (Cambridge Systematics, 2003)

The mean TTI (TTI_m) is the mean congested travel time divided by free flow travel time (Eq. 9). It is recommended that TTI_m be capped at a value of 6.0, which roughly corresponds to an average speed of 10 mph, because an overall annual average speed below 10 mph for a peak period was never observed in the data used to develop these reliability-related equations (SHRP2, 2013a).

Mean Travel Time Index: $TTI_m = 1 + FFS * (Recurring\ Delay + Incident\ Delay)$ (Eq. 9)

After TTI_m is estimated, other metrics of travel time reliability can be calculated (Eq. 10 to 14). These metrics enable estimation of a generalized time equivalent measure of reliability for the project roadway.

95th Percentile TTI: $TTI_{95} = 1 + 3.6700 * \ln(TTI_m)$ (Eq. 10)

95th Percentile TTI: $TTI_{80} = 5.37460/((1 + e^{(-1.5782 - 0.85867 * TTI_m)})^{(1/0.04953)})$; $TTI_{80} \geq 1.0$ (Eq. 11)

95^{th} *Percentile TTI:* $TTI_{50} = 4.01224/((1 + e^{(1.7417 - 0.93677 * TTI_m)})^{(1/0.82741)})$; $TTI_{50} \geq 1.0$ Eq. 12)

% Trips occurring at less than 45 mph $= 1 - e^{(-1.5115 * (TTI_m - 1))}$ (Eq. 13)

% Trips occurring at less than 30 mph $= 1 - \{0.333 + (0.672/(1 + e^{(5.0366*(TTI_m - 1.8256))}))\}$ (Eq. 14)

The median (TTI_{50}) of the TTI distribution is defined as the TTI equivalent (TTI_e) for recurring congestion (Eq. 15). The TTI equivalent needs to be computed for passenger vehicles (i.e., personal travel) and trucks (i.e., commercial travel) separately. The TTI equivalent for non-recurring (i.e., reliability-related) delay is estimated with Equation 16. Combining the TTI equivalents of recurring and non-recurring (reliability-related) congestion, one arrives at the TTI equivalent for the entire congested traffic flow on the segment being analyzed (Eq. 17).

TTI Equivalent for Recurring Congestion: $TTI_{e(Recurring,\ VT)} = TTI_{50}$ (Eq. 15)

TTI Equivalent for Non- Recurring Congestion: $TTI_{e(Reliability,\ VT)} = a * (TTI_{80} - TTI_{50})$ (Eq. 16)

TTI Equivalent: $TTI_{e(VT)} = TTI_{50} + a * (TTI_{80} - TTI_{50})$ (Eq. 17)

where

a = the Reliability Ratio (VOR/VOT), which is 0.8 for passenger cars and 1.1 for trucks

Value of travel time (VOT) refers to the monetary values that travelers are willing to pay on reducing their travel time and the value of reliability (VOR) relates monetary values travelers place on reducing the variability of their travel time. Past studies have used the Reliability Ratio (VOR/VOT) to measure reliability empirically. The range of reliability ratio is found to be from 0.5 to 1.5 in most past studies. A Florida DOT study recommended a Reliability Ratio range of 0.8 to 1.0, based on their assessment of the most rigorous studies (Elefteriadou and Cui 2007). The SHRP2 C11 report suggests reliability ratio of 0.8 for passenger cars and 1.1 for trucks.

Total annual benefits or costs associated with reliability are estimated by first calculating the total equivalent annual weekday delay in vehicle-hours with Equation 18, computed for passenger vehicles and trucks separately. The total equivalent annual weekday recurring delay is obtained by multiplying the total equivalent weekday delay with the recurring TTI fraction (Eq. 19). Reliability-related delay is obtained by subtracting recurring delay from the total delay (Eq. 20).

$\text{Total Equivalent Annual Weekday Delay}_{(VT)} = ((TTI_{e(VT)} / \text{Free Flow Speed}) - (1/\text{Free Flow Speed})) * AVMT_{VT}$ (Eq. 18)

$\text{Total Equivalent Annual Weekday Delay}_{(Recurring,\ VT)} = \text{Total Equivalent Annual Weekday Delay}_{(VT)} * (TTI_{e(Recurring,\ VT)} / (TTI_{e(Recurring,\ VT)} + TTI_{e(Reliability,\ VT)}))$ (Eq. 19)

$\text{Total Equivalent Annual Weekday Delay}_{(Reliability,\ VT)} = \text{Total Equivalent Annual Weekday Delay}_{(VT)} - \text{Total Equivalent Annual Weekday Delay}_{(Recurring,\ VT)}$ (Eq. 20)

where

$AVMT_{VT}$ = Annual Weekday Vehicle Miles Traveled = Hourly Volume (vehicles) * Section Length (miles) * Pct * 260 (weekdays), computed for passenger Vehicles and Trucks separately

Pct = percent of trucks in traffic stream (for commercial traffic) or 1 - percent of trucks in traffic stream (for passenger travel)

The cost associated with total delay is obtained by multiplying the total equivalent annual weekday delay with the unit cost of each vehicle-hour of delay for personal vehicles and trucks separately (Eq. 21). The cost associated with recurring delay is obtained by multiplying the total delay cost with the recurring TTI fraction (Eq. 22). Reliability-related cost is obtained by subtracting recurring delay cost from the total delay cost (Eq. 23).

$$\textit{Total Delay Cost}_{(VT)} = \textit{Total Equivalent Annual Weekday Delay}_{(VT)} * \textit{Unit Cost}_{(VT)} \quad \text{(Eq. 21)}$$

$$\textit{Recurring Delay Cost}_{(VT)} = \textit{Total Delay Cost}_{(VT)} * (TTI_{50} / TTI_{e(VT)}) \quad \text{(Eq. 22)}$$

$$\textit{Reliability (Non-recurring Delay) Cost}_{(VT)} = \textit{Total Delay Cost}_{(VT)} - \textit{Recurring Delay Cost}_{(VT)} \quad \text{(Eq. 23)}$$

4.6.2 Market Accessibility Productivity Gain

Transportation networks are crucial in regional economic development because they provide access for buyers and suppliers to expand markets across different regions. To model the benefits or costs of changes in market access, we followed the analysis methods developed by the SHRP2 C11 project (SHRP2, 2014). The methods are implemented in a spreadsheet-based tool, Effective Density (ED): Buyer-Supplier Market Access Tool, which is designed to estimate regional market accessibility impacts following a transportation improvement by assessing the value of the productivity gains associated with changes in market access (SHRP2, 2014). The tool is suited for evaluation of major projects that significantly change the structure of the regional accessibility, such as network and road system improvements.

The methods implemented in the ED tool follow the framework for the estimation of agglomeration impacts as featured in Graham (2007) and used by the U.K. Department for Transport. It makes use of a gravity form of decay function to estimate accessibility of a particular zone. The decay function follows the analogy of the law of gravity, treating the number of employment activities at a work zone like the attraction and the average travel time from one zone to another as the distance between the pair of zones. The tool can be used with zonal employment data to capture the effect of transportation projects on expanding economic markets by providing access for firms and employees to reach each other. This approach reflects the effects of both business localization and urbanization brought by improved accessibility.

For market accessibility impact analysis using the gravity function, the following are required as inputs:

- Analysis zones of the region. The geography of the region that is expected to benefit from the project is divided into zones for analysis. Census geographies (e.g., census tracts and block groups) may all be used as the analysis zones. For regions that use a travel demand model for transportation planning, the traffic analysis zones of the model can also be used for accessibility analysis.

- Zonal activity data. The employment data of the zones are typically used as the indicator of business activities of the zones. Alternatively, population data can be used to measure accessibility for commuting, shopping, or other forms of travel from homes.
- Interzonal travel impedance. With the regional analysis zones specified, the ease of travel (i.e., travel impedance) between any pair of zones in the system needs to be calculated. The interzonal travel impedance can be represented as travel time or generalized cost for travel among the zones. The interzonal travel impedance of the region need to be calculated for both baseline (i.e., no-build) and alternative (i.e., build) scenarios.

The outputs of the methods consist of:

- Effective density values for each zone and the total for both scenarios
- Monetary value of productivity output in each zone

The Effective density (ED) is a measure of accessibility to employment or any business activities, depending on the type of zonal data used as attraction. This measure is used to approximate agglomerative effects from transportation projects in the U.K. (Graham 2007). The effective density of employment accessible to any firm located in a zone *i* is given by an inverse power decay function (Eq. 24).

$$Effective\ Density_{\,i} = \frac{E_i}{{d_{ii}}^{\alpha}} + \sum_{j}^{i \neq j} \frac{E_j}{{d_{ij}}^{\alpha}} \qquad \text{(Eq. 24)}$$

where

E_i = the employment in zone i
d_{ii} = the intrazonal impedance (travel time or generalized cost) of zone i
α = the impedance decay parameter.
E_j = the total employment in zone j;
d_{ij} = the impedance (travel time or generalized cost) between i and j

The first term on the right hand side of the equation is termed the scale factor, which accounts for accessibility to employment within zone *i*. *a* is a behavioral parameter that can be estimated with data from the regional travel demand models.

Productivity benefits (*P*) from changes in accessibility to markets for all zones in the impact area is expressed by Equation 25.

$$P = \sum_{i} \left\{ \left[\left(\frac{EDB_i}{EDNB_i} \right)^{\mu} - 1 \right] * per\ worker\ (GRP_i) * E_i \right\} \qquad \text{(Eq. 25)}$$

where

P = Productivity benefits
EDB_i = the Effective Densities of zone i for a project Build scenario
$EDNB_i$ = the Effective Densities of zone i for the No Build scenario

μ = an elasticity or response parameter reflecting response of productivity to changes in market access
GRP_i = per worker (employee) Gross Regional Product in zone i
E_i = Total number of employment in Zone i

The productivity elasticity μ is an important parameter in determining the scale of the productivity response from a given change in accessibility (as measured by Effective Density). The selection of an appropriate elasticity value requires an understanding of the industry mix of the study area. Graham and Gibbons (2009) documented productivity elasticity values of effective density using U.K. data. They report an elasticity value 0.044 for the overall economy, which is a composite of four general industries: manufacturing (0.024), construction (0.034), consumer services (0.024), and business services (0.083). It is not known if the same values are applicable in the US. The SHRP2 C11 project team recommends that sensitivity testing using a range of elasticity values such that ranges of productivity responses per elasticity value change can be taken into account in interpretation of the analysis results (SHRP2, 2014).

4.6.3 Intermodal Connectivity Productivity Gain

The aspect of intermodal connectivity that can create benefits to surface freight transportation involves improvement of access to and from a particular intermodal terminal. The SHRP2 C11 intermodal connectivity analysis tool is designed to evaluate the level of connectivity from a project site to airports, marine ports, and rail terminals in the United States (SHRP2, 2014). It works by computing connectivity indices (Eq. 26 to 28) that reflect the ease of travel from the project to the intermodal terminal and the extent of connecting services to other destinations that can be accessed from it. An exponential distance decay function is used to estimate the percentage of passenger or freight vehicles that will use the terminal from the project site. The further from the intermodal facility the project is, the fewer vehicles traveling to and from the facility there are.

$$\textit{Freight Connectivity Index} = \textit{Tons of freight} * \textit{Average value per ton} * \textit{Number of distinct locations served} \quad \text{(Eq. 26)}$$

$$\textit{Freight Connectivity Index} = \textit{Containers of freight} * \textit{Average value per container} * \textit{Number of distinct locations served} \quad \text{(Eq. 27)}$$

$$\textit{Passenger Connectivity Index} = \textit{Number of passengers} * \textit{Number of distinct locations served} \quad \text{(Eq. 28)}$$

The inputs needed to compute the intermodal connectivity index include the followings:

- Level of activity (e.g., number of vehicles) utilizing the intermodal terminal.
- Level of connecting services provided at the terminal, including the frequency of air, marine, or rail services and the number of different origins and destinations that can be reached.
- Level of business activity (i.e., employment) in the vicinity of the terminal and the associated Gross Regional Product (GRP).

- Characteristics of the project—location, distance and travel time to and from an intermodal facility.

The tool provides three outputs:

- Total vehicle-hours saved by enhanced access to a specific intermodal terminal
- The connectivity indices
- Weighted connectivity indices, each of which is the product of the preceding two metrics (i.e., aggregate time savings) and the value of time.

The freight and passenger weighted connectivity scores can be used to rank different investments on their relative value for improving intermodal connectivity. The tool provides a connectivity index and does not directly assess impacts on productivity. However, its use for productivity analysis is enabled by focusing on assessing changes in truck access to cargo terminals. An elasticity could be used to assess the effect of a given percent change in intermodal accessibility to a resulting change in market scale economies.

In addition to the three outputs mentioned, similar to market accessibility, improved connectivity at intermodal terminals can result in productivity gain at the regional or national level. The NCHRP Report 786 (NCHRP, 2014) contains example productivity elasticities (i.e., % value added per 1% increase in intermodal access index) that can be used to estimate the value of productivity gain from improved intermodal connectivity at different types of intermodal terminals (i.e., rail, airport, and marine).

It is important to note that there is a potential overlap between the results of this tool and the results of the market accessibility tool that reflects the effects of expanding the buyer-supplier markets. Connectivity to intermodal terminals is best considered a special case of market accessibility, affected by the connecting transportation services at the intermodal terminals. For that reason, this tool is recommended for situations where the project improves a connector or access road to an intermodal terminal. Table 14 summarizes the variables involved in estimating the WEB.

Table 14 Wider Economic Benefit Variables

Process	Variable	Unit	Description	Comments
Estimate Reliability Benefits	HCM peak capacity	Passenger cars/hour /lane	Peak capacity	Estimated by users using highway capacity manual methods
	Terrain in the project area		Flat, rolling, or mountainous	For analysis with freeways and rural highways when HCM peak capacity is not available
	G/C ratio		Effective Green time divided by Cycle length	For analysis with signalized corridors when HCM peak capacity is not available
				Default =0.45 for arterials and 0.35 for other highway classes, based on SHRP2 Reliability Analysis Tool Technical Documentation
	Personal vehicle reliability ratio		VOR/VOT for personal vehicle	Default =0.8, based on SHRP2 Reliability Analysis Tool Technical Documentation
	Commercial vehicle reliability ratio		VOR/VOT for commercial vehicle	Default =1.16, based on SHRP2 Reliability Analysis Tool Technical Documentation
Estimate Productivity Gain of Market Accessibility	No Build Zonal Activity		Employment or population no build scenario	Available from regional travel demand model or estimated by users with available social demographic data
	Build Zonal Activity		Employment or population build scenario	Available from regional travel demand model or estimated by users with available social demographic data
	No build impedance	Hours or minutes	Impedance matrix of no build scenario	Available from regional travel demand model or using sketch planning methods
	Build impedance	Hours or minutes	Impedance matrix of build scenario	Available from regional travel demand model or using sketch planning methods
	Constant decay factor (α)		A parameter for the calculation of effective density	Available from the trip distribution process of a regional travel demand model
				Default parameter α is between 0 and 5, based on SHRP2 Accessibility Analysis Tools Technical Documentation.
	Gross Regional Product (GRP)	$	Per capita GRP proxies for the zones	Estimated by users with regional economic data
	Productivity elasticity of market effective density	$/unit effective density change	Productivity elasticity (% value added per 1% change in effective density)	Relevant information available from NCHRP Report 786

Table 14, continued

Process	Variable	Unit	Description	Comments
Estimate Productivity Gain of Improved Intermodal Connectivity	Facility type		Airport freight, airport passenger, rail freight, rail passenger, marine	
	Lift capacity	Container	Number of annual containers for rail freight intermodal facilities. Rail freight only.	
	Distance of improvement from facility	Miles	Distance of improvement project to the intermodal terminal	Estimated with a GIS or other mapping applications
	Number of trucks within study area		The number of trucks per year using the project	Estimated by the users with regional freight data
	Hours saved per truck	Hours	The hours saved per truck due to the project	Estimated by the users based on project information
	Fraction of trucks associated with project	%	Assume that the further away from the intermodal facility the less trucks associated with the facility	Use default value calculated by a distance decay function if local data not available
	Number of passenger vehicles within study area		The number of trucks per year using the project	Estimated by the users with regional traffic data
	Hours saved per passenger vehicle	Hours	The hours saved per passenger car due to the project	Estimated by the users based on project information
	Fraction of passenger vehicles associated with project	%	Assume that the further away from the intermodal facility the less passenger cars associated with the facility	Use default value calculated by a distance decay function if local data not available
	Productivity elasticity for intermodal terminal connectivity	$/intermodal access index	Productivity elasticity (% value added per 1% change in intermodal access)	Relevant information available from NCHRP Report 786

4.7 Benefit-Cost Analysis

The two most commonly used measures for comparing project benefits to costs are Net Present Value (NPV) and the Benefit-Cost Ratio (BCR). To account for the time value of resources set aside for the project, all benefits and costs over a project's life cycle need to be discounted to the present values (FHWA, 2003). Through discounting, different investment alternatives can be objectively compared based on their respective present values. The standard formula for discounting the project's benefits or costs is shown in Equation 29.

$$PV = [1/(1+r)^t] * A_t \qquad \text{(Eq. 29)}$$

where

PV = present value at time zero (the base year)
r = discount rate
t = time (year)
A_t = amount of benefit or cost in year t

Most highway projects generate costs and benefits incrementally over the entire life cycles. The entire series of costs and benefits need to be discounted to the present by multiple applications of Equation 28 for each applicable year throughout the life cycle. The discounted values are then summed together for each year of the life-cycle analysis period, yielding the formula (Equation 30) for the resent value of the project benefits or costs over the entire analysis period.

$$PV = \sum_{t=1}^{N} [1/(1+r)^t] * A_t \qquad \text{(Eq. 30)}$$

where

N = Life cycle analysis period of the project

The U.S. Office of Management and Budget (OMB) sets the value of discount rate for the federal agencies to evaluate public investments and regulations. In accordance with OMB Circular A-94, applications to the discretionary grant programs should use a discount rate of 7 percent per year to discount benefits and costs in the BCA (USDOT, 2018). After discounting, for each alternative, the present value of costs are subtracted from that of the benefits to yield the NPV of the alternative. If benefits exceed costs, the NPV of the alternative is positive and considered to be economically viable.

