Life Cycle Costs and Benefits Analysis of Freight Transportation

Final Report

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Report prepared for:

Florida Department of Transportation Research Center

October 29, 2020

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DISCLAIMER

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation.

UNITS CONVERSION

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOLL
Length				
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOLL
Area				
in2	squareinches	645.2	square millimeters	mm2
ft2	squarefeet	0.093	square meters	m2
yd2	square yard	0.836	square meters	m2
ac	acres	0.405	hectares	ha
mi2	square miles	2.59	square kilometers	km2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
Volume				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft3	cubic feet	0.028	cubic meters	m3
yd3	cubic yards	0.765	cubic meters	m3
NOTE: volumes greater than 1000 L shall be shown in m3				

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
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")

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	℃

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m2	cd/m2

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

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
AREA				
mm2	square millimeters	0.0016	square inches	in2
m2	square meters	10.764	square feet	ft2
m2	square meters	1.195	square yards	yd2
ha	hectares	2.47	acres	ac
km2	square kilometers	0.386	square miles	mi2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m3	cubic meters	35.314	cubic feet	ft3
m3	cubic meters	1.307	cubic yards	yd3

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
TEMPERATURE (exact degrees)				
℃	Celsius	1.8C+32	Fahrenheit	°F

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m2	candela/m2	0.2919	foot-Lamberts	fl

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised June 2020)

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16. Abstract

Freight plays an increasing role in the national, state, and local economy. However, the life-cycle costs and benefits of freight investments are difficult to quantify, and there is a lack of specific tools to evaluate the potential benefits of freight investment projects.

In this research, we developed and implemented a methodology to evaluate life-cycle costs and benefits of freight transportation projects based on our previously developed economic impact analysis tool, FreighTEC. A post-processing tool, FreighTEC 2.0, is developed to assist the project prioritization process for the Florida Department of Transportation (FDOT) based on the freight forecast model -- Freight Supply-chain Intermodal Model (FreightSIM). The FreighTEC 2.0 considers costs of the entirely life-cycle of freight investment projects, including planning, construction, operation and maintenance, and estimates the direct benefits to the users and economic impacts to the impacted county (i.e. local impacts) and state as a whole (i.e., state impacts).

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EXECUTIVE SUMMARY

Background statement

Freight plays an increasing role in the national, state, and local economy. However, the life-cycle costs and benefits of freight investments are difficult to quantify, and there is a lack of specific tools to evaluate the potential benefits of freight transportation investments. Traditional cost-benefit analysis focuses on the cost and direct benefits of building specific facilities at the project level, which is insufficient to understand the broader impacts of freight transportation investments on the local and state economy.

Freight transport can significantly enhance the efficiency of goods and cargo movement by connecting markets and businesses from different regions and locations and therefore could stimulate local and regional economic growth. Improvements on freight transportation such as freight route improvement or freight service enhancement will lead to more efficient deliveries through reducing travel time and operation costs, thus directly and indirectly reduce the production costs of goods. Increased freight efficiencies could also be translated into industry productivity and potentially influence economic growth, regional employment, or other socio-economic developments. Therefore, it is essential for decision-makers to better understand the interaction of freight and regional or local economy and to make more informed decisions in freight transportation investments.

Project objective(s)

To evaluate the potential benefits of freight investments, the life-cycle costs and benefits, as well as economic impacts of a freight investment need to be quantified. However, given the implicit impacts of transportation investments and the difficulty to quantify all-related life-cycle costs on transportation systems, existing transportation analysis framework mainly employs traditional cost-benefit analysis approach to evaluate proposed transportation projects. Although increasingly state department of transportations (DOTs) are using activity-based models to evaluate alternative transportation projects, there is a lack of a standardized methodology and a separate tool to evaluate the associated economic benefits of freight-related projects. This creates tremendous work and uncertainties for DOTs to evaluate individual

freight investment project. Therefore, to better understand the potential benefits and costs of freight investments and make informed decisions, there is a need for the study on the life-cycle costs and benefits analysis for freight transportation projects.

The overall goal of this project is to develop and implement the methodology to evaluate life-cycle costs and benefits of transportation projects as well as economic impacts on the local and state economy based on the economic analysis tool (FreighTEC) developed in a previous project. The new methodology and tool are developed to further quantify the life-cycle costs and benefits, and the economic impacts of freight projects and to assist the project prioritization process for the Florida Department of Transportation (FDOT) based on the economic input-output model and results of the Freight Supply-chain Intermodal Model (FreightSIM).

Research outcomes

In this research, we developed and implemented a methodology to evaluate life-cycle costs and benefits of freight transportation projects based on our previously developed economic impact analysis tool, FreighTEC. A post-processing tool, FreighTEC 2.0, is developed to assist the project prioritization process for the Florida Department of Transportation (FDOT) based on the freight forecast model -- Freight Supply-chain Intermodal Model (FreightSIM). The FreighTEC 2.0 considers costs of the entirely life-cycle of freight investment projects, including planning, construction, operation and maintenance, and estimates the direct benefits to the users and economic impacts to the impacted county (i.e. local impacts) and state as a whole (i.e., state impacts). The Python-based tool FreighTEC 2.0 has been tested in three case studies, and the results appeared to be reasonable.

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ABBREVIATION

Abbreviation	Stands For
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average daily traffic
BCA	Benefit-cost analysis
DOT	Department of Transportation
EIA	Economic impact analysis
ESAL	Equivalent single axle loads
FAF	Freight Analysis Framework
FDM	Freight Demand Model
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FreightSIM	Freight Supply-chain Intermodal Model
FreighTEC	Florida Freight Transportation Economic Impact Kit
IO	Input-Output
LCCA	Life-cycle cost analysis
MPO	Metropolitan Planning Organizations
PPM	Pavement Performance Model
RSL	Remaining service life
SEMCOG	Southeast Michigan Council of Government
VHT	Vehicle Hours of Travel

1. Literature review

1.1 Background

Freight travel has been a major component of travel demand. Millions of trucks move over the highway system every day to meet the needs of individuals and businesses. The freight volume has been increasing significantly over the past decades. For example, in the United States, today's freight movement in terms of tonnage of goods has increased by over 70% compared to that in 1998 (Mallett et al., 2004). On the other side, businesses and individuals are expecting a more fixable and timely freight transportation service. The growth of freight movement is placing enormous pressure on the increasingly congested transportation system. To maintain and improve the freight service for consumers, transportation planners and decisionmakers are paying attention to congestions on freight transportation and the needs for freight investment. Therefore, a better understanding of the cost and benefit of transportation projects during its life cycle would be crucial for freight relayed policy-making (U.S. DOT, 2017).