The benefit-cost ratio (BCR) is another BCA measure frequently used in project evaluation. In BCR, the present value of benefits is placed in the numerator and the present value of costs is the denominator. For projects with restricted budgets or projects applying for the discretionary grant programs, it is recommended that the denominator include only the initial agency costs (i.e., the capital cost) of implementing the project (USDOT, 2018). All other BCA values, including periodic O & M costs and/or user costs should be included in the ratio's numerator as negative or positive benefits. Economists generally hold that the direct benefits and costs of transportation improvements measured using BCA are converted into wider, indirect, economic impacts through the operation of the marketplace. These converted, indirect effects are assumed to have the same net monetary value as the BCA-measured direct effects. Significantly, the value of most converted economic effects is not additive to the value of the BCA-measured direct effects—rather, the former value is a restatement or capitalization of the latter value.

4.8 Economic Impact Analysis

Economic impact analysis (EIA) is the study of the way in which the direct benefits and costs of a highway project (e.g., reduced congestion) are converted to the indirect, wider economic benefits that affect the local, regional, or national economy through effects such as reorganization, localization and urbanization (). Unlike BCAs, there is usually no requirement to conduct an EIA for a project that is to be considered for a grant program (USDOT, 2018). However, the indirect economic impacts measured by EIA can be of major interest to decision makers, planners, and the public, especially for large projects that are expected to generate major direct transportation benefits and costs. EIA can identify the sectors of the public who are likely to be affected by the project and how they will be affected. EIA can also be of great interest to the decision makers when the main objective of the project is to stimulate the regional economy such as projects that target freight transportation.

Depends on the scale, complexity, and controversy of the project, the methods and efforts involved in conducting an EIA for the project can vary significantly. The wider economic benefits of reliability, market accessibility, and intermodal connectivity measured by the aforementioned SHRP2 C11 tools are examples of EIA that analyze the regional and broader productivity impacts of the projects (SHRP2, 2014). Regional economic models are more advanced EIA methods that can reveal broader economic impacts in the region such as retail spending, business activity, tax revenues, jobs, wage levels, and property values. Input-output analysis is a key component of most regional economic models that are used to quantify the multiple economic effects resulting from a change in the demand for a specific product or service. These economic effects manifest through a series of demand-supply changes that are driven by improved transportation in the region. This chain of effects captures the distributive benefits of transportation investments across a broad range of industries (FHWA, 2003).

A significant amount of effort is required to develop a valid regional economic model. The decision to conduct an EIA should thus be made after considering the project's objectives, total budget, complexity, and expected scale of impacts. In the event that a comprehensive EIA is demanded for a project by the funding agency, it is important to note that USDOT recommends that the EIA be done as an independent add-on exercise after assessing the direct benefits and costs of the project with a BCA (USDOT, 2018).

In the next phase of the project, we explored the potential for integrating an EIA tool into the freight project prioritization tool. We will assess the need for such an integration as well as the amount of effort involved before making the decision for the EIA tool integration.

4.9 Risk Analysis

In the process of conducting a BCA, the analysts inevitably make assumptions about the operating conditions of the project and the regional economy in the future. Each of these assumptions is associated with a certain level of uncertainty. In the BCAs, elements of the analysis that are subject to large uncertainty need to be identified, especially those with the greatest potential of influencing the outcome of the BCA (USDOT, 2018). USDOT recommends the use of sensitivity analysis to help point out how the results of a BCA would change if the value of an uncertain variable is to change. In general, if the sensitivity analysis indicates that changes in an uncertain variable will not change the relative ranking of project alternatives in the BCA, then the results can be regarded as robust. Alternatively, if a reasonable change in an uncertain input severely alters the results of the BCA, methods to reduce the risk of a change in that variable need to be investigated. If the risk cannot be mitigated, other alternatives that are not critically influenced by that variable may be considered (FHWA, 2003).

In addition to sensitivity analysis, Monte Carlo simulation is another common risk analysis method that is most useful when more than one uncertain variables change values simultaneously. In Monte Carlo simulation, an appropriate probability distribution is assigned to each of the uncertain variables in the analysis. The simulation samples randomly from the probability distributions for each variable and applies the sampled values to the BCA formulas to generate corresponding economic results. This sampling and calculation process is repeated over and over again, resulting in an average BCA result and a probability distribution covering all potential outcomes of the BCA.

Similar to our approach on integrating an EIA tool with the freight project prioritization tool, we will also explore the option of developing tool component for risk analysis as part of the project prioritization tool.

4.10 Rank Alternatives and Recommend Prioritization

Evaluation performed with the proposed framework essentially renders two key pieces of information that can assist in ranking alternatives and making recommendations for project prioritization: a standard BCA and metrics for the WEB associated with travel time reliability, market accessibility, and intermodal connectivity. The BCA results of this framework conform to USDOT's requirements for discretionary grant programs and the methodologies for assessing the WEB are obtained from federally sponsored research programs. Although the two groups of metrics are both measured in monetary values, they cannot be aggregated per USDOT guidance. Thus, specific criteria for ranking the alternatives based on these two groups of metrics need to be based on the requirements of the funding sources.

5. CASE STUDY

This chapter presents three case studies to demonstrate how the methodologies for the freight project prioritization decision support system can be implemented with real-world data. We selected three transportation projects in the State of Florida that are expected to generate wider economic benefits. The projects were selected based on their potential impacts on different aspects of wider economic benefits in reliability, connectivity, and productivity.

1. The first project involves a new interchange on I-95 at Central Boulevard in Palm Beach County (FDOT, 2016a). The main purpose of this project is to reduce congestion and improve mobility in the northern Palm Beach County area. The new interchange is expected to improve travel time reliability with congestion reduction, and improve market accessibility, leading to productivity gain in the region.
2. The second project involves improvement to an existing interchange on I-95 at 45th Street (FDOT, 2017), also in Palm Beach County. The purpose of this project is to relieve congestion at the interchange with the 45th Street, which serves as the main access point between I-95 and the Port of Palm Beach. This project is expected to generate economic benefits via improved intermodal connectivity.
3. The third project is the Port of Miami Tunnel Project (FDOT, 2011), which provides direct access to the Port from I-95. Productivity gain is expected through improved connectivity to the Port for freight activities.

Through these three case studies, we intend to demonstrate how the analytical methods of the project prioritization decision support system capture different aspects of project benefits:

- New interchange project - standard traveler benefits, travel time reliability, and market accessibility;
- Interchange improvement project - intermodal connectivity to Port of Palm Beach, and market accessibility;
- Port of Miami tunnel - intermodal connectivity, with a market that has larger Gross Regional Product (GRP) than the Port of Palm Beach.

5.1 SR-9/I-95 at Central Boulevard Interchange

5.1.1 Project Description

The Florida State Road 9 (I-95) serves as the major north-south artery in the Palm Beach County. Traffic to and from I-95 influences the operating conditions of adjacent highway network in the County. This combined with existing high-density commercial developments and planned future developments created the need for transportation solutions in the immediate and long-term future. District Four of the Florida Department of Transportation (FDOT) has conducted a Project Development and Environment (PD&E) study to evaluate potential improvements for State Road 9/I-95 from north of Northlake Boulevard to south of Donald Ross Road; PGA Boulevard from west of Military Trail to west of Lake Victoria Gardens Avenue; and Central Boulevard from one mile south of I-95 to one mile north of I-95 (FDOT, 2016a). The study evaluated alternatives that could reduce congestion and improve mobility in the northern Palm Beach County area. The improvements evaluated include construction of a new interchange at I-95 and Central Boulevard. In 2015, the I-95 at Central Boulevard Interchange Justification Report prepared by FDOT (FDOT, 2015) estimated an annual reduction of over 1.4 million hours in delay on area roads with construction of a new interchange at Central Boulevard.

The SR 9/I-95 at Central Boulevard Interchange PD&E study evaluated two alternatives for the I-95 mainline improvements and two configurations for the proposed Central Boulevard interchange (FDOT, 2016a). Based on a comprehensive comparative analysis, the project team selected construction of a collector distributor (CD) road system along mainline I-95 with a tight diamond urban interchange (see Figure 9). Currently, the project is undergoing public hearing process with an estimated 3-year construction period scheduled to begin in Spring of 2025 (FDOT, 2019a). Cost for construction of the recommended alternative is 33.9 million, estimated in 2013 dollars (FDOT, 2015).

5.1.2 Standard Traveler Benefits

Major sources of information used for benefit-cost analysis of the project include the two aforementioned reports prepared by FDOT:

- I-95 at Central Boulevard Interchange PD&E Study Preliminary Engineering Report (FDOT, 2016)
- I-95 at Central Boulevard Interchange Justification Report (FDOT, 2015)

In this case study, benefit-cost analysis focused only on segment of I-95 between PGA Boulevard and Donald Ross Road, as the forecasted daily traffic for the segment between PGA Boulevard and Northlake Boulevard differ by only a few hundred vehicles between No Build and Build scenarios, thus no significant benefits are expected of this segment.

Table 15 below summarizes the major inputs and data sources for this benefit-cost analysis. Unit values for converting various standard traveler benefits to monetized values came from the Benefit-Cost Analysis Guidance for Discretionary Grants Programs of U.S. Department of Transportation (USDOT, 2018). 2018 annual fuel price per gallon was obtained from US Energy Information Administration (2018).

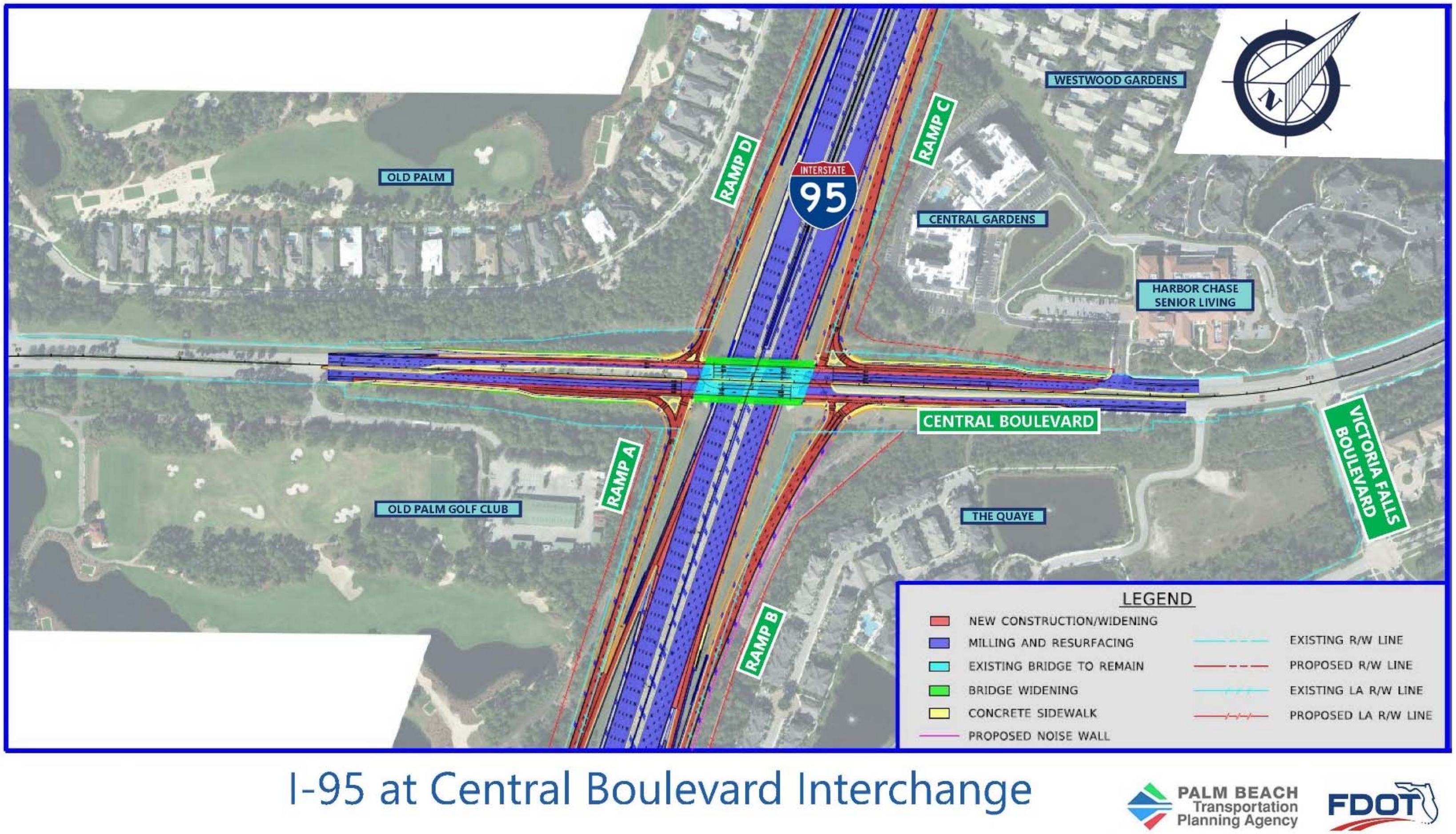

Figure 9 Recommended Urban Interchange between Central Boulevard and I-95 (Source: FDOT, 2016a)

Table 15 Major Inputs and Data Sources for the Benefit-Cost Analysis

Factors	Values	Sources
2020 AADT	119,200	I-95 Interchange Justification Report
2040 No Build AADT	142,400	
2040 Build AADT	127,100	
% Truck of AADT	8%	FDOT TTMS #930217
% 5-Hr Peak Period of AADT	0.41	
% HOV of AADT	0.15	I-95 Managed Lane Master Plan
Hourly Values of Travel Time Savings – Personal Travel ($/hour)	$14.8	USDOT Benefit-Cost Analysis Guidance for Discretionary Grants Programs
Hourly Values of Travel Time Savings – Truck Traffic ($/hour)	$28.6	
Average Vehicle Occupancy (persons/vehicle)	1.68	
Fuel Price per Gallon ($/gallon)	$2.813 (i.e., 2018 annual average)	US Energy Information Administration
Accident Injury Level Monetized Values ($/event)		
O – No Injury	$3,200	USDOT Benefit-Cost Analysis Guidance for Discretionary Grants Programs
C – Possible Injury	$63,900	
B – Non-incapacitating	$125,000	
A – Incapacitating	$459,100	
K – Killed	$9,600,000	
U – Injured (Severity Unknown)	$174,000	
# Accidents Reported (Unknown if Injured)	$132,200	
Property Damage Only ($/vehicle)	$4,300	
Vehicle Emissions Costs ($/Short Ton)		
Volatile Organic Compounds (VOCs)	$2,000	USDOT Benefit-Cost Analysis Guidance for Discretionary Grants Programs
Nitrogen oxides (NO_x)	$8,300	
Particulate matter ($PM_{2.5}$)	$377,800	
Sulfur dioxide (SO_2)	$48,900	

To estimate crash reduction benefits, Florida statewide crash data of the latest 3 years (i.e., 2015, 2016, 2017) were obtained from the Florida Highway Safety and Motor Vehicles (FHSMV, 2018). The data are summarized in Table 16.