The development of freight transportation in the US has some emerging characteristics. According to the *USDOT's* draft national freight strategic plan (2015), current freight transportation are facing the challenges of increasing freight tonnage, underinvestment in freight system, and difficulties in planning and implementing freight projects, which result from future urbanization, high investment, and decentralized freight-related agencies, respectively (FWHA, 2004). Freight investments can reduce the travel cost of freight transportation, which will improve the competitiveness of local businesses. Analytic tools for project planning, reviewing, and permitting are highly encouraged to expedite transportation project delivery (FWHA, 2004). Improvements in data collection and modeling tools for freight projects analysis would benefit the understanding of freight trends and render informed decisions on freight investments. Due to the limited established funds for freight transportation projects, freight targeted investments must be effective in improving the movement of freight and meet the economics of regional goals. New and better methods to evaluate benefit and cost of freight improvements and investments are necessary for local

Metropolitan Planning Organizations (MPOs) and State Department of Transportations (DOTs) (O'Rourke, Beshers, & Stock, 2015).

Florida's population has increased over 6 million since 2000 and will continue to grow in the near future (FDOT, 2009). In addition, over 98.7 million visitors and tourists are attracted to Florida each year. Freight transportation plays a major role to meet the daily needs of local people in Florida. There has been growing recognition that the increase of travel demand would negatively affect the performance of freight transportation (FDOT, 2009). The Florida DOT (FDOT) develops a 5-year work program to manage the state's transportation working plan to meet the increase in transportation demand (FDOT, 2012). As discussed in the earlier project, economic impacts of transportation investments include increases in employment, business output, added value, and personal income. Our previous FDOT project mainly addresses the economic impacts of transportation improvement projects on the local economy. Although the developed freight analysis tool is able to reflect the economic impacts of freight investment for different industry sectors, it cannot measure the benefits and costs over the lifetime of transportation investments. Therefore, the current model has a shortage to compare the economic benefits of alternative transportation projects. To close the gap between evaluating economic impacts of transportation projects and measuring the cost-benefit of alternative projects, this part of the study provides a review of existing research and practices in addressing the economic impact analysis (EIA) and benefit-cost analysis (BCA).

Transportation investments affect transportation system performance through transportation system capacity, efficiency, reliability, and level of service. The improvements in the transportation system would lead to cost-saving and transit time saving, which could be captured by a BCA. Moreover, changes in production cost would also result in business changes in the long run, such as business growth, relocation, and reconstructing, etc. When evaluating the economic impacts of transportation investments, it is important to consider the supply chain effects, including the first-order effects and second-order effects. The first-order effects include cost saving in freight transportation. The second-order effects refer to the

business changes related to the increased freight volume. The Federal Highway Administration (FHWA) suggests including secondary-order effects into freight benefit and cost analysis (FWHA, 2015).

1.2 Data and modeling tools

Data availability is an important consideration for agencies to conduct the economic analysis of freight investments. Publicly available data sources may include the Freight Analysis Framework (FAF), the TIGER BCA guide, and State- and local-level freight data (O'Rourke et al., 2015). The nationwide FAF datasets include information on truck volumes by segments of freight highways and other types of roadways. Although national-level datasets provide a comprehensive picture of freight movement among states by all modes of transportation, it has difficulties to allocate freight flows to a smaller geographical region. The TIGER BCA guide is prepared by the FHWA for conducting BCA (FWHA, 2015). For example, the TIGER BCA guide suggests an average value of $25.75 per hour for freight truck travel time-saving. The cost of the truck is usually higher than other types of vehicles. While the average delay cost of trucks is $31.44 per hour, which is much higher compared to the $16.98 per hour for a medium-sized automobile. The reliability is then measured as the variance of transit time or average delay time, which could further incorporate into truck delivery to account for congestion by recurrent delays. The TIGER BCA guide also suggests monetary values for categories of long-term outcomes specified by the US DOT. They include (1) value of statistical life, (2) value of injuries, (3) property damage crashes, (4) value of travel time, (5) value of emissions. Examples of categories of monetary values include the value of statistical life ($9,400,000 in 2013 US dollars), the value of travel time ($25.8 per person-hour for trucks), and values of emissions (varies for pollutants), etc.

State-level and local-level freight data are important sources for local agencies to measure economic impacts. Some datasets can be used to measure local economic and transportation situation, while other datasets are integrated into the modeling tool to reflect the travel characteristics on the transportation network. Therefore, modeling tools are another important source to analyze the impacts of freight investment on the local economy. Transportation economic impacts are evaluated through a two-step

process. First, transportation impacts are usually represented through travel demand or freight demand model. Afterward, the outputs of a travel demand model serve as inputs of an economic model to measure economic impacts. Economic activities are usually reflected through changes in land uses, employment, or economic output, which further result in changes in freight supply and demand. Some agencies developed simplified economic analysis methods, such as a spreadsheet-based approach, for economic analysis (SEMCOG, 2012). Some agencies provide guidance, spreadsheet template, and sample values for conducting economic analysis (Minnesota DOT, 2018). Most of the existing studies use the four-step travel demand model to estimate future freight traffic volume on the transportation network. The four-step involves the trip generation, trip distribution, mode choice, and network assignment, which covers the number of trips, the origin, and destination of trips, the travel mode, and specific routes of trips. Simulation outputs from the four-step travel demand model are important input files to estimate costs and benefits of freight investments. More specifically, travel speed, travel delays, transit time, and traffic volume that are generated from the four-step travel demand model could be used to compare alternative transportation investments. Following is an introduction of some commonly used methods to evaluate the economic impacts of transportation projects.

1.3 Existing methods

Due to the unclear understanding of future rewards of freight projects, freight investments are underinvested and face challenges at the planning and implementing stages. Methods and modeling tools to measure the economic impacts of freight projects would be necessary. Currently, there are several types of analysis methods on freight projects: (1) Benefit-cost analysis (BCA), (2) Economic impact analysis (EIA), (3) Dynamic models, (4) Simplified approach, and (5) Life-cycle cost analysis (LCCA) (O'Rourke, Beshers, & Stock, 2015; US DOT, 2002). Not all methods are appropriate for all circumstances. Below is an introduction of each methods.

BCA evaluates whether freight investments are economically and socially beneficial through a standardized method to measure the value of different types of benefits at different points in time. The

future benefits and costs are discounted to present value to measure alternative projects(Jawad & Ozbay, 2006). The net present value of benefits and costs or the ratio of benefits to costs can be considered in comparing alternative freight investments.

BCA provides an analytical framework to measure investment decisions of transportation improvements, which would benefit freight delivery across various modes. The BCA is conducted by comparing a set of alternative transportation projects with a base scenario. A BCA includes following steps: (1) establish objectives, (2) specify assumptions, (3) define the base and alternative scenarios, (4) analyze traffic effects, (5) measure the relative costs and benefits of alternative scenarios to the base scenario, (6) compare net benefits and rank alternative scenarios, and (6) make recommendations (Jones, Moura, & Domingos, 2014). The BCA approach relies on several assumptions (Vickerman, 2007). For example, the forecast traffic growth over the lifetime of the project is based on the estimated trends of the vehicle fleet. Since freight flows are determined by shifting the global supply chain, freight traffic may be fluctuated by factors outside of the study region. In addition, the constraints of environment, policy, and legislation also need to be identified in the analysis. BCA approach can be applied together with a travel demand model. The forecasted traffic volume and travel time of travel demand model under different scenarios are the basis for the BCA. The cost of a freight investment includes construction cost, maintenance costs, delay cost, crash cost, vehicle operating cost, emission costs, etc. The benefits of alternative freight investments are measured by comparing with the base scenario. More specifically, the saving in travel time, delay and reliability could be translated into monetary value as project benefits.

EIA is another approach to evaluate a freight improvement project. EIA forecasts the income, employment, local property values, and business impacts of a transportation project. Three kinds of economic impacts are considered in the EIA, namely direct impacts, indirect impacts, and induced impacts *(Wang & Charles, 2010)*. The results of BCA and EIA are often separated to reflect different aspects of the economic impacts of a project.

EIA process involves the following steps (O'Rourke et al., 2015). First, defining which industry sectors to be included in the analysis. Second, defining the study area for the analysis. Third, estimate indirect and induced impacts of transportation projects. The direct economic impacts are translated into indirect and induced economic impacts through an economic model. The Impact Analysis for Planning (IMPLAN) and the Regional Input-Output Modeling System (RIMS-II) are two major approaches to achieve this goal. IMPLAN and RIMS-II use matrices of industry sectors to describe the multiplier effect of one industry sector to another industry sector. For a freight investment project, the direct economic impact refers to the direct economic activity on the transportation system, such as the costs of construction, the increase of employment, and the reduced travel time of freight transit on the highway network, etc. Indirect economic impacts are caused by economic activities between industries. The direct expenditure of transportation improvement will result in additional demand for other industries. The induced economic impacts refer to the new demand from the increased employees. The investment in the freight system will create new job opportunities. New workers will spend their wages to purchase goods in their daily life. A number of measures used to evaluate the economic impacts include total employment, aggregate personal income, value added, and industry output (Forkenbrock & Glen Elliot Weisbrod, 2001). These measures reflect different aspects of the economic impacts of transportation investment. For example, total increased employment is an important indicator for evaluating the benefits of a project, but it overlooks the quality of economic growth. The average income reflects the quality of increased new jobs, but it underestimates the total benefits by excluding business growth. Value-added considers more comprehensively by including business profits and personal income, while it tends to overestimate the benefits. The business output reflects the economic impacts of each industry, but it cannot distinguish whether the output comes from the local operation or inter-regional economic activity. For transportation projects, the economic output and employment gains are commonly used in the EIA (Wang & Charles, 2010).

To reflect impacts of a freight investment through the Input-Output model, a general methodology would involve the following steps: (1) estimate improvements of system performance in freight

transportation, (2) estimate benefited industries from transportation improvements, (3) represent travel saving in industries in the EIA model (O'Rourke et al., 2015). The improvements in transportation system performance can be measured through the travel demand model. The share of freight by trucks of important industry sectors can be estimated by data from the Freight Analysis Framework. The reduced travel time can be converted to monetary values for each affected industry sector to represent the direct economic impacts. Finally, the benefits of travel time improvements can be estimated for each industry sector by the Input-Output model.

Except for the BCA and EIA approaches, dynamic modeling tools are another kind of methods to measure regional productivity of a freight investment. The core methodology of the dynamic model is a set of equations that are linked with Input-Output table to estimate future economic impacts of transportation projects across industries. REMI and TREDIS are two kinds of approaches to regional economic analysis.

REMI TranSight is capable of estimating improvements in regional productivity. The core methodology in REMI is a set of equations that are linked with Input-Output table to estimate future economic impacts of transportation projects across industries. TREDIS is another dynamic model that is specialized in evaluating transportation improvements. REMI and TREDIS have some important features: (1) they are dynamic models with adjusted growth rate based on previous year, (2) Both of them have BCA based on direct impacts of travelers, (3) They require two kinds of data: one is current and projected highway travel data, and anther data is input coefficients for Input-Output models. (4) both models require pre-processing of the input data (O'Rourke et al., 2015). The productivity is measured by the ratio of the dollar value of output to input, such as labor productivity. The dynamic model is a sophisticated approach to evaluate regional productivity of transportation improvement and require intensive data inputs. To solve these limitations, simplified methods have been employed by regional and local MPOs and DOTs through combining BCA and EIA to measure economic impacts of freight improvements.

Although BCA is commonly used to evaluate alternative transportation projects, it has been criticized for monetarizing non-market values in the process of decision-making. Moreover, the quality of

decisions is based on assumptions and estimates. The uncertainty and bias of inputs and outputs are not reflected in the process. Life-cycle cost analysis (LCCA) is an evaluation approach to inform investment decisions over the life of transportation project. It is considered as a restricted form of BCA by taking into account all of the incurred cost during the period of the alternative project lifetime (Ozbay, Jawad, Parker, & Hussain, 2004). LCCA is different from BCA in that LCCA does not combine with a freight demand model to measure the economic impacts of transportation projects. The reason for this is that LCCA only considers life-cycle costs of the project and does not include agency and user benefits into the evaluation. The final decision is evaluated based on the total life-cycle costs of alternative projects. LCCA is widely used in transportation infrastructure design.

LCCA considers total costs for both agency cost and user cost in evaluating transportation decisions. The agency costs include rehabilitation and maintenance activities created by the investment. The user costs include the initial activity and future activities to the public. The LCCA process involves following steps: (1) establish design alternatives, (2) determine activity timing, (3) estimate agency and user costs, (4) compute life-cycle costs, (5) results analysis (FWHA, 2018).

During the first step of LCCA, the activities for each alternative project are detailed and the analysis period is defined. Activities include the initial construction periodic maintenance and major rehabilitation of an asset. The FWHA recommends the period of LCCA analysis is not less than 35 years. In the second step, a detailed plan of activities for each alternative project is developed. When initially constructed or rehabilitated, transportation assets have a good condition and provide a designed level of service. However, as usage and aging of the transportation infrastructure, deteriorations would cause the level of service fail. Periodic rehabilitation and maintenance activities will improve infrastructure conditions and performance. Based on the desired level of service ability, agencies decide when to perform these activities. The rate of deterioration determines the timing of future activities. The timing of rehabilitation activities should be determined by existing performance records, including information from the agency's pavement and bridge management system.