Table 17 summarizes the BCA results of the standard traveler benefits in travel time savings, operational cost savings, crash reduction benefits, and emission reduction benefits. Considering the segment of I-95 between Donald Ross Road and PGA Boulevard, the proposed Central Boulevard interchange is expected to generate standard travel benefits of approximately $72 million dollars in net present value. For the estimated $33.9 million construction cost, the benefit-cost ratio of the interchange project is approximately 2.0 in net present value.

Table 16 Florida Statewide Crash Data 2015-2017

	2017	2016	2015	Average	Average / 1M miles
VMT (Millions)	218,825	215,231	206,721	213,592	
Total Crashes	402,385	395,785	374,342	390,837	1.830
Fatal Crashes	2,924	2,935	2,699	2,853	0.013
Injury Crashes	166,612	165,940	159,795	164,116	0.768
Property Damage Only crashes	232,849	226,910	211,848	223,869	1.048

Table 17 BCA Results of Standard Traveler Benefits

	Travel Time Savings	Vehicle Op. Cost Savings	Accident Reductions	Vehicle Emission Reductions	Total STB	Present Value of Project Cost	Net Present Value
Construction Period							
1						$11,300,000.00	($11,300,000)
2						$10,560,747.66	($10,560,748)
3						$9,869,857.63	($9,869,858)
Project Open							
1	$0	$0	$0	$0	$0	$0	$0
2	$1,380,037	$1,529,091	$235,629	$19,898	$3,164,655	$0	$3,164,655
3	$1,550,568	$1,783,963	$440,427	$26,816	$3,801,775	$0	$3,801,775
4	$1,693,856	$1,999,124	$617,421	$32,742	$4,343,143	$0	$4,343,143
5	$1,812,681	$2,174,809	$769,372	$37,694	$4,794,556	$0	$4,794,556
6	$1,909,580	$2,321,537	$898,800	$41,917	$5,171,833	$0	$5,171,833
7	$1,986,867	$2,438,922	$1,008,000	$45,432	$5,479,220	$0	$5,479,220
8	$2,046,648	$2,531,664	$1,099,065	$11,197	$5,688,573	$0	$5,688,573
9	$2,090,839	$2,596,863	$1,173,901	$11,630	$5,873,233	$0	$5,873,233
10	$2,121,185	$2,646,760	$1,234,242	$11,993	$6,014,180	$0	$6,014,180
11	$2,139,271	$2,677,891	$1,281,663	$12,227	$6,111,053	$0	$6,111,053
12	$2,146,534	$2,694,567	$1,317,598	$12,406	$6,171,105	$0	$6,171,105
13	$2,144,279	$2,692,593	$1,343,345	$12,530	$6,192,748	$0	$6,192,748
14	$2,133,690	$2,683,634	$1,360,085	$12,567	$6,189,976	$0	$6,189,976
15	$2,115,835	$2,663,882	$1,368,885	$12,568	$6,161,169	$0	$6,161,169
16	$2,091,682	$2,635,611	$1,370,712	$12,496	$6,110,501	$0	$6,110,501
17	$2,062,104	$2,594,547	$1,366,442	$12,397	$6,035,490	$0	$6,035,490
18	$2,027,890	$2,552,037	$1,356,864	$12,242	$5,949,033	$0	$5,949,033
19	$1,989,748	$2,503,551	$1,342,692	$12,066	$5,848,057	$0	$5,848,057
20	$1,558,769	$2,044,271	$1,324,566	$10,730	$4,938,336	$0	$4,938,336
Total	**$37,002,063**	**$45,765,318**	**$20,909,709**	**$361,547**	**$104,038,637**	**$31,730,605**	**$72,308,031**

5.1.3 Wider Economic Benefits

With the proposed new interchange at the Central Boulevard, it is expected that accessibility in northern Palm Beach County will be improved as a new access point to I-95 is provided. The new interchange is also expected to relieve existing congestion on PGA Boulevard from Military Trail in the west to Victoria Lake Gardens Avenue in the east, leading to improved travel time reliability for PGA Boulevard. In addition, although the Port of Palm Beach is approximately 10 miles south of Central Boulevard, the new interchange and associated improvement on PGA Boulevard are not expected to contribute to intermodal connectivity with Port of Palm Beach, because most freight trucks access the Port via the Blue Heron Boulevard and 45th Street interchanges in the south of PGA Boulevard.

Travel Time Reliability

Economic benefits from travel time reliability improvement are estimated for both I-95 and PGA Boulevard. Input data and sources for these data are summarized in Table 18.

Table 18 Required Data and Data Sources for Travel Time Reliability Analysis

Data Element	Description	Data Source
Lanes	Number of Lanes	I-95 Interchange Justification Report (FDOT, 2015)
Free Flow Speed	Speed Limits	Google Street View
ADT	Average Daily Traffic	2040 Forecasts from the I-95 Interchange Justification Report (FDOT, 2015)
% Trucks	Percentage of Traffic that are Trucks	FDOT TTMS #930217 (FDOT, 2019b)
Capacity	Vehicles Per Hour	Estimated with SHRP2 Equations (SHRP2, 2014)
Unit cost of passenger travel time ($/hour)	$19.86	SHRP2 (2014)
Unit cost of commercial travel time ($/hour)	$36.06	SHRP2 (2014)

For capacity estimation of I-95 and PGA Boulevard, we used the equations (Eqs. 1 and 2) developed by the SHRP2 (2014).

$$\textit{Freeway Capacity} = \textit{IdealCap} * N * \textit{FHV} \qquad \text{(Eq. 1)}$$

where

Freeway Capacity = Directional capacity in vehicles per hour
IdealCap = 2,400 passenger cars per hour per lane (pcphpl), if free flow speed >= 70 mph, or 2,300 otherwise
N = number of through lanes in one direction
HV = daily proportion of trucks in traffic stream.
FHV = heavy vehicle adjustment factor-- 1.0/(1.0 + 0.5 HV) for level terrain, 1.0/(1.0 + 2.0 HV) for rolling terrain, 1.0/(1.0 + 5.0 HV) for mountainous terrain (rare in urban areas)

$$\textit{Signalized Arterial Capacity} = \textit{IdealSat} * N * \textit{FHV} * g/C \qquad \text{(Eq 2)}$$

where

Signalized Arterial Capacity = Directional capacity in vehicles per hour
IdealSat = Ideal saturation flow rate (1,900 pcphpl)
g/C = effective green time divided by cycle length (0.45 for arterials, 0.35 for other highway classes)

Values of the input data used are summarized in Table 19. The resultant economic benefits of travel time reliability for the 2040 No Build and Build scenarios are presented in Table 20.

Table 19 Input Data for I-95 and PGA Boulevard Travel Time Reliability Analysis

Input Value	I-95 (PGA Blvd to Donald Ross Rd)		PGA Boulevard (FL Turnpike to Lake Victoria Gardens Ave)	
	2040 No Build	**2040 Build**	**2040 No Build**	**2040 Build**
Number of Lanes (one-way)	5	6	3	3
Free Flow Speed (MPH)	65	45	65	45
Project Length(Miles)	3.40	3.40	2.50	2.50
ADT	142,422	127,156	54,033	51,093
% Trucks in traffic	8	8	8	8
Peak Capacity (pcph, one-way)	11,058	13,846	2,224	2,502

Table 20 Results of I-95 and PGA Boulevard Travel Time Reliability Analysis

Delay Costs	I-95 (PGA Blvd to Donald Ross Rd)		PGA Boulevard (FL Turnpike to Lake Victoria Gardens Ave)	
	2040 No Build	**2040 Build**	**2040 No Build**	**2040 Build**
Recurring Delay - Passenger cars	$335,018	$304,079	$427,874	$160,021
Recurring Delay - Trucks	$63,036	$56,925	$45,734	$17,868
Total Recurring Delay	$398,054	$361,004	$473,607	$177,890
Reliability Delay - Passenger cars	$21,165	$20,135	$60,526	$12,357
Reliability Delay - Trucks	$5,476	$5,183	$8,895	$1,897
Total Reliability Delay	$26,641	$25,318	$69,421	$14,254
Total Delay	$424,695	$386,322	$543,028	$192,144
% Reduction		9%		65%

Table 20 shows that the new Central Boulevard interchange can reduce the delay cost associated with travel time reliability by 9% for I-95 and 65% for PGA Boulevard. The delay reduction on PGA Boulevard is achieved by vehicles detouring to the new Central Boulevard interchange.

Market Accessibility

The methodology to calculate market accessibility benefit is described in section 4.6.2. ED, a measure of accessibility to employment (Eq. 24), is used to approximate economic agglomerative effects from transportation projects (Graham, 2007). It is suggested that the value of the decay parameter is between 0 and 5 (SHRP2, 2014). In general, higher decay values place more weight on markets closer to the project location by penalizing markets farther away (SHRP2, 2014). For the I-95 Central Boulevard interchange project, the decay parameter is assumed to be equal to 1.8 based on the results reported in Graham et al. (2009) for the consumer and business service sectors, which represent the major industries in the areas close to Palm Beach County.

Productivity benefits (*P*) resulted from changes in accessibility to markets can be measured based on Eq. 25. Following the guidelines provided in SHRP2 (2014), a productivity elasticity value of 0.03 (for projects improving existing capacity) is selected for this case. Table 21 summarizes data required for market accessibility analysis as well as the sources used for this analysis.

Table 21 Required Data for Market Accessibility Analysis

Data Elements	Description	Sources and Methods of Estimation
Analysis Zones	Divisions of geographic areas for purposes of estimating population, employments and other economic activities	Traffic Analysis Zones of the Florida Statewide Model (FDOT, 2019d)
Zonal employments	Number of employments in the analysis zones	Traffic Analysis Zones of the Florida Statewide Model (FDOT, 2019d)
Impedance	Metrics representing the ease of traveling between a pair of zones	Congested travel time between a pair of zones calculated with the FLSWM model network (FDOT, 2019d)
Per worker GRP	Per employee gross regional product in a zone	GDP by county divided by total number of employments of the same county using data from Bureau of Economic Analysis (BEA, 2019a and 2019b)
Impedance decay parameter	1.8	SHRP2 (2014)
Productivity Elasticity	0.03	SHRP2 (2014)

The first step in our effort of modeling market accessibility for the Central Boulevard interchange project is to obtain a travel demand model that represent the transportation network and employment zones of the study area. The Southeast Regional Planning Model (SERPM) (FDOT, 2019d) is the representative model for the Palm Beach County. However, Melo, Graham, Levinson, and Sarabi (2017) estimated productivity gains from agglomeration economies for a sample of the largest metropolitan areas in the US using measures of employment density and employment accessibility. They found that most of the productivity gains in the sampled US cities occur within the first 20 minutes of automobile travel time, and the productivity gains do not appear to exhibit significant nonlinearities with respect to increasing travel time. Thus, to model market accessibility of a region, it is necessary for the model to cover an extended area within at least 20 minutes of travel time from the region. The proposed I-95 interchange with Central Boulevard is approximately 8 miles from the border of Palm Beach County and Martin County in the north. The network and TAZ data of SERPM cannot be used to model accessibility gain of the proposed Interchange as the geographic coverage of SERPM ends at the northern border of Palm Beach County. We instead used the 2010 Florida Statewide Model (FLSWM) (FDOT, 2019e) that provides network and TAZ coverage for the entire state of Florida.

We obtained from FSUTMSOnline.net (FDOT, 2019f) the 2040 FLSWM model, which contains 2040 population and employment projection data for all the TAZs as well as 2040 forecasted traffic volumes and congested travel time for all network links. Figure 10 shows the FLSWM network and TAZ coverage surrounding the location of the proposed Central Boulevard interchange with I-95. 257 TAZs are located within a 20-mile radius from the Interchange.

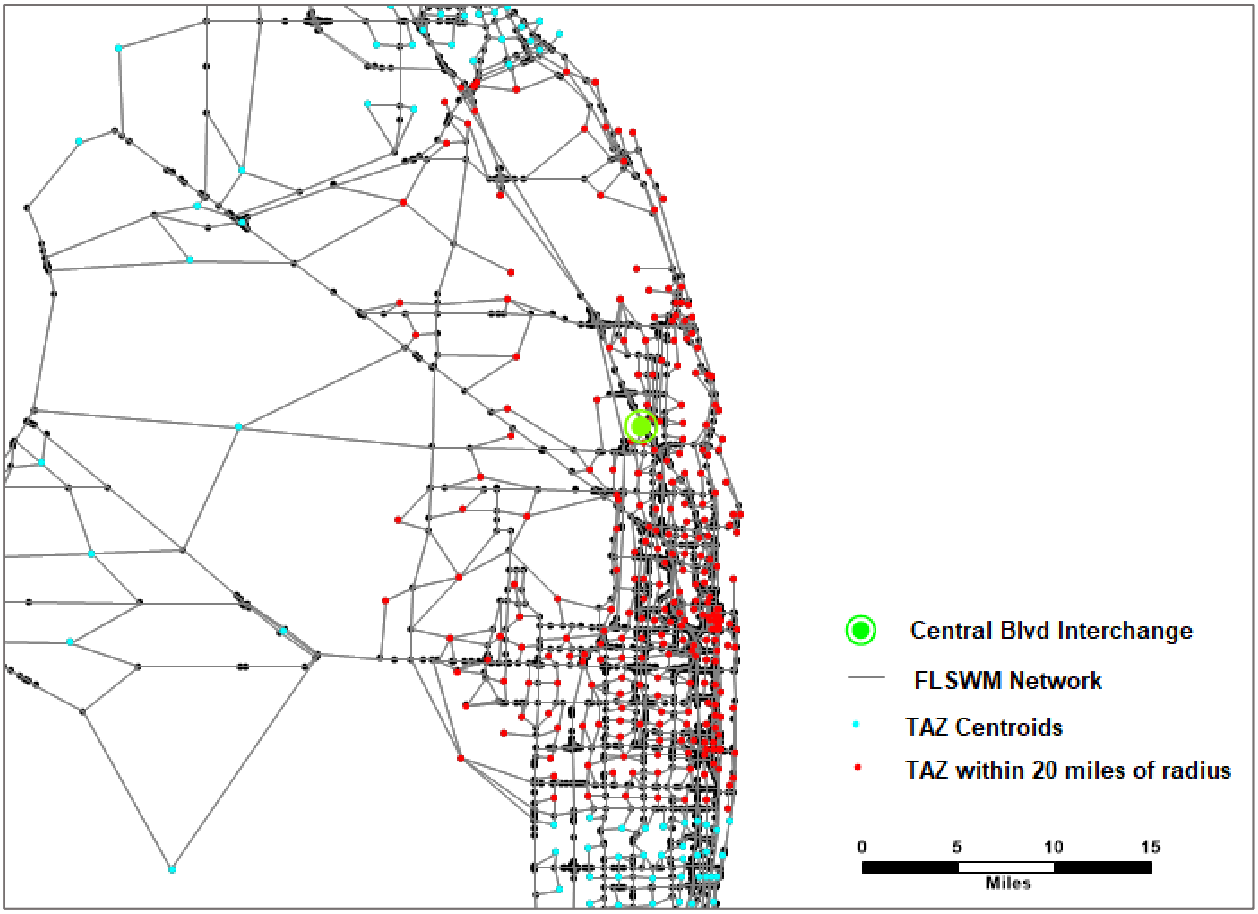

Figure 10 TAZs Located within 20-Mile Radius of the I-95/Central Boulevard Interchange

We then calculated a matrix of congested travel time between every pair of TAZs within the 20 miles radius for the 2040 no-build and build alternatives. The congested travel time between TAZi and TAZj is the impedance term d_{ij} in Equation 24. We choose to use the congested travel time as the impedance term because it reflects the ease of commuting from homes to workplaces by the employees better than free flow travel time. Table 22 shows the congested travel time matrix between the first 10 TAZs. It is noted that the intrazonal travel time within a zone (i.e., the diagonal cells in Table 22) is estimated with the same nearest neighbor theory used by FLSWM (FDOT, 2016b), which assumes that the intrazonal travel time within a zone is proportional to the amount of time it takes to get to the nearest adjacent zone or zones. Intrazonal travel time is calculated with Equation 5 shown below:

$$IZ_i = \frac{IVTT_a}{2} \quad \text{(Eq. 5)}$$

where

IZ_i = intrazonal travel time for zone i, and

$IVTT_a$ = in-vehicle travel time to nearest adjacent zone.

Table 22 2040 No-Build Impedance (Congested Travel Time) Matrix for the First 10 TAZs

	1168	1169	1171	1211	1214	1215	1216	1218	1219	1220
1168	1.42	35.95	34.43	26.31	18.70	22.01	2.83	36.87	40.57	34.19
1169	35.95	1.42	18.25	61.14	17.63	14.99	34.63	21.28	24.38	18.67
1171	34.43	18.25	0.89	59.28	15.85	12.95	32.88	3.02	6.68	3.50
1211	26.31	61.14	59.28	2.63	43.59	46.90	26.63	61.46	65.16	58.79
1214	18.70	17.63	15.85	43.59	0.64	3.31	17.19	18.37	22.07	15.69
1215	22.01	14.99	12.95	46.90	3.31	0.39	20.50	15.18	18.88	12.50
1216	2.83	34.63	32.88	26.63	17.19	20.50	0.99	35.06	38.77	32.39
1218	36.87	21.28	3.02	61.46	18.37	15.18	35.06	0.66	5.03	4.49
1219	40.57	24.37	6.68	65.16	22.07	18.88	38.77	5.03	1.10	7.36
1220	34.19	18.66	3.50	58.79	15.69	12.50	32.39	4.49	7.36	0.77

Note: Column and row headings are TAZ IDs and cells are congested travel time in minutes

Table 23 2040 No-Build Effective Densities for the 10 TAZs

	1168	1169	1171	1211	1214	1215	1216	1218	1219	1220
2040 Zonal Employment	6,823	156	2,517	2,728	891	928	4,045	3,905	8,219	2,425
1168	4,816.73	4.34	73.09	103.67	47.64	42.16	1,427.79	105.93	202.61	70.93
1169	189.82	109.86	137.90	44.62	50.54	61.91	116.79	183.55	337.22	129.94
1171	198.14	8.55	2,844.07	46.02	56.22	71.66	123.03	1,291.94	1,230.09	692.86
1211	259.29	2.55	42.46	1,038.61	20.44	19.79	151.92	63.53	126.13	41.25
1214	364.83	8.85	158.81	62.59	1,403.15	280.36	235.34	212.58	372.39	154.51
1215	309.97	10.41	194.36	58.17	269.18	2,410.39	197.34	257.33	435.42	194.00
1216	2,408.37	4.50	76.55	102.46	51.84	45.27	4,098.88	111.37	212.02	74.87
1218	185.08	7.33	832.73	44.38	48.50	61.15	115.36	5,961.83	1,634.75	539.85
1219	168.19	6.40	376.70	41.86	40.37	49.16	104.35	776.70	7,471.82	329.41
1220	199.56	8.36	719.14	46.40	56.77	74.24	124.89	869.32	1,116.46	3,149.35

Table 24 2040 Build Effective Densities for the 10 TAZs

	1168	1169	1171	1211	1214	1215	1216	1218	1219	1220
2040 Zonal Employment	6,823	156	2,517	2,728	891	928	4,045	3,905	8,219	2,425
1168	4,815.05	4.38	73.61	104.09	48.13	42.52	1,427.30	106.68	204.60	71.47
1169	191.74	109.83	138.26	44.85	50.74	61.89	117.57	183.95	337.34	130.24
1171	200.43	8.57	2,843.20	46.10	56.21	71.64	123.09	1291.54	1,229.74	692.63
1211	260.34	2.56	42.53	1,038.29	20.49	19.83	152.53	63.63	126.31	41.32
1214	371.89	8.88	158.79	62.73	1,402.72	280.28	235.64	212.52	372.29	154.47
1215	315.04	10.40	194.30	58.30	269.10	2,409.68	197.54	257.25	435.29	193.95
1216	2,407.53	4.53	76.53	102.87	51.82	45.26	4,097.46	111.33	211.96	74.85
1218	188.33	7.35	832.48	44.45	48.49	61.14	115.42	5,959.94	1,634.28	539.69
1219	173.18	6.40	376.60	42.20	40.36	49.15	105.84	776.48	7,469.84	329.32
1220	203.36	8.37	718.91	46.48	56.76	74.22	124.96	869.07	1,116.15	3,148.34

We use the 2040 total employments in TAZi as the E_i in Equation 24. With the travel impedance matrix and the TAZ employment data, we calculate the ED for every TAZ located within the 20-mile radius of the Central Boulevard interchange. Table 23 presents the ED of the 2040 No Build for the same first 10 TAZs. Effective densities of the 10 TAZs for the 2040 Build in Table 24.

To calculate productivity gain of improved effective density, we also need the per worker (employee) Gross Regional Product (GRP) for all the TAZs within 20-mile impact area (Equation 25). All of the selected TAZs are located in either Palm Beach County or Martin County. We obtained the per worker Gross Domestic Product (GDP) by County for the Palm Beach and Martin Counties from the US Bureau of Economic Analysis (BEA, 2019a). Table 25 shows the GDP and the number of total employments of the two counties.

Table 25 GDP and Employments by County for Palm Beach and Martin Counties

County	Industry	GDP by County (in $K)	Total Emp	GDP Projection (2.5% AGR)	Emp Projection (2.5% AGR)	GDP/ Emp
	Year	**2015**	**2015**	**2040**	**2040**	**2040**
Martin	All Industries	6,533,103	92,824	12,112,008	172,091	70.38
	Private goods-producing industries	756,524				
	Private services-providing industries	5,287,117				
	Government and government enterprises	489,462				
Palm Beach	All Industries	76,866,505	888,179	142,506,203	1,646,634	86.54
	Private goods-producing industries	6,117,657				
	Private services-providing industries	64,503,410				
	Government and government enterprises	6,245,438				

Note: Emp = Employment

Table 26 presents the estimated annual productivity gain for the first 10 TAZs, and the total annual productivity for all 257 TAZs within the 20 miles radius from the proposed Central Boulevard interchange.

Table 26 Annual Zonal Productivity for the 10 TAZs

Zone ID	COUNTY	2040 Total Employment	Annual Zonal Productivity (K$)
1168	Palm Beach	6,823	318
1169	Palm Beach	156	1
1171	Palm Beach	2,517	7
1211	Martin	2,728	25
1214	Palm Beach	891	5
1215	Palm Beach	928	3
1216	Palm Beach	4,045	88
1218	Palm Beach	3,905	11
1219	Palm Beach	8,219	24
1220	Palm Beach	2,425	7
Total Annual Productivity for 257 TAZs (K$)			**5,979**

5.2 SR-9/I-95 Interchange at 45th Street

5.2.1 Project Description

District Four of FDOT had conducted a PD&E Study to identify short-term and long-term needs of I-95 interchange with 45th Street and develop design concepts to address traffic spillback onto I-95, improve interchange operations, reduce congestion, and increase safety at the study interchange (FDOT, 2017). The improvements to the I-95 Interchange at 45th Street will provide additional capacity for vehicles traveling east-west as well as reduce peak hour traffic spillback to I-95 from the ramp intersections with the 45th Street. Local and network connectivity for the City of West Palm Beach, the Town of Mangonia Park and Palm Beach County will be improved.

The 45th Street interchange with I-95 is currently a diamond interchange located in City of West Palm Beach, and in close proximity to the Town of Mangonia Park, and the City of Riviera Beach in North Palm Beach County, Florida. The adjacent interchanges are Blue Heron Boulevard interchange to the north and the Palm Beach Lakes Boulevard interchange to the south (Figure 11). I-95 is a ten-lane divided interstate freeway providing four general purpose lanes and one high occupancy vehicle (HOV) lane in each direction. 45th Street is a six-lane divided roadway with a raised landscape median within the vicinity of the I-95 interchange. The 45th Street interchange is the main access point for freight trucks to access the Port of Palm Beach from I-95 (Port of Palm Beach, 2017). Improvement to operation at this interchange is expected to contribute to improved intermodal connectivity with the Port, which became one of the top 25 ports in the US in throughput of total number of containers (BTS, 2018).

The PD&E study found that intersections at both the northbound and southbound ramps with the 45th Street are going to operate at LOS F during the AM peak hour by year 2040 if no improvement take place. A Diverge Diamond Interchange is recommended as the preferred alternative for the interchange improvement (Figure 12).

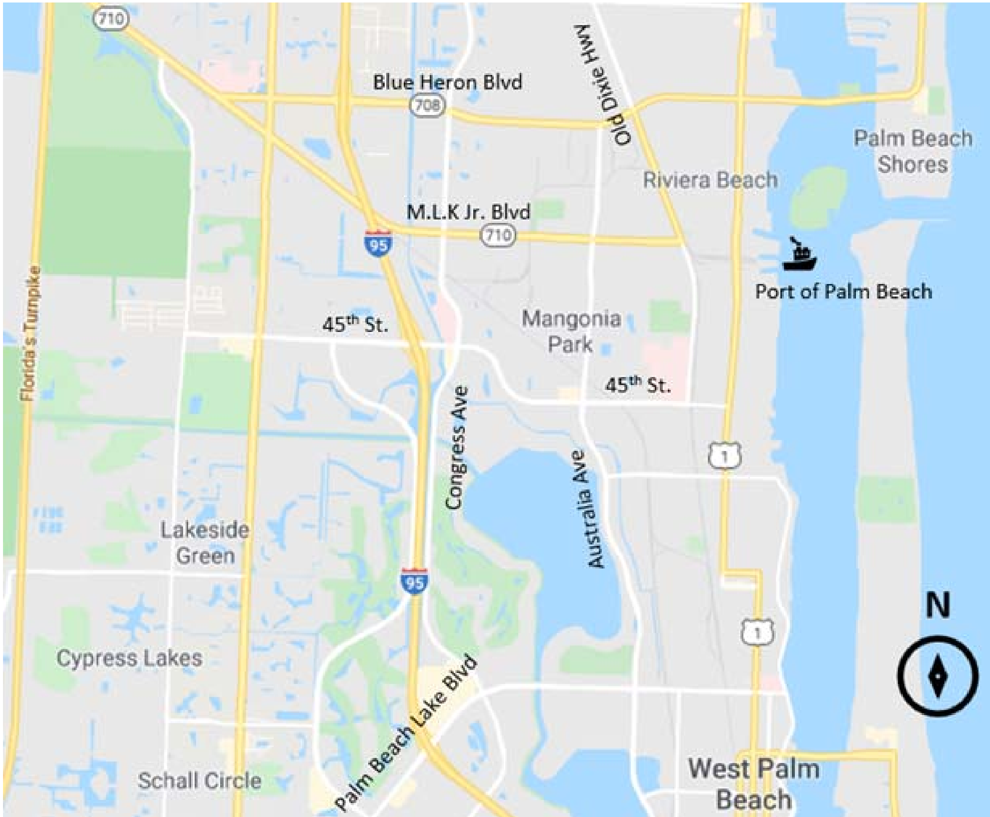

Figure 11 Location of the 45th Street Interchange (Adapted from Google Maps)

5.2.2 Wider Economic Benefits

The aspect of intermodal connectivity that can create benefits for surface freight transportation involves improvement of access to and from a particular intermodal terminal. Currently, most external traffic which arrives at the Port of Palm Beach from outside the adjacent community uses the I-95 corridor and exits at 45th Street, accessing the Port by way of Australian Avenue or Congress Avenue to SR-710/MLK Blvd (Port of Palm Beach, 2017). With improved operation at the I-95 interchange with 45th Street, it is expected that productivity gain will increase from improved intermodal connectivity. In addition, the 45th Street interchange is approximately 7 miles south of the proposed new Central Boulevard interchange. We analyzed the market accessibility benefits for the 45th Street Interchange improvement such that comparison with Central Boulevard interchange can be made.

Intermodal Connectivity

The intermodal connectivity analysis method is designed to evaluate the level of connectivity from a project site to airports, marine ports, and rail terminals in the United States (SHRP2, 2014). It works by computing connectivity indices (Eqs. 6 and 7) that reflect the ease of travel from the project to the intermodal terminal and the extent of connecting services to other destinations that can be accessed from it.

Figure 12 Recommended Diverge Interchange at 45th Street (Source: FDOT, 2017)

*Freight Connectivity Index (Bulk Cargo) = Tons of freight * Average value per ton * Number of distinct locations served* (Eq. 6)

*Freight Connectivity Index (Containers) = Containers of freight * Average value per container * Number of distinct locations served* (Eq. 7)

For every port with significant activities in the U.S., the intermodal connectivity analysis tool developed by the SHRP2 C11 project provides 2010 values for the parameters in the above equations (SHRP2, 2014). We updated those numbers for the Port of Palm Beach with the latest available data in 2016. We also adjusted the average value per ton and per container to reflect 2016 dollars. The results of the updated parameters for the freight connectivity index and the sources of data are shown in Table 27.

Table 27 Parameters for Port of Palm Beach Freight Connectivity Index Calculation

Parameters	Sources	Updated Values
Total tons (Bulk cargo)	U.S. Army Corps of Engineers, Waterborne Tonnage for U.S. Ports in 2016 (USACE, 2016a)	2,382,153
Total number of containers		136,363
Average value per ton	Bureau of Transportation Statistics, Freight Analysis Framework (BTS, 2019)	$522
Average value per container		$51,626
Number of unique port destinations and origins (Bulk cargo)	U.S. Army Corps of Engineers, Vessel Entrances, and Clearances Data (USACE, 2016c)	109
Number of unique port destinations and origins (Containers)		34

Table 28 shows the input data sources and specific values applied to estimate intermodal connectivity improvement from the proposed 45th Street Interchange.

Table 28 Input Data for 45th Street Interchange Intermodal Connectivity Analysis

Data	Sources	2040 No Build	2040 Build
Distance of Improvement from Facility (miles)	Measured in Google Map	3	3
2040 forecast of annual number of trucks within study area	2018 FDOT Truck AADT (FDOT, 2019b) on Martin Luther King Jr. Boulevard (i.e., Port Entrance) Applied with 2.5% Annual Growth Rate	302,232	302,232
Estimated Speed (mph)	Posted speed limits identified in Google Street View	35	35
Travel time (hours) per truck	Estimated with average speed and delays at traffic signals	0.25	0.18
Default value per truck hour saved	SHRP2 (2014)	$57	$57
Fraction of trucks assoc. with the Port	2018 FDOT Truck AADTs (FDOT, 2019b) on Blue Heron Boulevard and 45th Street (i.e., two main access points to the Port from I-95)	63%	63%

Table 29 shows the results of intermodal connectivity analysis. The project is expected to generate approximately $800,000 in time savings. The percent change in the weighted connectivity index (28%) is used to calculate productivity gains. This percent change is multiplied by the elasticity value of 0.005 (SHRP2, 2014) to estimate the % change in Gross Regional Product (GRP) attributed to improved connectivity.