The third step involves the estimation of cost. It is preferred to use constant dollars, which excluded inflation component in cost estimation. For construction costs, data can be obtained from historical records and engineering judgment. The user costs include vehicle operation costs, travel time costs, and crash costs, which are usually estimated based on the timing, duration, scope, and the number of construction and rehabilitation activities for each project. LCCA considers both near-term and long-term activities on the transportation system. Economic parameters, such as discounting rate, inflation rate, and analysis period, are important for LCCA.

Due to money spent at different times has a different present value, economic methods are needed to convert expenditures to present dollar value (Arribas, Angel, & Léonard, 2017). An expenditure stream diagram can be developed to show (1) initial and future activities of alternative projects, (2) agency and user costs involved in these activities, (3) the timing of these activities and costs. Designed alternative projects should be compared over equivalent periods of analysis. However, in case of some alternative scenarios will have a service life that is longer than the analysis period, a remaining service life (RSL) value would be needed. The FHWA recommends a method to measure RSL value based on project cost and percentage of designed life remaining at the end of the analysis period. Finally, economic analysis in the LCCA emphasizes on the time value of money. A given amount of money received today would worth higher than the same amount of money received later. The FHWA recommends using the present value approach in the analysis. Two approaches are commonly used in computing life-cycle cost: the deterministic and the probabilistic approach. The probabilistic approach will take into account of the variation and uncertainty for LCCA input parameters. In the FHWA transportation asset management report, the Colorado DOT applies a probabilistic approach to address variation associated with inputs (FWHA, 2018). For the probabilistic approach, thousands of samples are randomly generated for uncertain parameters based on their corresponding probability density function. A single forecasted present value output is computed for each sample. When analyzing LCCA results, the deterministic approach provides a

single PV without considering uncertainty. While probabilistic LCCA approach shows underlying uncertainty in each alternative project (Ozbay et al., 2004).

1.4 Case studies

1.4.1 Case study 1 (Minnesota DOT, 2018)

The Minnesota DOT developed a spreadsheet approach to evaluate the performance of transportation investment through a BCA. The methodology provides a standardized template, spreadsheet guidance, and recommended values to compare different BCAs for key model parameters. A series of studies have been accomplished based on the developed approach. In one of the studies, the BCA is applied to evaluate the economic impacts of lifting all vehicle restrictions during the spring thaw period (Levinson et al., 2005). Since the load restrictions are used to extend the lifetime of road, this policy increases the burden to trucks by forcing truck drivers to re-route or increase the number of trips to adhere to the policy. The potential cost of this project includes reduced pavement life, while the potential benefits include cost saving of freight carriers. The BCA combines results from Freight Demand Model (FDM) and the Pavement Performance Model (PPM). The FDM estimates the truck volume on the road network, and the PPM estimates the pavement life under these truck volumes in each scenario. The cost estimates for different road types in Minnesota were applied to measure the structure and functional overlay costs of pavement for each category of road. The pavement life extension benefit is then calculated based on a link-by-link basis.

To estimate the damage of trucks on the road network, the daily freight volumes of different kinds of truck and weight distributions are calculated for each road link, a damage coefficient table is further used to measure the damage of road links from freight transportation. In the spring lifting restriction scenario, the number and type of trucks on the road network are changed, and therefore the rutting failure times are different for each scenario. The total cost of trucks is measured to account for the maintenance cost. Operating cost per kilometer and the value of time are used to compute the cost of trucks. The number of trucks, kilometer per truck, cost per kilometer, and length of travel time are used to estimate the cost of

trucks with a fixed interest rate and lifetime period. In addition, the benefits of road owners are estimated by measure the travel time saving before rutting failure and then converted into monetary value.

1.4.2 Case study 2 (Srivastava, Perry, & Ahn, 2019)

Wisconsin DOT supported a study to evaluate the classic cases in evaluating economic benefits from freight investments. In the report, a comparison between BCA and EIA are focused. The study provides three case studies to compare how BCA and EIA are conducted in the evaluation of project economic benefits. In the first case study provided by the report, a BCA is performed for a railway equipment upgrade project in Kansas. The project evaluates a 10-year study period with 2018 as the fiscal base year. The construction of the project will be initiated in 2018, and the benefit of the project will be measured since 2021. The study provides the cost comparison for existing scenario and build scenario, where costs include capital cost, annual maintenance cost, fuel cost, vehicle miles per year cost, cost of delays, reliability cost, and availability rate. On the other side, the benefits are measured as emission cost-saving, fuel cost-saving, incremental Operation and Management saving, reliability cost saving, residual value for the discounted and undiscounted situation. The final economic benefit outputs are measured through net present value, benefit-cost ratio, discounted payback period, and internal rate of return.

The second case study is about the economic analysis of public ports from Missouri DOT. The study measured over 4 million tons of freight with a value of over $12 billion, which covers various industry sectors of the state economy. The direct impacts of the port system are measured in terms of employment, income, added value, market growth, gross state product, and state and local tax revenue. The indirect and induced impacts are measured for industries that depend on the port. The study uses IMPLAN model to conduct the statewide economic impact analysis.

In the third case study, the economic impacts of statewide airports in Missouri are performed following the Federal Aviation Administration guideline. Direct, indirect, and multiplier effects are evaluated based on an EIA and comprehensive survey data for the direct impacts. The study also found

some un-quantifiable benefits that the state airports bring for people, such as various flying-related recreational activities.

Comparing the methods and the impacts considered in the three case studies, we found that BCA is more suitable for evaluating the economic impacts of project improvements, while EIA considers the regional impacts of an entire infrastructure. Moreover, BCA focuses on selected categories of impacts, while EIA is suitable for evaluating the overall economic impacts generated.

1.4.3 Case study 3 (SEMCOG, 2012)

The Southeast Michigan Council of Government (SEMCOG) developed a "Simplified Economic Analysis Tool" based on spreadsheet for economic analysis of transportation improvements. In their approach, the travel demand model is used to estimate traffic changes in counties. The economic model is based on the MDOT REMI model derived elasticities to evaluate impacts by industry sectors. The developed tool can be used to evaluate the overall benefits of transportation projects. Several types of economic analysis are conducted in the model. BCA is one of the economic analysis approaches to measure user benefit of project improvements. The tool provides direct user benefits in travel time saving, reliability improvements, vehicle operation cost-saving, safety cost saving, and emission cost saving. The direct user benefits are then translated into a benefit-cost ratio and net present value through a BCA. Later, indirect impacts from industries are estimated through cost reduction in business, increase production to respond to the increased spending of households, materials, and services for the improvement project. The induced impacts from households are also estimated through an increase in income and spending. Afterward, the tool provides estimated changes in economic output, income, and employment in multiple industry sectors.