Table 29 Results of 45th Street Interchange Intermodal Connectivity Analysis

Measurement Category	2040 No Build	2040 Build	Units
# of trucks associated with facility	190,406	190,406	Trucks
Truck hours – facility	47,602	34,273	Hours
Value of time – facility	$2,709,849	$1,951,091	US Dollars
Weighted connectivity index	6,486,227.5	4,670,083.8	Index
% Change in Weighted Connectivity index	28%		

Because GRP estimate is only available at the scale of a Metropolitan Statistical Area (MSA), GRP equivalent for the Palm Beach County was derived based on information for the Miami-Dade MSA. GRP to personal income ratio of 1.22 was calculated as shown in Table 30.

Table 30 GRP, Income, and GRP-to-Wage Ratio of Miami-Dade County

Miami Dade GRP 2016 (million$)	$146,200
per capita income 2016	$43,920
Miami Dade Population	2,736,500
Miami Dade Total Personal Income 2016 (million$)	$120,187
GRP/Personal Income ratio	1.22

Table 31 shows the process of productivity benefit estimation. The interchange improvement is expected to produce productivity benefits in $25 million.

Table 31 Productivity Benefits of Intermodal Connectivity to Port of Palm Beach

Measures	Values	Source/Method
Weighted Connectivity Index (WCI) % Improvement	28%	Table 15
Elasticity	0.005	SHRP2, 2014
% Change GRP	0.14%	WCI % change * Elasticity
Palm Beach total personal income 2016 (million$)	$101,947	Bureau of Economic Analysis
GRP/Personal Income Ratio	1.22	Table 16
2016 Palm Beach County GRP Equivalent (million$)	$124,375	Personal income *1.22
2040 Palm Beach County GRP Equivalent (million$)	$224,677	Consider 2.5% annual growth rate
% of Industry impact	8%	% of Manufacturing industry
GRP Affected (million$)	$17,974	Total GRP * % of industry affected
Productivity Benefit (million$)	**$25**	GRP affected * % Change in GRP

Market Accessibility

Market Accessibility for the proposed 45th Street interchange improvement is estimated with the same procedure as for the Central Boulevard Interchange. Figure 13 shows the FLSWM network and TAZs selected. It shows that the 45th Street interchange is in areas with higher density (i.e., more TAZ centroids) development than the Central Boulevard interchange.

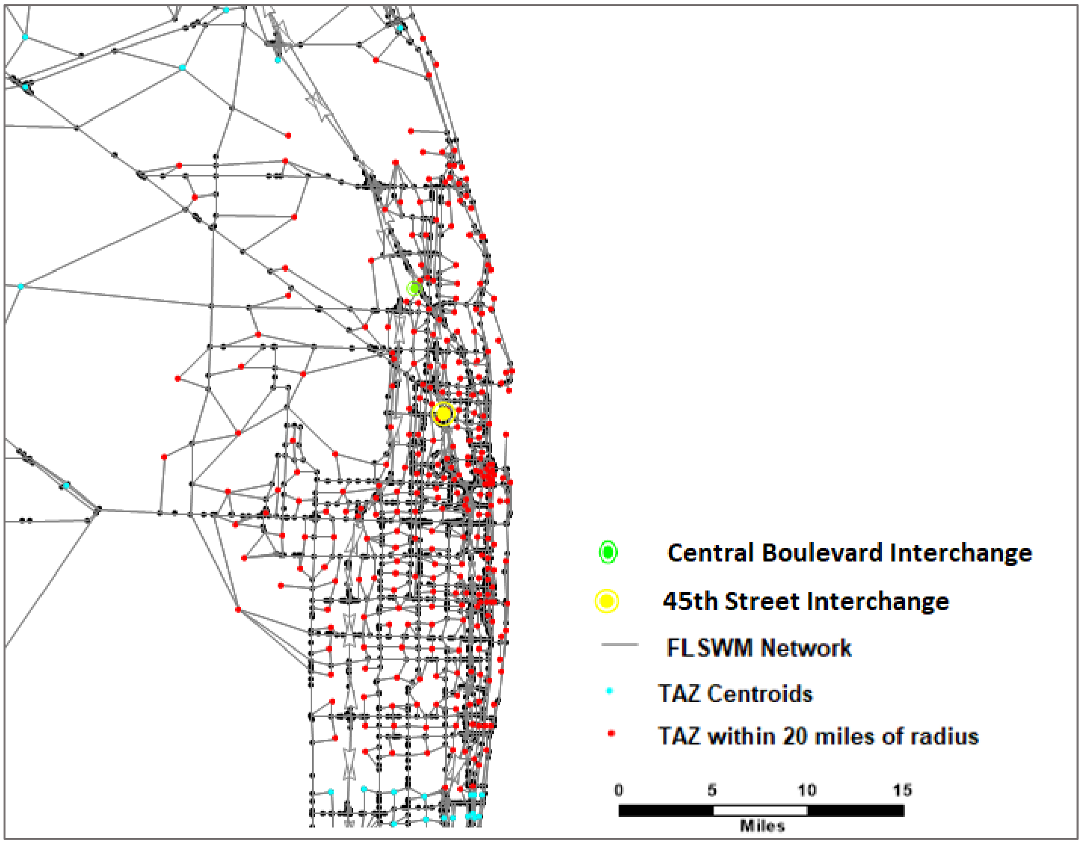

Figure 13 TAZs Located within 20-Mile Radius of the I-95/45th Street Interchange

For 2040 Build scenario, the congested travel speeds and travel times on the 45th Street in 2040 FLSWM network were then updated according to the plan documented in the 45th Street PD & E Study. Results of the market accessibility analysis is summarized in Table 32, which also include the same summary measures of the proposed Central Boulevard Interchange for comparison.

Table 32 Comparison of Market Accessibility between Central Boulevard and 45th Street Interchanges

	New Central Boulevard Interchange	Existing 45th Street Interchange Improvement
Number of TAZs within the 20-miles radius	257	291
2040 No Build Average TAZ-to-TAZ congested travel time (minutes)	23.53	23.08
2040 Build Average TAZ-to-TAZ congested travel time (minutes)	23.36	23.06
2040 No Build Average TAZ Zonal Effective Density	46,498	50,065
2040 Build Average TAZ Zonal Effective Density	46,695	50,182
Annual Total Productivity (million$)	**5.98**	**3.43**

Table 32 shows that the annual productivity gain from improvement of the existing 45th Street interchange is expected to be 3.43 million dollars, which is less than what is expected from the new Central Boulevard interchange at 5.98 million dollars. The reason for the difference is in the amount of travel time reduction. The new Central Boulevard interchange will create a new access point to I-95, which will shorten congested travel time significantly for many TAZs in the vicinity of the new interchange. On the other hand, the improvement on the existing 45th Street interchange will only result in a small amount of travel time reduction on 45th Street at the interchange. Thus, only a small amount of reduction in average TAZ-to-TAZ travel time is expected between the 2040 No Build and 2040 Build scenarios. Consequently, the increase in effective density from 2040 No Build to 2040 Build scenarios is also small, resulting in smaller annual total productivity than the Central Boulevard interchange project.

5.3 Port Miami Tunnel

5.3.1 Project Description

The Port of Miami Tunnel is a 4,200 feet undersea tunnel in Miami, Florida (FDOT, 2011). It consists of two parallel tunnels (one in each direction) that travel beneath Biscayne Bay, connecting the MacArthur Causeway on Watson Island with Port Miami on Dodge Island (See **Figure 14**). Prior to the tunnel's opening to traffic in August of 2014, cargo trucks and cruise tour buses accessing the port had to go through the same streets that serve Miami's downtown areas. The tunnel provides direct access for these trucks and buses from I-95 to the Port, thus avoiding delay caused by congestion in downtown Miami.

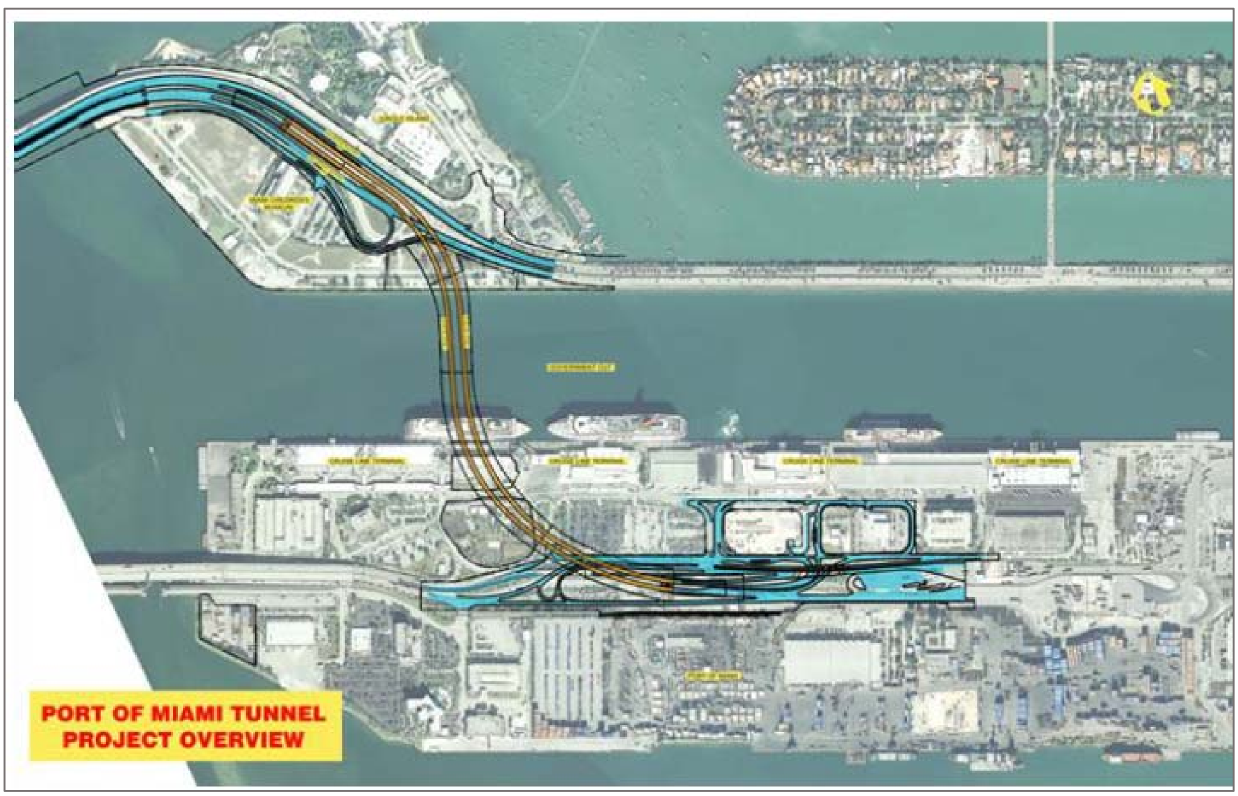

Figure 14 Port Miami Tunnel (Source: portofmiamitunnel.com)

5.3.2 Intermodal Connectivity

The same procedure for intermodal connectivity analysis as described in the previous case study was used for the Port of Miami Tunnel. Port data used to estimate freight connectivity index are shown in Table 33.

Table 33 Parameters for Port of Miami Freight Connectivity Index Calculation

Parameters	Sources	Updated Values for Port of Palm Beach, FL
Total tons (Bulk cargo)	U.S. Army Corps of Engineers, Waterborne Tonnage for U.S. Ports in 2016 (USACE, 2016a)	8,026,654
Total number of containers		778,817
Average value per ton	Bureau of Transportation Statistics, Freight Analysis Framework (BTS, 2019)	$522
Average value per container		$51,626
Number of unique port destinations and origins (Bulk cargo)	U.S. Army Corps of Engineers, Vessel Entrances and Clearances Data (USACE, 2016c)	56
Number of unique port destinations and origins (Containers)		52

Table 34 shows the input data sources and specific values applied to estimate intermodal connectivity improvement from the Tunnel and

Table 35 shows the results of intermodal connectivity analysis.

Table 34 Input Data for Port Miami Tunnel Intermodal Connectivity Analysis

Data	Sources	2040 No Build	2040 Build
Distance of Improvement from Facility (miles)	Measured in Google Map	0.1	0.1
Annual number of trucks within study area	2018 FDOT Truck AADT (FDOT, 2019b) of the Tunnel. Applied with 2.5% Annual Growth Rate	1,894,969	1,894,969
Estimated Speed (mph)	Posted speed limits	40	60
Travel time (hours) per truck	No Build travel time estimated with average speed and delays at signals from I-95 to the Port via downtown streets. Build travel time estimated with average speed from I-95 to the Port via the tunnel.	0.5	0.25
Default value per truck hour saved	SHRP2 (2014)	$57	$57
Fraction of trucks assoc. with the Port	Tunnel connected to the Port directly	100%	100%

Table 35 Results of 45th Street Interchange Intermodal Connectivity Analysis

Measurement Category	2040 No Build	2040 Build	Units
# of trucks associated with facility	1,894,969	1,894,969	Trucks
Truck hours – facility	947,485	473,742	Hours
Value of time – facility	$53,938,118	$26,969,059	US Dollars
Weighted connectivity index	1,127,732,641	563,866,321	Index
% Change in Weighted Connectivity index	50%		

Productivity gain resulting from the 50% weighted connectivity increase is derived for both Miami-Dade and Broward counties. The results are shown in Table 36, which also include the same metrics of the 45th Street interchange project for comparative purpose. Table 36 shows that Port of Miami tunnel is expected to generate a productivity of 81 million dollars annually, while that of the 45th Street interchange improvement is significantly smaller at 25 million dollars. The difference in the estimated number comes from two sources. First, Port of Miami serves a region with higher GRP than Port of Palm Beach. Second, the Port of Miami tunnel provides direct access to the Port that reduces more travel time between No Build and Build scenario than the 45th Street interchange.

Table 36 Comparison of Intermodal Connectivity Benefits between Port Miami Tunnel and 45th Street Interchange

	Port Miami Tunnel	45th St. Interchange
WC Index % Improvement	50%	28%
Elasticity	0.005	0.005
% Change GRP	0.25%	0.14%
2040 Miami Dade GRP + 2040 Broward GRP Equivalent (million $)	$460,126	$224,677
% of Industry impact	7%	8%
GRP Affected (million$)	$32,208	$17,974
Productivity Benefit (million$)	$81	$25

6. TOOL DEVELOPMENT

Given the framework and methodology described earlier in the report and based on the experienced obtained through the case study, we developed a spreadsheet-based tool to help FDOT conduct BCA analysis and prioritize freight-related project. This Freight BCA WEB Analysis Tool integrates standard BCA with analysis tools for Wider Economic Benefits, including reliability, market accessibility, and intermodal connectivity. This section provides instructions on how to use the spreadsheet. Detailed description of the analysis methodologies and result interpretation can be found in the previous chapters of the report. A quick reference for users to look up sources of all input data is provided in the Appendix.

The Excel workbook contains 12 worksheets. To save workspace, only 4 worksheets are active upon opening the workbook for the first time. Other hidden worksheets can be activated for specific analyses or viewing results when necessary. The workbook contains the following worksheets:

Active worksheets

- Project Information
- Parameters
- Benefit-Cost Analysis (BCA) Inputs
- Summary Results

Hidden worksheets

- Reliability
- Accessibility
- Intermodal Connectivity
- Costs Calculation
- TravelTimeSaving
- OperationCost
- AccidentCost
- EmissionCost

6.1 Project Information

The Project Information worksheet (Figure 15) lets users enter identification information about the project. The Project Type dropdown list is intended to help users determine which analysis tools are appropriate for a specific type of project. Selecting an individual project type will check analysis tools that are applicable for that project type. For example, selecting project type Roadways – Capacity Expansion/Congestion Reduction will check Benefit-Cost Analysis and Reliability Analysis, and at the same time, uncheck Market Accessibility and Intermodal Connectivity (Figure 16).

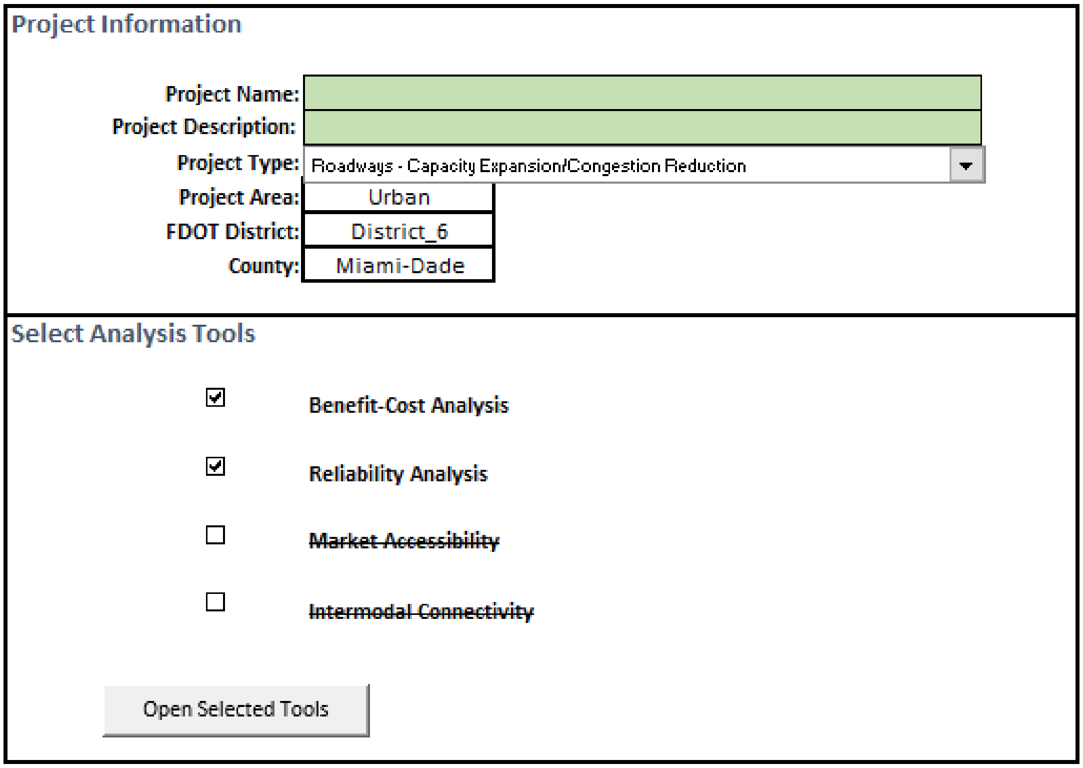

Figure 15 Project Information Worksheet

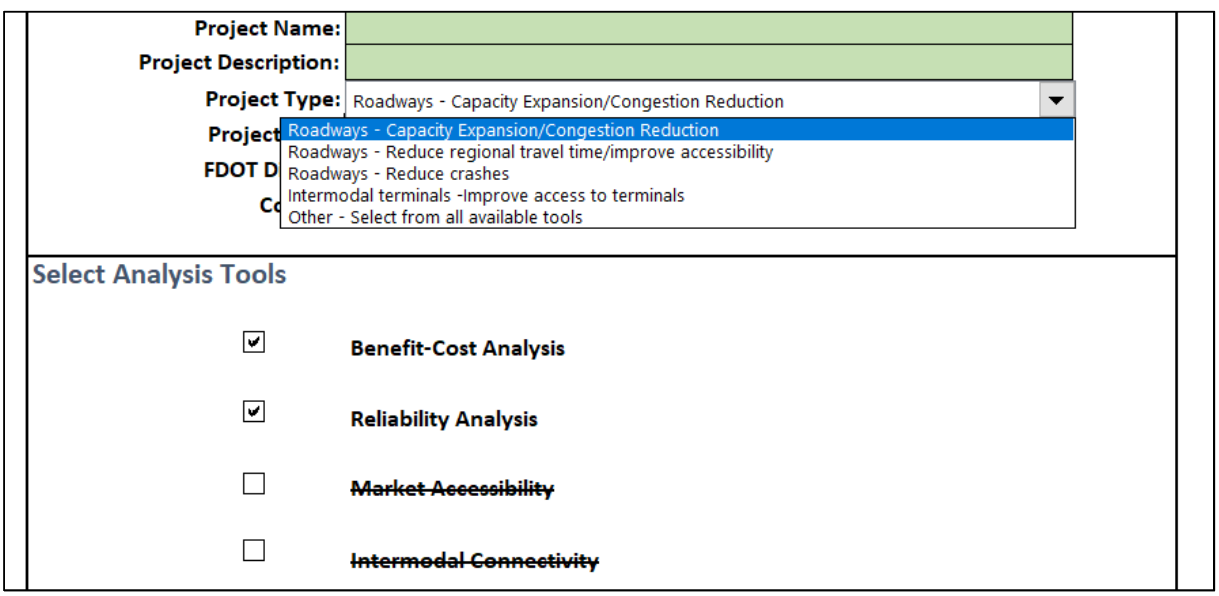

Figure 16 Selecting Analysis Tools by Project Type.

Users can also overwrite the recommended tool selection by manually checking or unchecking the analysis checkboxes. Once the desired analysis tools are checked, clicking at the Open Selected Tools button will activate (unhide) the initially hidden worksheets for data entry and calculations.

6.2 Parameters

The parameters worksheet contains default values used for standard BCA. Most of these parameters are recommended by USDOT in the latest Benefit-Cost Analysis Guidance for Discretionary Grant Programs (USDOT, 2018). The accident rates are the averages of available data in the last three years (i.e., 2016, 2016, and 2017), obtained from the Florida Highway Safety and Motor Vehicles (FHSMV, 2018). These accident rates can be edited when users have valid crash data that are specific for the project location. Emission factors are from EPA's MOVES model (USEPA, 2014). Note that emission factors for years past 2035 remain the same as those of year 2035 as they are not available for implementation in this version of the tool. The emission factors and other parameter values should be edited when updated values become available. Table 37 summarizes the parameters and the sources.

Table 37 List of Parameters

Parameters	Source
Present Value Discount Rate	Benefit-Cost Analysis Guidance for Discretionary Grant Programs (USDOT, 2018)
Average Vehicle Occupancy	
Value of Time	
Vehicle Operating Cost per Mile	
Costs of Highway Accidents	
Costs for Pollutant Emissions	
Crash Frequencies per Vehicle Mile Traveled by Injury Types	Florida Traffic Crash Facts Annual Report 2017 (FHSMV, 2018)
Emission Factors (grams/mile) by Pollutants	MOtor Vehicle Emission Simulator (MOVES) (USEPA, 2014)

6.3 Benefit-Cost Analysis Inputs

The Benefit-Cost Analysis Inputs worksheet contains four data entry tables: Analysis Scenario, Costs by Year, Traffic Data, and the optional Crash Modification Factor.

Analysis Scenario

The Analysis Scenario table (Table 38) contains essential data required for BCA of the project.

Table 38 Analysis Scenario Table

Analysis Scenario	
Base Year:	2020
Project Open Year:	2023
Analysis Time Horizon:	30
Forecast Year:	2052
Project Length (Miles):	3.4

Base Year refers to the year in which grant money begins to be applied to the project and construction starts. Project Open Year is the year in which the project is scheduled to be opened for use. Analysis Time Horizon sets the number of years to perform the BCA. The dropdown list contains three typical values for a BCA: 20, 25, and 30 years. Forecast Year is the final year of the BCA and is calculated with the following equation:

Forecast Year = Project Open Year + Analysis Time Horizon - 1

Project Length refers to the length of the roadway project in miles.

Costs by Year

The Costs by Year table (Table 39) contains cells for users to enter estimated one-time Capital Costs for construction and periodic Operating and Maintenance Costs in units of thousand US dollars in the currency of the year of analysis (e.g., 2019 dollars). Once users enter base year, project open year, and time horizon in the Analysis Scenario table, the spreadsheet automatically labels the cell by years, beginning with the base year and ending with the Forecast Year.

Table 39 Costs by Year Table

Costs By Year	1 2020	2 2021	3 2022	4 2023	5 2024	6 2025	7 2026	8 2027
Capital Costs (K$):	$1,130	$1,130	$1,130					
Operating & Maintenance Costs (K$):				$50	$50	$50	$50	$50

Traffic Data

To perform BCA for the project, users need to enter traffic data pertaining to the baseline (i.e., open year) and future BUILD vs. NO BUILD traffic conditions of the forecast year (Table 40).

Table 40 Traffic Data Table

Traffic Data	Open Year 2023	NO BUILD Forecast Year 2052	BUILD Forecast Year 2052
AADT:	119,211	142422	127156
%Truck:	8%	8%	8%
%Peak Period:	41%	41%	41%
%HOV (peak period):	15%	15%	15%
Average Peak Period Non-HOV Speed:	70	70	70
Average Peak Period HOV Speed:	70	70	70
Average Peak Period Truck Speed:	55	55	55
Average Non-peak Speed:	70	65	65
Average Non-peak Truck Speed:	55	65	65

These traffic data include traffic volumes and average speeds by vehicle types of HOV (High Occupancy Vehicles), non-HOV and trucks. They can be obtained from statewide (FDOT, 2019a) or the regional travel demand model such as the South East Regional Planning Model (FDOT, 2019b). Sketch planning approaches with existing AADT and an annual growth rate can also be used to estimate future traffic volumes. Table 41 contains definitions of the traffic data.

Crash Modification Factor (CMF)

For projects involving crash reduction measures, a CMF specific to the project can be entered. Reduced crash cost is then estimated with the following equation:

*Reduced Crash Cost = Vehicle Miles Traveled * Baseline annual rates by crash injuries per VMT * (1-CMF) * Expected cost per injury incidence*

The Crash Modification Factor Clearinghouse hosted by the Federal Highway Administration (FHWA, 2017) contain CMFs for various types of highway projects.

Table 41 Traffic Data Definitions

Traffic Data	Definition
AADT	Annual Average Daily Traffic (AADT) on the segment that are affected by the project.
%Truck	The share (in percent) of AADT that is truck traffic.
%Peak Period	The share of AADT that occurs during the peak period, which is defined by the hours when HOV lanes are in operation (e.g., 7-9 am and 3-6 pm for a total of 5 hours). If the project involves HOV lanes, users need to identify the specific number of hours of the peak periods. For projects that don't have HOV lanes, peak period can be defined as the morning and evening peak hours (i.e., 7-9 am and 4-6 pm) when the average speeds are significantly lower than non-peak hours.
%HOV (peak period):	The share of HOV in peak period traffic volume. For projects with no HOV lanes, this number is simply zero and all traffic are either non-HOV or trucks.
Average Peak Period Non-HOV Speed:	Average travel speed of non-HOV vehicles during peak period in miles per hour.
Average Peak Period HOV Speed:	Average travel speed of HOV vehicles during peak period in miles per hour.
Average Peak Period Truck Speed:	Average travel speed of trucks during peak period in miles per hour.
Average Non-peak Speed:	Average travel speed of passenger cars during non-peak period in miles per hour. Note that there is no distinction between HOV and non-HOV during non-peak hours as HOV lanes are accessible by all vehicles.
Average Non-peak Truck Speed:	Average travel speed of trucks during non-peak period in miles per hour.

6.4 Reliability

The Reliability worksheet implements analysis methods of the Reliability Analysis Tool developed for the Second Strategic Highway Research Program (SHRP2) Project C11 (SHRP2, 2014). Users are referred to the full report of this project and the user guide of the SHRP2 tool (SHRP2, 2013b) for technical details of the analysis methods. A summary of the input data is provided here to facilitate data entry. Table 42 shows the data entry table for the reliability analysis tool. Table 43 provides definitions for all the input variables for reliability analysis.

Table 42 Reliability Analysis Input Data

Reliability Analysis Input Data	NO BUILD Forecast Year 2052	BUILD Forecast Year 2052
AADT:	142,422	127,156
%Truck in traffic:	8%	8%
Highway types:	Freeways and multilane highways	Freeways and multilane highways
Project length:	3.4	3.4
Number of lanes:	4	6
Free flow speed:	65	65
HCM peak capacity:		
Terrain (Enter if HCM peak capacity unknown):	Flat	Flat
G/C (Enter for signalized arterial):	0.45	0.45
Unit cost of passenger travel time ($/hour):	$14.80	$14.80
Unit cost of commercial travel time ($/hour):	$28.60	$28.60
Reliability ratio of passenger cars:	0.80	0.80
Reliability ratio of commercial trucks:	1.10	1.10

Table 43 Reliability Analysis Data Definitions

Data	Definition
AADT	Annual Average Daily Traffic of the project. The value of this cell is referenced from the Benefit-Cost Analysis Input worksheet.
%Truck in traffic	The share (in percent) of AADT that is truck traffic. Referenced from the Benefit-Cost Analysis Input worksheet.
Highway types	• Freeways and multilane highways • Two-lane rural highways • Signalized arterials
Project length	The length of the project in miles. Referenced from the Benefit-Cost Analysis Input worksheet.
Number of lanes	The number of lanes in one traffic direction (does not apply to Two-lane Rural).
Free flow speed	The average speed that a vehicle would travel if there is no congestion or other adverse conditions. Measured in mile per hour.
HCM peak capacity	Peak hour capacity of the project roadway estimated with methods of Highway Capacity Manual (HCM).
Terrain (Enter if HCM peak capacity unknown)	If HCM capacity is not available, for freeways, multilane highways, and two-lane rural highways, capacity of the project can be estimated with the terrain where the project is located: • Flat • Rolling • Mountainous
G/C (Enter for signalized arterial)	Effective green time divided by cycle length) for signalized arterials. Enter this value to estimate peak capacity of the roadway if HCM capacity is not available.
Unit cost of passenger travel time ($/hour)	Default value recommended by USDOT (2018) is $14.8/hour.
Unit cost of commercial travel time ($/hour)	Default value recommended by USDOT (2018) is $28.6/hour.
Reliability ratio of passenger cars	The ratio of value of travel time reliability over value of travel time for drivers of passenger cars. Default value recommended by SHRP2 is 0.8.
Reliability ratio of commercial trucks	The ratio of value of travel time reliability over value of travel time for drivers of commercial trucks. Default value recommended by SHRP2 is 1.1.

6.5 Accessibility

The Accessibility worksheet implements analysis methods of the Accessibility Analysis Tool developed for the SHRP2 Project C11 (SHRP2, 2014). Technical details of the analysis methods and results interpretations are included in the user guide of the SHRP2 tool (SHRP2, 2013c). A summary of the input data and output variables are provided here to facilitate data entry. The Accessibility analysis worksheet contains three data entry tables: Zonal employment and Gross Regional Product (GRP) or GRP proxy of the study area, travel impedance matrix of the future NO BUILD scenario, and travel impedance matrix of the future BUILD scenario. Table 44 shows the data entry table for the Accessibility worksheet.