1.4.4 Case study 4 (Wilde, Waalkes, Harrison, & River, 1999)

In a case study to evaluate LCCA methodology for Portland cement concrete pavement, measures to estimated pavement design, construction, maintenance, and user impacts during the analysis period are discussed. Since vehicular loading is one of the significant parameters that have the greatest effects on the performance of cement concrete pavements, the study proposed approaches to evaluate the amount of

vehicular loading. One proposed approach is to predict the equivalent single axle loads (ESAL), which is a concept developed by the American Association of State Highway and Transportation Officials (AASHTO) road test to measure the loads and damage relationship for comparing effects of axles with different loads. Another approach is to use the average daily traffic (ADT) to predict the vehicular loading during the analysis period. The similarity between these two approaches is that a growth rate is applied to increase the value annually. The growth rate could be determined from the initial year and the final year ESAL or ADT values based on historical data. Secondly, to predict the failure of pavement in relation to traffic loading, a Weibull distribution to measure the relationship between the fraction of failure and cumulative ESAL or ADT. For a simplified method, the accumulative damage of transportation infrastructure could also be evaluated by calculating the percentage of accumulative traffic load on the network. The study also discusses a method based on state highway design guide to measure the remaining serviceable life of a pavement. The user costs are divided into travel delay costs, vehicle running costs, speed change cycle costs, and accident, which are based on specific parameters.

1.5 Conclusions

Comparing with existing approaches used to measure the economic impacts of transportation projects, we found some unique characteristics for each method. The BCA is a commonly used approach to comparing the benefits of alternative transportation improvements, it can combine with transportation demand model to reflect potential user benefits from transportation improvements. However, due to model assumptions and estimation of input parameters in the BCA, it is criticized for outputs bias and uncertainty. EIA is an approach to measure different types of economic impacts for different industry sectors. The evaluation approach is usually relied on an Input-Output model to disaggregate user benefits into direct, indirect, and induced impacts. EIA is not suitable for comparing the long-term cost and benefits of alternative transportation projects because it disaggregates economic impacts into different industry sectors. Dynamic models could measure both the economic impacts and the cost-benefit of a project, while it is more complex and based on existing commercial software. Instead, transportation agencies prefer to use

simplified approach rather than complex models, which combines BCA and EIA, to evaluate economic impacts and cost benefits of a transportation investment (Minnesota DOT, 2018; SEMCOG, 2012). Comparing with these methods, LCCA measures total costs of a project during its life period, which has been widely applied in evaluating benefits of transportation projects (US DOT, 2002; Wilde et al., 1999). LCCA only considers potential costs of a project during the lifecycle of a project, therefore, it has fewer assumptions in estimating non-monetary values of a project. Based on previous studies (FWHA, 2018; Ozbay et al., 2004), we will use LCCA approach to evaluate alternative transportation investments. On the other hand, the economic impacts of a transportation project will be measured based on previous developed approaches to quantify the impacts of freight improvements in different industry sectors.

2. FLORIDA FREIGHT ECONOMIC IMPACT KIT

2.1 Introduction

Florida Freight Transportation Economic Impact Kit (FreighTEC) combines data from the input-output (IO) economic model and Florida Freight Supply-Chain Intermodal model (FreightSIM) to evaluate the economic impacts of alternative freight projects. It aims to facilitate the Florida Department of Transportation (FDOT) in the freight investment process. The previous version of FreighTEC provides functions to measure travel time saving and disaggregate economic benefits to different industrial sectors. However, it did not consider the life-cycle costs of a freight investment. In the updated model, functions to measure the life-cycle cost of a transportation project are added to the existing software. The updated FreighTEC 2.0 allows users to estimate the cost of a transportation project during its life cycle as well as its economic impacts.

The updated tool is developed based on Python 3.7 on a Windows operating system. To run the program file, at least a windows 8 operating system would be required. No additional software or packages are needed to use the software.

In this report, we first introduce the research methodology used to evaluate the life-cycle cost of transportation projects. Afterward, a user manual is presented to show how to use the updated model and new functions.

2.2 Methodology

The methodology of life-cycle cost analysis (LCCA) of a freight project includes two parts: The estimation of life-cycle agency cost and the estimation of life-cycle user cost. Three parts are included in the life-cycle agency cost: initial construction cost, maintenance and operation costs, and rehabilitation costs. Annual growth rates are applied to estimate the annual routine costs of maintenance and rehabilitation in the future (Li and Madanu, 2009). Similarly, for user costs, we use the first-year user cost under normal operation with a geometric VHT growth rate to estimate annual user cost in future years. The direct user

benefit in a transportation project refers to the travel cost saving on the transportation system. The user benefit is calculated by measuring the reduced travel cost of a transportation project. All model results are discounted using the net present value (NPV). The NPV is defined by the following function (Walls & Michael, 1998):

$$NPV = Initial\ cost + \sum_{k=1}^{N}(Rehab\ Cost_k + Maint\ Cost_k)\frac{1}{1+i^{n_k}} \qquad (2\text{-}1)$$

In equation (2-1), $Initial\ cost$ refers to the initial construction cost of a transportation project, $Rehab\ Cost_k$ is the kth rehabilitation cost, $Maint\ Cost_k$ represents the accumulated maintenance cost at kth rehabilitation activity, i is the discounting factor, n^k is the year of rehabilitation activity in the life cycle. According to FHWA's LCCA manual, the discounting rate ranges between 3%-5% based on regions and states (Walls and Michael, 1998).

The construction cost is usually estimated based on the cost per mile model, which can be estimated based on historical pavement and bridge construction costs. Since FDOT has provided the average unit costs per centerline mile (Cost Per Mile Models) by facility and improvement type to estimate transportation project cost, we suggest to use the Cost Per Mile Models from FDOT to estimate the construction cost. Table 2.1 shows the unit cost for different types of roadways in Florida. These unit costs originated from the FDOT Long Range Estimating System or from the Cost Per Centerline Mile estimates use by FDOT District 7.

Table 2-1 An example of construction cost per mile in Florida[1].

	Model	Cost per Mile ($)
Rural	New Construction Undivided 2 Lane Rural Road	$2,231,964.86
	New Construction Undivided 3 Lane Rural Road	$2,711,718.95
	New Construction Undivided 4 Lane Rural Road	$3,285,190.24
Urban	New Construction 2 Lane Undivided Urban Arterial with 4' Bike Lanes: U01	$4,898,101.57
	New Construction 3 Lane Undivided Urban Arterial with Center Lane and 4' Bike Lanes: U02	$4,674,668.70
	New Construction Undivided Urban Arterial	$5,072,526.74
Suburban	New Construction Suburban 4 Lane with Paved Shoulders Outside and Curb Median: S01	$4,536,023.67
	Widen Existing Rural Facility to the Inside with Addition of Closed Drainage System and Median Barrier Wall: S02	$3,545,190.31
	Widen 4 Lane Suburban Roadway with 6.5' Paved Shoulder and Convert to C&G Out;	$2,779,313.87

Based on costs per mile in Table 2.1, the initial construction cost based on the summation of all categories in Table 2.2, which includes contingencies for construction mobilization, maintenance of traffic

[1] Data sources for the Cost per Mile Model:
https://www.fdot.gov/programmanagement/estimates/lre/costpermilemodels/cpmsummary.shtm

during construction (MOT), project unknowns (scope), long range planning, design, and CEI, which refers to the transportation management cost.

Table 2-2 Construction cost estimation approach[2]

Category	Definition	Calculation
A	MOT	10% of cost per mile
B	Mobilization	10% of (cost per mile + A)
C	Construction subtotal	cost per mile + A + B
D	Scope Contingency	25% of construction subtotal
E	CEI	15% of (construction subtotal + B)
F	Long Range Planning	25% of construction subtotal
G	Total Construction Cost	Construction subtotal + D + E + F
H	Design	15% of total construction

According to the methodology of NPV, the rehabilitation cost is calculated based Equation (2):

$$Rehab\ Cost = \sum_{k=1}^{N} Rehab\ cost * (1 + g_r)^{n_k} * \frac{1}{(1+i)^{n_k}} \qquad (2\text{-}2)$$

In equation (2-2), the rehabilitation cost can be estimated based on empirical data or initial cost, g_r represents annual rehabilitation cost growth rate. The total rehabilitation cost of a transportation project during its life-cycle ranges from 10%-19% of the total cost (Li & Madanu, 2009). Therefore, depending on the number of rehabilitations during the life cycle of a transportation project, the rehabilitation cost per mile could be determined. Except for rehabilitation cost per mile, the length of years for the rehabilitation is also required for the analysis. A transportation project usually has a predefined length for rehabilitation and maintenance. The year length for rehabilitation is between 7-20 years (Walls & Michael, 1998; Li & Madanu, 2009).

[2] Data sources for construction cost estimation: https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/content/structures/structuresresearchcenter/final-reports/bb879.pdf?sfvrsn=73363aa7_0

The calculation of maintenance cost is similar to the rehabilitation cost except for the calculation which is based on the annual basis, and then aggregate during each rehabilitation activity. The maintenance cost of a transportation project varies depending on the type of roads and scale of the transportation project. Currently, FODT does not provide methodology to estimate maintenance cost of a transportation project. In our analysis tool, we estimate maintenance cost based on the initial cost of transportation projects. The maintenance cost is usually about 2%-5% of construction cost (Li & Madanu, 2009). The user benefit is measured by calculating the enhanced VHT on the transportation network, which can be defined as:

$$User\ benefit = \sum_{k=1}^{N} \Delta VHT * hourly\ cost * 365 * (1 + g_{VHT})^k * \frac{1}{(1+i)^k} \quad (3)$$

In equation (2-3), ΔVHT is the total changed VHT between the built scenario and non-built scenario. The value of hourly cost is usually calculated based on the Highway Economic Requirements System State Version (HERS-ST, 2020). For example, the commercial truck driver's hourly wage is about $27.5, and the vehicle operating cost is about $27.2/hour, and including other user costs, such as truck maintenance, emission, and safety, etc. The total hourly cost of travel time is between $56~ $60. The g_{VHT} is the annual traffic growth rate. The annual traffic growth rate usually ranges between 1% to 3% (Todd, 2009). Finally, the salvage value is measured by estimating the remaining life of the project, as shown in Equation (2-4).

$$Salvage\ value = cosntruction\ cost * \frac{N_R}{N} * \frac{1}{(1+i)^k} \quad (4)$$

The equation (2-4) is derived based on Walls & Michael (1998), N_R is the remaining life of a transportation project, and N is the life-cycle length of a transportation project. We use the above approach to measure life-cycle cost and benefit of a transportation project.

3. FLORIDA FREIGHT ECONOMIC IMPACT KIT(FreighTEC 2.0) USER MANUAL

The Florida Freight Transportation Economic Impact Kit (FreighTEC 2.0) is an economic analysis tool based on a Florida-specific economic Input-Output (IO) model. It utilizes output files from the Florida Statewide Model's (FLSWM) Freight Component (FreightSIM) to evaluate life-cycle costs and benefits of freight projects. This tool provides a method to aid conservative evaluation of projects to support transportation planning.

3.1 Project Window

To use FreighTEC 2.0 tool, users should first extract the file on a local drive. The executable file could be found at "...\FDOTTool\program code\FDOT Tool\FDOTtool.exe". Users could either directly click the application (.exe) or create a shortcut of the application on the desktop and then click the application to start the program. A quick user guide is available in the Documentation folder for reference. After clicking the application, the program start window is shown in Figure 3.1. users need to click the New Project button to create a new project.

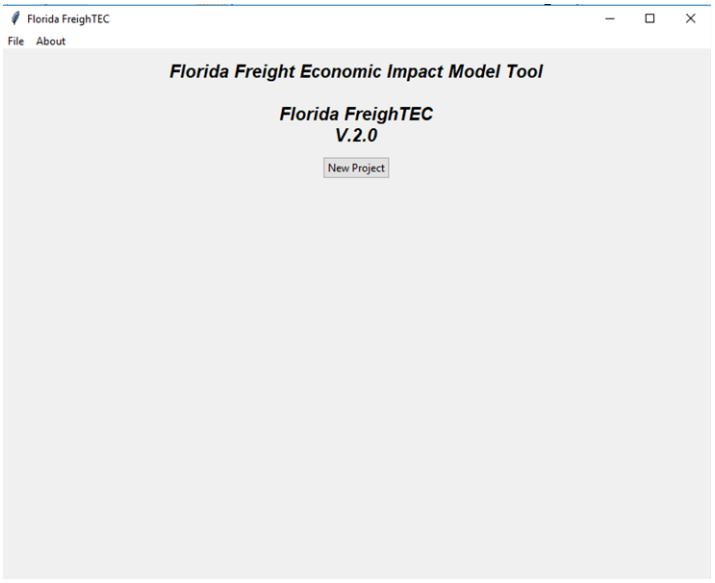

Figure 3-1 Project start window

3.2 Project property

The project information window allows users to enter project-related information, including analysis data, project name, and project description, as shown in Figure 3.2.