Table 44 Accessibility Analysis Data Entry Tables

Enter Accessibility Analysis Data

Analysis Parameters	
Constant Decay	1.00
Productivity Elas	0.03

Zone	2052 Employment	2052 GRP (or proxy)
1	6823	86.54393
2	156	86.54393
3	2517	86.54393
4	891	86.54393
5	928	86.54393
6	4045	86.54393
7	3905	86.54393
8	8219	86.54393
9	2425	86.54393
10	4450	86.54393
11	2181	86.54393
12	2282	86.54393
13	2408	86.54393
14	324	86.54393
15	667	86.54393
16	2285	86.54393
17	1049	86.54393
18	5756	86.54393
19	848	86.54393
20	1525	86.54393

Enter NO BUILD Impedance Matrix

	NO BUILD 2052 Impedance																			
Zone/Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1.42	###	###	###	###	2.83	###	###	###	###	###	###	###	###	###	###	46.11	###	31.19	###
2	35.95	1.42	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	18.71
3	34.43	###	0.89	###	###	###	3.02	6.68	3.50	3.63	6.98	5.04	7.43	8.24	7.91	9.27	###	7.94	3.46	###
4	18.70	###	###	0.64	3.31	17.19	###	###	###	###	###	###	###	###	###	###	###	11.79	###	13.12
5	22.01	###	###	3.31	0.39	###	15.18	###	###	11.45	12.15	###	18.17	###	###	###	###	8.60	9.49	11.41
6	2.83	###	###	17.19	###	0.99	###	###	###	###	###	###	###	###	###	###	###	###	###	###
7	36.87	###	3.02	###	15.18	###	0.66	5.03	4.49	5.81	6.72	4.58	5.69	6.50	6.17	7.62	9.93	10.13	6.08	###
8	40.57	###	6.68	###	###	###	5.03	1.10	7.36	8.73	9.59	7.45	7.52	7.82	8.00	2.59	5.54	###	9.79	###
9	34.19	###	3.50	###	###	###	4.49	7.36	0.77	1.54	4.67	2.53	6.16	6.98	6.64	9.95	###	7.45	3.41	11.95
10	33.14	17.61	3.63	###	11.45	###	5.81	8.73	1.54	0.77	4.18	3.22	7.53	8.34	7.99	11.32	###	6.40	2.36	###
11	32.88	18.41	6.98	###	###	###	6.72	9.59	4.67	4.18	1.26	2.52	6.18	7.52	6.28	12.19	###	3.87	5.92	7.65
12	35.37	###	5.04	###	###	###	4.58	7.45	2.53	3.22	2.52	1.26	5.98	7.07	6.08	###	###	6.39	5.52	9.82
13	37.61	###	7.47	###	###	###	5.73	7.52	6.20	7.56	6.22	6.02	0.68	2.43	1.45	9.72	11.78	###	9.61	###
14	38.92	###	8.28	###	19.14	###	6.54	7.82	7.01	8.38	7.25	7.05	2.43	0.48	1.24	###	###	11.12	###	12.16
15	37.69	###	7.95	###	17.91	###	6.21	8.00	6.68	8.01	6.30	6.10	1.45	1.24	0.49	###	###	10.11	###	11.07
16	43.16	###	9.27	###	###	###	7.62	2.59	9.95	11.32	12.19	###	9.48	###	9.96	1.26	2.95	###	###	###
17	46.11	###	###	###	###	###	9.93	5.54	###	###	###	###	11.54	11.89	###	2.95	1.07	###	###	###
18	30.02	###	7.95	11.79	8.60	###	8.85	11.72	6.79	5.74	3.77	6.21	9.95	11.29	###	14.31	###	0.81	4.89	6.65
19	31.19	###	3.46	###	9.49	###	6.08	9.79	3.41	2.36	5.92	5.52	9.57	###	###	###	###	4.89	1.02	11.52
20	29.70	###	###	13.17	###	###	###	###	11.53	###	7.14	9.34	###	11.81	###	###	21.21	6.13	###	0.32

Enter BUILD Impedance Matrix

	BUILD 2052 Impedance							
Zone/Zor	1	2	3	4	5	6	7	8
1	1.42	###	###	###	###	2.83	###	###
2	35.95	1.42	###	###	###	###	###	###
3	34.43	###	0.89	###	###	###	3.02	6.6
4	18.70	###	###	0.64	3.31	17.19	###	###
5	22.01	###	###	3.31	0.39	###	15.18	###
6	2.83	###	###	17.19	###	0.99	###	###
7	36.87	###	3.02	###	15.18	###	0.66	5.0
8	40.57	###	6.68	###	###	###	5.03	1.1
9	34.19	###	3.50	###	###	###	4.49	7.3
10	33.14	17.61	3.63	###	11.45	###	5.81	8.7
11	32.88	18.41	6.98	###	###	###	6.72	9.5
12	35.37	###	5.04	###	###	###	4.58	7.4
13	37.61	###	7.47	###	###	###	5.73	7.5
14	38.92	###	8.28	###	19.14	###	6.54	7.8
15	37.69	###	7.95	###	17.91	###	6.21	8.0
16	43.16	###	9.27	###	###	###	7.62	2.5
17	46.11	###	###	###	###	###	9.93	5.5
18	30.02	###	7.95	11.79	8.60	###	8.85	11.7
19	31.19	###	3.46	###	9.49	###	6.08	9.7
20	29.65	###	###	###	###	###	###	###

To perform accessibility analysis, users need to first divide the study area into analysis zones. Projection of forecast year employment can be obtained from either the regional travel demand models or from U.S. Census employment data applied with an appropriate annual growth rate. Projection of GRP information can usually be obtained from state or regional government. (e.g., Miami-Dade County). If GRP data are not available for the project county, GRP proxy derived from total wage of the county can be used. Descriptions of how GRP proxy can be estimated can be found in the next section (i.e., 6.6 Intermodal Connectivity).

Travel impedance refers to zone-to-zone travel time in the study area. Travel impedance matrices of the NO-BUILD and BUILD conditions are usually obtained from regional travel demand models. Chapter 5 of this report contains two case studies that illustrate how accessibility analyses can be performed with data from Florida statewide travel demand model. For projects in the rural area where the statewide or regional travel demand model does not have sufficient network coverage, sketch planning approaches with manual estimates of zone-to-zone travel time can also be made with local knowledge. A mapping application such as Google Maps can also be used to aid zone-to-zone travel time estimation.

6.6 Intermodal Connectivity

The Intermodal Connectivity worksheet implements analysis methods of the Connectivity Analysis Tool of the SHRP2 Project C11 (SHRP2, 2013d). This spreadsheet implementation of the connectivity tool contains two data entry tables: Connectivity Analysis Data (Table 45) and Project Location GRP Proxy Data (Table 46).

Table 45 Connectivity Analysis Data Table

Connectivity Analysis Data	NO BUILD Forecast Year 2052	BUILD Forecast Year 2052
Facility Type:	Marine	Marine
Facility Name:	Palm Beach	Palm Beach
Unit lift capacity (for Rail Freight Only):	50,000	50,000
Project Description:		
Distance of Improvement from Facility (miles):	10.00	10.00
Number of trucks within study area:	10,000	10,000
Hours per truck:	0.55	0.25
Default value per truck hour:	$56.93	$56.93
Default fraction of trucks with intermodal location:	0.63	0.63

Table 46 GRP Reference and GRP Proxy Data Table

Reference Gross Regional Product data	
Reference GRP year:	2,016
Miami Dade GRP:	$146,200,000,000
Miami Dade per capita income:	$43,920
Miami Dade Population:	2,736,500
Miami Dade total personal income:	$120,187,080,000
GRP/Wage ratio:	1.22

Project Location GRP Proxy Data	
Reference GRP year:	2,016
Project County:	Palm Beach
Perr capita income:	$70,241
Palm Beach County population:	1,453,800
Palm Beach County total personal income:	$102,116,365,800
Palm Beach County GRP equivalent:	$124,218,116,290
Growth Rate:	0.025
Palm Beach County GRP Equivalent 2052:	$302,164,954,727
% Industry impact:	8%

Table 47 contains definitions of the input data for analysis of connectivity improvement of the project.

Table 47 Connectivity Analysis Data Definitions

Data	Definitions
Productivity Elasticity	A parameter used to reflect how much GRP change can be resulted from change in weighted connectivity. The default value recommended by SHRP2 is 0.005.
Facility Type	Type of intermodal facility. Three different types of intermodal facilities can be analyzed: • Air (airports) • Marine (seaports) • Rail (train stations)
Facility Name	Name of the facility. Depending on the facility type selected, a list of existing facilities in the State of Florida will become available in the dropdown list. For example, if Marine is chosen, all seaports in the State of Florida are listed. (e.g., Miami, Palm Beach)
Unit lift capacity (for Rail Freight Only)	Annual number of containers handled at the rail terminals. This field is only applicable for rail facilities.
Project Description	Text descriptions of the project entered by the users.
Distance of Improvement from Facility (miles)	Distance of the transportation improvement from the intermodal facility being evaluated, in miles.
Number of trucks within study area	Annual number of trucks (for freight facilities) using the project segment.
Hours per truck	Hours required for a truck to access the intermodal facility from the project site. This value should be entered as the fraction of an hour (e.g., 10 minutes should be entered as 0.1667 or =10/60).
Default value per truck hour	Assumed value per truck hour accessing the intermodal facilities. For freight facilities, this value is a combined crew cost and freight logistics costs. The default value recommended by SHRP2 is $56.93.
Default fraction of trucks with intermodal location	This fraction assumes that the further away from the intermodal facility the improvement is, the less impact it will have on the intermodal facility. The default exponential distance decay function used to estimate the fraction (f) based on the distance of improvement from facility, d, is: $f = 1/(d)^{0.2}$ User can overwrite this default value if valid data is available.

Project Location GRP Proxy Data

Project Location GRP proxy refers to an estimate of the GRP for the county where the project is located. To estimate the productivity gain from improved intermodal connectivity, an estimate of the GRP for the county where the project is located is required. However, GRP estimates typically are only available for large metropolitan areas. For example, in southeast Florida, GRP data are available for Miami-Dade county. For projects located in counties that do not have such data, GRP proxy derived from total income of the project county can be used. To estimate GRP proxy, a reference GRP/Wage ratio is required. The spreadsheet provides the 1.22 GRP/wage ratio of Miami-Dade County as reference for counties that do not have GRP data (see Table 46).

To calculate GRP proxy, users are required to enter the per capita income and total population of the project county. GRP proxy (equivalent) for the county is then calculated as the total income of the county multiplied by the reference GRP/wage ratio of 1.22. An appropriate annual grow rate to project for the forecast year GRP is also required.

Users also need to enter a number for the % industry impact variable to estimate productivity gain of improved connectivity. % industry impact is the percentage of industries in the project county that is expected to be impacted by the improved intermodal connectivity. Typically, the types of industries impacted by an intermodal facility include transportation, warehousing and manufacturing. An appropriate % industry impact can be estimated by examining the project county's employment data by industries. The Bureau of Economic Analysis (BEA) provides a variety of data on regional income and employment (BEA, 2019b) that can be used for GRP and GRP proxy estimation. Users are referred to the two case studies in Chapter 5 of this report to learn how to obtain appropriate data for this analysis. Table 48 summarizes all the variables for the Project Location GRP proxy data tables.

Table 48 GRP Reference and GRP Proxy Data Definitions

Variables	
Reference Gross Regional Product data	
Reference GRP year	The year for which the reference GRP estimate was made. The reference county is Miami-Dade and the year is 2016.
Miami Dade GRP	The GRP estimate of Miami-Dade County in 2016 is $146,200,000,000.
Miami Dade per capita income	The per capita income of Miami Dade is $43,920.
Miami Dade Population	The population of Miami Dade County is 2,736,500
Miami Dade total personal income	Total personal income of Miami-Dade County is $120,187,080,000
GRP/Wage ratio	The ratio of GRP to total personal income on Miami-Dade County is 1.22.
Project Location GRP Proxy Data	
Reference GRP year	The year for which the reference GRP estimate was made.
Project county	The county where the project is located.
Per capita income	The per capita income of the project county in the reference year.
Project county population	The population of the project county in the reference year.
Project county total personal income	Total personal income of the project county in the reference year.
Project county GRP equivalent	The GRP proxy of the project county, which is total personal income of the county multiplied by the reference GRP/wage ratio.
Growth Rate	Annual growth rate to project GRP of the forecast year.
Project county GRP equivalent in forecast year	Projection of the GRP equivalent for the forecast year.
% Industry impact:	Percentage of industries in the project county that is expected to be impacted by the improved intermodal connectivity

6.7 Summary Results

A summary of the analysis results is provided in the Summary Results worksheet. Four summary tables are included in the worksheet, including BCA, reliability, accessibility, and intermodal connectivity (see Table 49 to Table 52). Two buttons are located on top of the worksheet for users to show and hide calculation worksheets used for Benefit-Cost Analysis (see Table 49). The NET PRESENT VALUE of the BCA summary table (Table 49) is the difference between the present values of the project's total benefits and costs. The net present value provides an indication for the project's cost effectiveness. The Total Benefits of total equivalent delay from the reliability analysis (Table 50), the total annual productivity of the accessibility analysis (Table 51), and the productivity gain of the intermodal connectivity analysis (Table 52) are additional indicators that can be used to assess the potentials for economic returns by investing in the project.

Table 49 Summary Table of BCA Results

Summary of Analysis Results   Show BCA Calculation Worksheets   Hide BCA Calculation Worksheets

Benefit Cost Analysis Summary	PRESENT VALUE OF USER BENEFITS					PRESENT VALUE OF PROJECT COSTS	NET PRESENT VALUE
Year	Travel Time Savings	Vehicle Operation Costs Savings	Accident Reductions	Vehicle Emission Reductions	Total Benefits		
Design & Construction							
2020						$1,130,000	($1,130,000)
2021						$1,056,075	($1,056,075)
2022						$986,986	($986,986)
Project Open							
2023	$193,526	$222,864	$174,305	$10,730	$601,426	$40,815	$560,611
2024	$362,027	$416,568	$325,804	$17,713	$1,122,113	$38,145	$1,083,968
2025	$507,935	$583,974	$456,735	$22,026	$1,570,670	$35,649	$1,535,020
2026	$633,471	$727,694	$569,140	$24,912	$1,955,216	$33,317	$1,921,899
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 50 Summary Table of Reliability Analysis

Reliability Analysis Results Total Annual Weekday Congestion Costs ($)	NO BUILD 2052	BUILD 2052	Total Benefits
Total Equivalent Delay	**$174,055**	**$141,872**	**$32,182**
Recurring Equivalent Delay	**$162,548**	**$132,982**	**$29,566**
Passenger Delay	$134,635	$110,028	
Commercial Delay	$27,913	$22,954	
Incident Equivalent Delay	**$11,506**	**$8,890**	**$2,616**
Passenger Delay	$8,954	$6,908	
Commercial Delay	$2,553	$1,982	

Table 51 Summary Table of Accessibility Analysis

Zone	2052 Effective Density	2052 Effective Density	2052 Zonal Productivity(K$)	2052 Total Annual Productivity
1	10980.29	10981.07	$1.259	**$13.912**
2	252.27	252.27	$0.000	
3	9626.94	9626.94	$0.000	
4	2606.75	2613.23	$5.736	
5	3835.28	3835.28	$0.000	
6	7883.56	7883.56	$0.000	
7	16006.98	16006.98	$0.000	
8	25692.25	25692.25	$0.000	
9	11175.17	11175.17	$0.000	
10	20228.87	20228.87	$0.000	
11	7564.97	7565.52	$0.414	
12	8608.38	8609.08	$0.476	
13	10407.88	10410.17	$1.374	
14	1580.43	1580.71	$0.146	
15	3491.84	3492.47	$0.312	
16	6410.64	6410.64	$0.000	
17	2646.74	2646.74	$0.000	
18	19681.99	19681.99	$0.000	
19	3099.67	3099.67	$0.000	
20	7135.05	7142.62	$4.194	

Table 52 Summary Table of Intermodal Connectivity Analysis

Connectivity Productivity Analysis Results	NO BUILD 2052	BUILD 2052
Number of annual trucks	10,000	10,000
Total truck hours (all trucks)	5,500	2,500
Total Value	$313,102	$142,319
Number of trucks associated with the facility	6,310	6,310
Time savings for facility	3,470	1,577
Value of time savings for facility	$197,554	$89,797
Weighted Connectivity	60,630	27,559
% Improvement in Weighted Connectivity		55%
Productivity Elasticity		0.005
% Change in GRP		0.27%
Palm Beach County GRP Equivalent 2052:		$302,164,954,727
% of Industry impact		8%
Palm Beach County GRP Affected in 2052:		$24,173,196,378
Productivity Gain in 2052:		**$65,926,899**

6.8 BCA Calculation Worksheets

The worksheets used to calculate results for the BCA are initially hidden in the spreadsheet workbook. These worksheets can be activated for review by clicking at the Show Calculation Worksheet button located on top of the Summary Results worksheet. The calculation worksheets include Costs Calculation, TravelTimeSaving, OperationCost, AccidentCost, and EmissionCost.