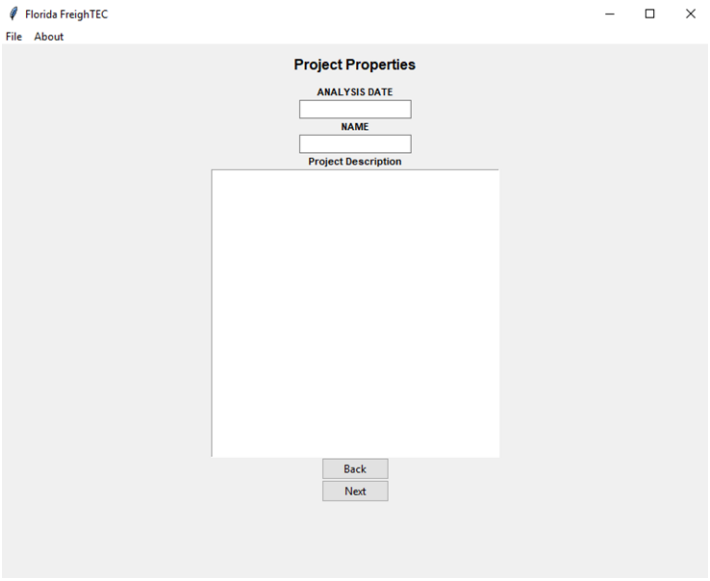

Figure 3-2 Project property

3.3 Project information

The project property includes key inputs for the analysis. It allows users to select the study area, forecasting year, the hourly value of travel time, and the discounting factor in NPV analysis. All these inputs are required inputs for the analysis. These values will be used in both the project life-cycle cost analysis and economic impact analysis. The discounting factor will be used as the default discounting factor for analysis, while different discounting factors will be applied in the life-cycle cost sensitivity analysis. An example of input is shown in Figure 3.3 and Figure 3.4.

Choose study area: This is a drop-down list of all counties in Florida. Users can choose the study county from here. In addition, there is an additional option called Florida in the drop-down list. If users want to do statewide analysis, choose that option. Figure 3.3 shows the county impacts analysis, and Figure 3.4 shows statewide impacts analysis.

Value of travel time: The value of travel time is calculated based on the Highway Economic Requirements System State Version (HERS-ST, 2020), which can be accessed through http://bca.transportationeconomics.org/models/hers-st. Usually, the commercial truck driver's hourly wage is about $27.5, and the vehicle operating cost is about $30 /hour, and including other user costs, such as truck maintenance, emission, and safety, etc. The total hourly cost of travel time is between $56~ $60. The value of travel time and vehicle hour traveled (VHT) will be used to calculate the user cost in the project.

Discounting factor: The discounting factor is used to discount future monetary costs to current year monetary value. According to FHWA's LCCA manual, the discounting rate usually ranges between 3%-7% based on regions and states (Walls and Michael, 1998). In FreighTEC, we use 5% as the default discounting factor in the analysis.

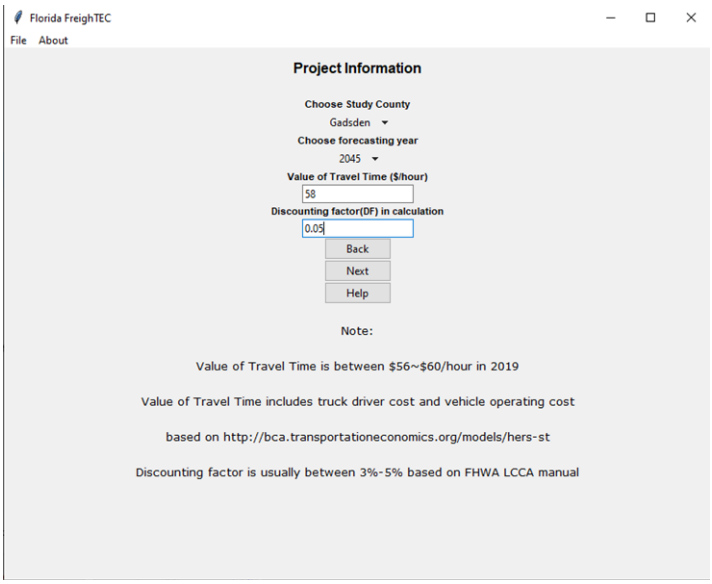

Figure 3-3 Project information

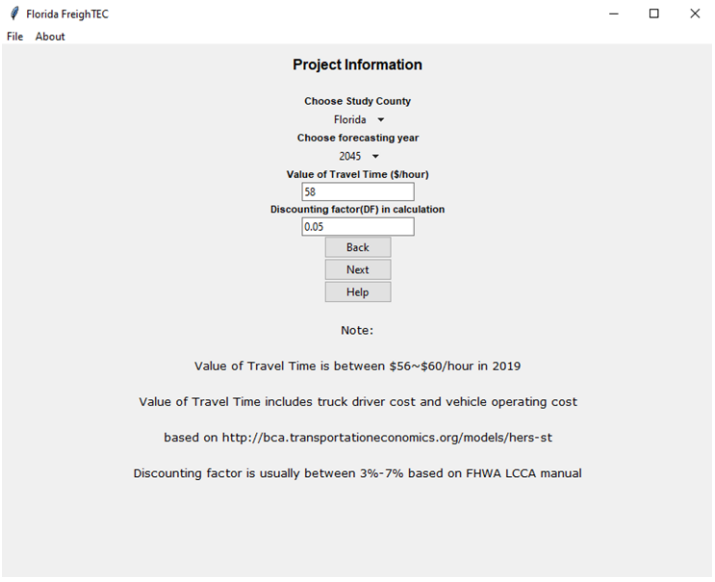

Figure 3-4 Project information

3.4 Scenario inputs

This step provides consistent functionalities with the previous version of the tool. Two kinds of scenarios, built scenario and non-built scenario, will be calculated using the FreightSIM output files (Link.dbf) in the base year. These two scenario outputs are based on the same year of FreightSIM model, which is the year when the new project is constructed. In our case studies, we choose 2015 FreightSIM model to run all scenarios. For future applications, users may consider to use a latest FreightSIM model with future travel demand forecasting in the analysis. Users need to browse to the local folder with the VHT link file, and the tool can calculate the total VHT of the county or of the whole state for each scenario. Once the VHT run is finished, users can see either a pop-up message or a message in the Calculation Status box suggesting that users can proceed for the next step. Figure 3.5 shows the scenario input for built VHT analysis. Figure 3.5 and Figure 3.6 show countywide and statewide VHT results for built scenarios respectively. Figure 3.7 and Figure 3.8 show countywide and statewide VHT results for no-built scenarios respectively.