Cost Calculation contain calculation of present values for the capital costs and operating and maintenance costs that users entered on the Benefit-Cost Analysis Input worksheet. TravelTimeSaving worksheet contains calculations of benefits resulted from travel time savings due to the project's effectiveness. OperationCost includes calculations of operation cost reduction. AccidentCost and EmissionCost are for benefits of reduced crashes and reduced emissions. The equations used for the calculations are recommended by USDOT (USDOT, 2018). Detailed description of the equations can be found in previous chapters of this report.

7. CONCLUSIONS

With conclusion of this project, we accomplished three objectives established for the project:

1. Identify existing analytical methods to quantify reliability and other WEB (i.e., market accessibility and intermodal connectivity) associated with proposed highway and multimodal system improvements;
2. Develop a data-driven freight project prioritization framework, with considerations of both standard benefit-cost metrics and WEB; and
3. Develop a spreadsheet tool that can be used to perform analyses associated with the developed freight project prioritization framework.

The first objective is achieved with a comprehensive review and synthesis of existing research and practice in transportation project evaluation and prioritization. Methodologies for both standard benefit-cost analysis and WEB productivity estimation are examined in the review process. Our review of existing studies reveals that most of the existing project evaluation methodologies and analytical tools are not capable of capturing WEB of freight projects from improved travel time reliability, better accessibility to markets, and better connectivity to intermodal facilities. We identify two particular studies: FHWA's Freight Benefit/Cost Study (FHWA, 2008) and NCHRP Project 02-24 (NCHRP, 2014), that offer valid analytical methods and associated tools (e.g., Highway Freight Logistics Reorganization Benefits Estimation Tool and TREDIS) for quantifying the WEB of freight projects.

The second objective is accomplished with results from the literature review process. We develop a procedural analysis framework that integrates methods for estimating WEB of freight transportation projects into a standard BCA process that is consistent with requirements from funding authorities such as USDOT and FHWA. The BCA process recommended by FHWA is comprehensive and practical for quantifying the direct benefits of projects at the State or regional level. Consideration of WEB incorporates analytical elements from the aforementioned FHWA and NCHRP studies. We also recognized the importance of EIA in complementing BCA in addressing a project's effects in regional job market and economic growth. The framework is a strategic combination of these three elements: a standard BCA process, methods for quantifying WEBs, and integration with an EIA.

To demonstrate the practicability of the methodologies and framework, we conducted three case studies to show how the methodologies and the framework for the freight project prioritization decision support system can be implemented with real-world data. We selected three transportation projects in the State of Florida that are expected to generate wider economic benefits. The projects were selected based on their potential impacts on different aspects of wider economic benefits in reliability, connectivity, and productivity. Results of the case studies show that the analytic methods can be readily applied with publicly available data to generate metrics of BCA and the WEB of improved reliability, market accessibility, and intermodal connectivity.

With data and computational resources developed for the case studies, we accomplish the third objective by developing a spreadsheet tool that integrates standard Benefit-Cost Analysis (BCA) with analysis tools for Wider Economic Benefits, including reliability, market accessibility, and intermodal connectivity. A user guide for the tool is also developed and included in this report for users to learn how to use the tool.

With findings of this project and the spreadsheet tool developed, the next step toward a better practice of evaluating freight projects in the State of Florida is to begin implementing the developed project evaluation framework and conducting analyses using the spreadsheet tool in the project evaluation and prioritization process. In addition to metrics from a BCA that meets USDOT guidance, the spreadsheet tool can also produce WEB productivity metrics that enable decision makers to evaluate higher order long-term economic benefits beyond those offered by a BCA. We note that our spreadsheet tool is different from other existing tools in that elements of data entry and calculation for BCA and WEB are integrated, resulting in a streamlined process for all analyses, making evaluation of WEB more tractable than other existing tools. Together with the information and guidance presented in this report, a comprehensive evaluation of projects' cost-effectiveness and higher order economic benefits can be readily achieved with the framework and the spreadsheet tool.

For projects involving significant financial investment (e.g., those receiving federal funds) and/or those expected to generate significant direct and indirect economic benefits (e.g., improving regional accessibility to labor markets), EIA and risk analyses should also be conducted to complement the results of BCA. Such a comprehensive approach can ensure that long-term economic benefits of the projects can be fully considered during the project prioritization and selection process (USDOT, 2003). In the future, integration of the spreadsheet tool with elements of EIA and risk analyses can be considered. The integration is expected to produce a complete decision support system that can produce metrics for all elements of project evaluation and prioritization. Implementing the system with a GIS as an Internet application is another avenue that can further enhance the process of decision support for project evaluation and prioritization. Another potential area for future research is to conduct before-and-after analyses of WEB and EIA of transportation investments in the State of Florida. Results of such analyses can generate evidence to support the incorporation of higher order economic analyses in project evaluation. They can also help identify precise parameter values for WEB estimation in the State.

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APPENDIX – A Quick Reference of Sources for Input Data of The Spreadsheet Tool

<table>
<tr><th>Data</th><th>Source</th></tr>
<tr><td colspan="2">Parameter Worksheet</td></tr>
<tr><td>Present Value Discount Rate</td><td rowspan="6">USDOT Benefit-Cost Analysis Guidance for Discretionary Grant Programs
https://www.transportation.gov/office-policy/transportation-policy/benefit-cost-analysis-guidance-discretionary-grant-programs-0</td></tr>
<tr><td>Average Vehicle Occupancy</td></tr>
<tr><td>Value of Time</td></tr>
<tr><td>Vehicle Operating Cost per Mile</td></tr>
<tr><td>Costs of Highway Accidents</td></tr>
<tr><td>Costs for Pollutant Emissions</td></tr>
<tr><td>Crash Frequencies per Vehicle Mile Traveled by Injury Types</td><td>Florida Traffic Crash Facts Annual Report
https://www.flhsmv.gov/resources/crash-citation-reports/</td></tr>
<tr><td>Emission Factors (grams/mile) by Pollutants</td><td>1. EPA MOtor Vehicle Emission Simulator (MOVES)[a]
https://www.epa.gov/moves
2. FDOT Freight Rail Investment Calculator[b]

a. Involves running MOVES to obtain latest projections of the factors
b. Contains the same emission factors that can be directly applied</td></tr>
<tr><td colspan="2">Benefit-Cost Analysis Inputs Worksheet</td></tr>
<tr><td>AADT</td><td rowspan="4">1. Florida Traffic Online
https://tdaappsprod.dot.state.fl.us/fto/
2. Loaded networks of Florida statewide or regional travel demand models
https://www.fsutmsonline.net/index.php?</td></tr>
<tr><td>%Truck</td></tr>
<tr><td>%Peak Period</td></tr>
<tr><td>%HOV (peak period):</td></tr>
<tr><td>Average Peak Period Non-HOV Speed:</td><td rowspan="5">1. Loaded networks of Florida statewide or regional travel demand models
https://www.fsutmsonline.net/index.php?
2. Estimate with a volume delay function such as the Bureau of Public Roads (BPR) function[a]

a. See Calibration and Evaluation of Link Congestion Functions: Applying Intrinsic Sensitivity of Link Speed as a Practical Consideration to Heterogeneous Facility Types within Urban Network by Enock T. Mtoi and Ren Moses of Florida State University for an appropriate volume delay function:
https://fsu.digital.flvc.org/islandora/object/fsu:205142/datastream/PDF/download/citation.pdf</td></tr>
<tr><td>Average Peak Period HOV Speed:</td></tr>
<tr><td>Average Peak Period Truck Speed:</td></tr>
<tr><td>Average Non-peak Speed:</td></tr>
<tr><td>Average Non-peak Truck Speed:</td></tr>
<tr><td>Crash Modification Factor</td><td>FHWA Crash Modification Factors Clearinghouse
http://www.cmfclearinghouse.org/</td></tr>
</table>

Reliability	
AADT	See AADT in Benefit-Cost Analysis Inputs worksheet.
%Truck in traffic	See %Truck in Benefit-Cost Analysis Inputs worksheet.
Project length	Length of the project in miles. Referenced from the Benefit-Cost Analysis Input worksheet.
Number of lanes	The number of lanes in one traffic direction (does not apply to Two-lane Rural).
Free flow speed	Design speed of the highway project. If design speed is not available, the posted speed limit can be used.
HCM peak capacity	Peak hour capacity of the project roadway estimated with methods in Highway Capacity Manual (HCM). http://www.trb.org/Main/Blurbs/175169.aspx Can also be estimated with HCS 7. https://mctrans.ce.ufl.edu/mct/index.php/hcs/ If estimation of the HCM capacity cannot be done, this value can be skipped. Enter data for Terrain and G/C to obtain rough estimates of the peak capacity.
Terrain (Enter if HCM peak capacity unknown)	If HCM capacity is not available, for freeways, multilane highways, and two-lane rural highways, capacity of the project can be estimated with the terrain where the project is located: • Flat • Rolling • Mountainous
G/C (Enter for signalized arterial)	Effective green time divided by cycle length for signalized arterials. Enter this value to estimate peak capacity of the project roadway if HCM capacity is not available.
Unit cost of passenger travel time ($/hour)	Default value recommended in 2018 USDOT Benefit-Cost Analysis Guidance for Discretionary Grant Programs is $14.8/hour.
Unit cost of commercial travel time ($/hour)	Default value recommended in 2018 USDOT Benefit-Cost Analysis Guidance for Discretionary Grant Programs is $28.6/hour.
Reliability ratio of passenger cars	The ratio of value of travel time reliability over value of travel time for drivers of passenger cars. Default value recommended by SHRP2 is 0.8. http://www.tpics.us/tools/documents/SHRP-C11-Reliability-Tech-Doc-and-User-Guide.pdf
Reliability ratio of commercial trucks	The ratio of value of travel time reliability over value of travel time for drivers of commercial trucks. Default value recommended by SHRP2 is 1.1. http://www.tpics.us/tools/documents/SHRP-C11-Reliability-Tech-Doc-and-User-Guide.pdf

Accessibility	
Analysis Zones	1. Traffic analysis zones of the Florida statewide model or regional travel demand model https://www.fsutmsonline.net/index.php? 2. US Census geography (e.g., block groups or tracts). Download Census TIGER/Line Shapefile from: https://www.census.gov/cgi-bin/geo/shapefiles/index.php
Zonal employments	1. Baseline and future employment projection for the traffic analysis zones of the Florida statewide model or regional travel demand model https://www.fsutmsonline.net/index.php? 2. US Census employment data https://www.census.gov/topics/employment.html 3. US Bureau of Labor Statistics employment projection https://www.bls.gov/emp/
Impedance	1. Congested travel time between a pair of zones calculated with the Florida Statewide model or regional travel demand model network https://www.fsutmsonline.net/index.php? 2. Manually estimate zone-to-zone congested driving time using a mapping application (e.g., Google Maps) and local knowledge
Per worker GRP	1. GDP by county divided by total number of employments of the same county using data from Bureau of Economic Analysis (BEA) GDP by county: https://www.bea.gov/data/gdp/gdp-county-metro-and-other-areas Employment by county: https://www.bea.gov/data/employment/employment-county-metro-and-other-areas 2. GRP proxy by county divided by total number of employments of the same county using data from Bureau of Economic Analysis (BEA) See GRP proxy in Intermodal Connectivity for references of GRP proxy data
Impedance decay parameter	The default value 1.8 is suggested by SHRP2 Project C11 in Accessibility Analysis Tool: Technical Documentation and User's Guide. http://www.tpics.us/tools/documents/SHRP-C11-Accessibility-Tech-Doc-and-User-Guide.pdf
Productivity Elasticity	The default value 0.03 is suggested by SHRP2 Project C11 in Accessibility Analysis Tool: Technical Documentation and User's Guide. http://www.tpics.us/tools/documents/SHRP-C11-Accessibility-Tech-Doc-and-User-Guide.pdf

Intermodal Connectivity	
Productivity Elasticity	A parameter used to reflect how much GRP change can be resulted from change in weighted connectivity. The default value 0.05 is suggested by SHRP2 Project C11 in Connectivity Analysis Tool: Technical Documentation and User's Guide. http://www.tpics.us/tools/documents/SHRP-C11-Connectivity-Tech-Doc-and-User-Guide.pdf
Unit lift capacity (for Rail Freight Only)	Annual number of containers handled at the rail terminals. This field is only applicable for rail facilities. Uplift capacity of the facility can be obtained from the web site of the facility or by contacting the facility directly.
Distance of Improvement from Facility (miles)	Distance of the transportation improvement from the intermodal facility being evaluated, in miles. The distance can be measured in a mapping application such as Google Maps.
Number of trucks within study area	Annual number of trucks (for freight facilities) using the project segment. The number can be obtained from %Truck of the AADT on the study segment, using data from FDOT's Florida Traffic Online: https://tdaappsprod.dot.state.fl.us/fto/
Hours per truck	Hours required for a truck to access the intermodal facility from the project site. This value should be entered as the fraction of an hour (e.g., 10 minutes should be entered as 0.1667 or =10/60). The travel time required to access the facility can be estimated by dividing the distance measured a mapping application such as Google Maps with estimated driving speed on the study segment.
Default value per truck hour	Assumed value per truck hour accessing the intermodal facilities. For freight facilities, this value is a combined crew cost and freight logistics costs. The default value $56.93 is suggested by SHRP2 Project C11 in Connectivity Analysis Tool: Technical Documentation and User's Guide. http://www.tpics.us/tools/documents/SHRP-C11-Connectivity-Tech-Doc-and-User-Guide.pdf
Default fraction of trucks with intermodal location	This fraction assumes that the further away from the intermodal facility the improvement is, the less impact it will have on the intermodal facility. The default exponential distance decay function used to estimate the fraction (*f*) based on the distance of improvement from facility, *d*, is: $f = 1/(d)^{0.2}$ User can overwrite this default value if valid data is available.

Reference Gross Regional Product data	
Reference GRP year	The year for which the reference GRP estimate was made. The reference county is Miami-Dade and the year is 2016.
Miami Dade GRP	The GRP estimate of Miami-Dade County (MDC) in 2016 is $146,200,000,000. Periodic estimate of GRP of MDC is available from the county government: https://www.miamidade.gov/stateofthecounty/economic-development.asp
Miami Dade per capita income	The per capita income of Miami Dade is $43,920. This can be obtained from US Census Quick Facts: https://www.census.gov/quickfacts/fact/table/US/INC910218
Miami Dade Population	The population of Miami Dade County is 2,736,500. This can be obtained from US Census Quick Facts: https://www.census.gov/quickfacts/fact/table/US/INC910218
Miami Dade total personal income	Total personal income of Miami-Dade County is $120,187,080,000. This is estimated by multiplying the county population with per capita income.
GRP/Wage ratio	The ratio of GRP to total personal income on Miami-Dade County is 1.22.
Project Location GRP Proxy Data	
Per capita income	The per capita income of the project county in the reference year. This can be obtained from US Census Quick Facts: https://www.census.gov/quickfacts/fact/table/US/INC910218
Project county population	The population of the project county in the reference year. This can be obtained from US Census Quick Facts: https://www.census.gov/quickfacts/fact/table/US/INC910218
Growth Rate	Annual growth rate to project GRP of the forecast year. This can be a projection made by the regional governments. If such projection is not available, it can be estimated with trend exhibited by historic personal income level data from the Bureau of Economic Analysis: https://www.bea.gov/data/income-saving/personal-income-county-metro-and-other-areas
% Industry impact:	Percentage of industries in the project county that is expected to be impacted by the improved intermodal connectivity. This can be estimated by the % of industries that can benefits from the intermodal project. The employment by county data from the Bureau of Economic Analysis can be used to estimate the %: https://www.bea.gov/data/employment/employment-county-metro-and-other-areas