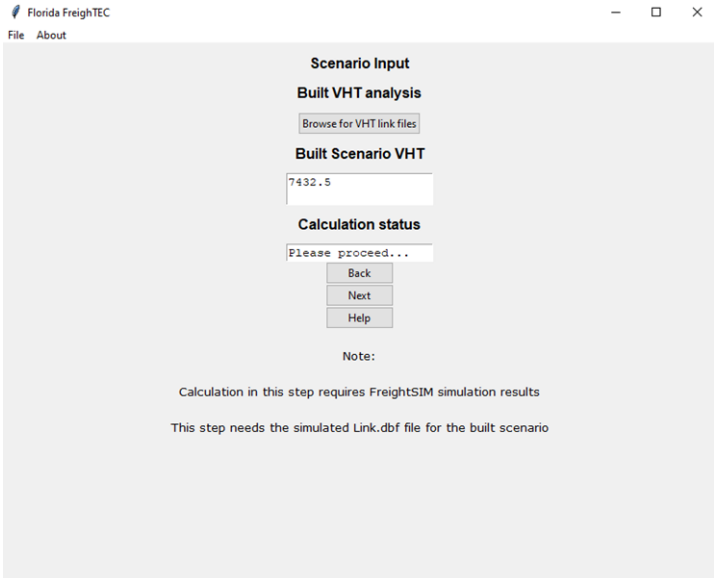

Figure 3-5 Countywide Built VHT analysis results

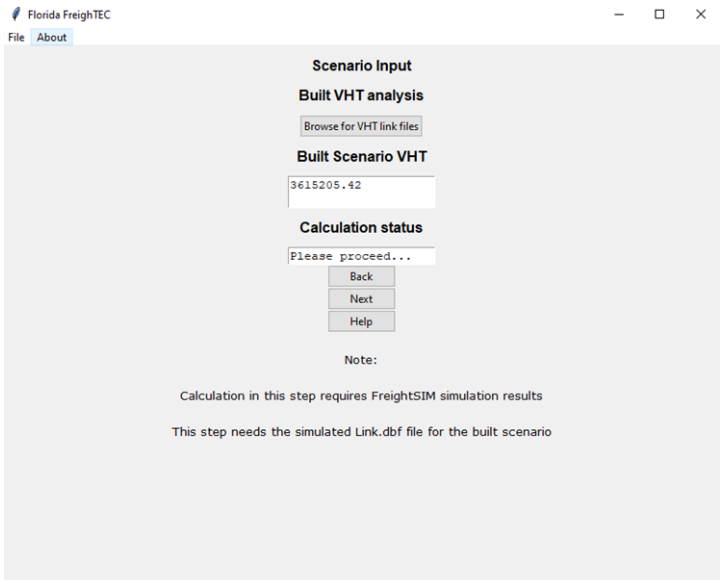

Figure 3-6 Statewide Built VHT analysis results

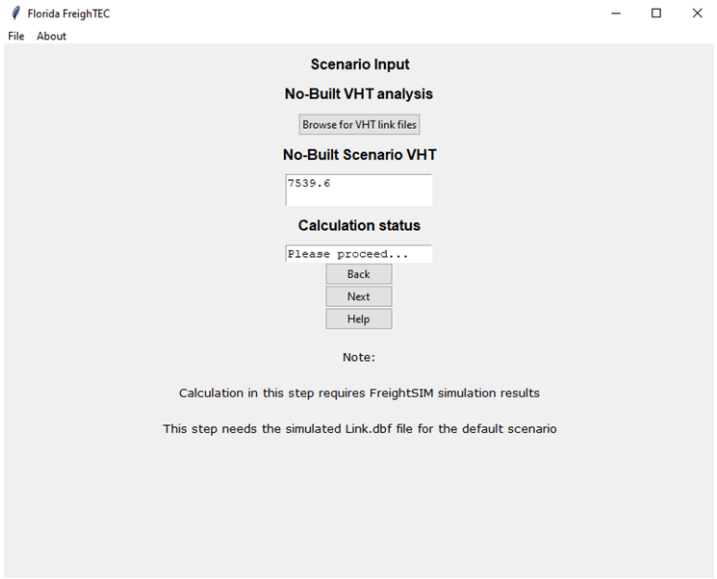

Figure 3-7 Countywide Non-built VHT analysis results

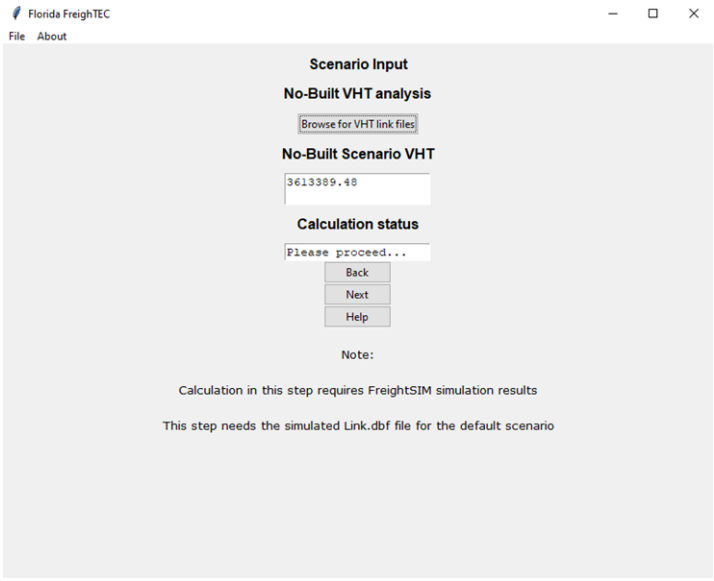

Figure 3-8 Statewide Non-built VHT analysis results

3.5 Freight Life-cycle cost analysis

After users enter input data for the analysis, the tool will first go to measure project life-cycle cost. A life-cycle cost analysis interface will pop-up, as shown in Figure 3.9. Users can click start to begin the analysis.

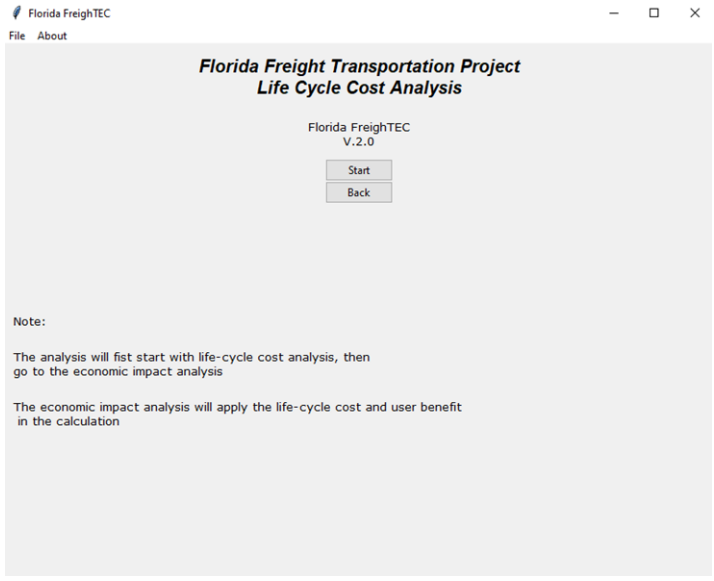

Figure 3-9 Life-cycle cost analysis interface

3.6 Life-cycle cost and benefit analysis inputs

The life-cycle cost and benefit analysis require inputs for construction cost per mile, maintenance cost per mile, rehabilitation cost per mile, rehabilitation interval, and annual VHT growth rate, as shown in Figure 3.10. These values are estimated based on different sources. If no values are entered, the tool will use default values to evaluate the life-cycle cost.

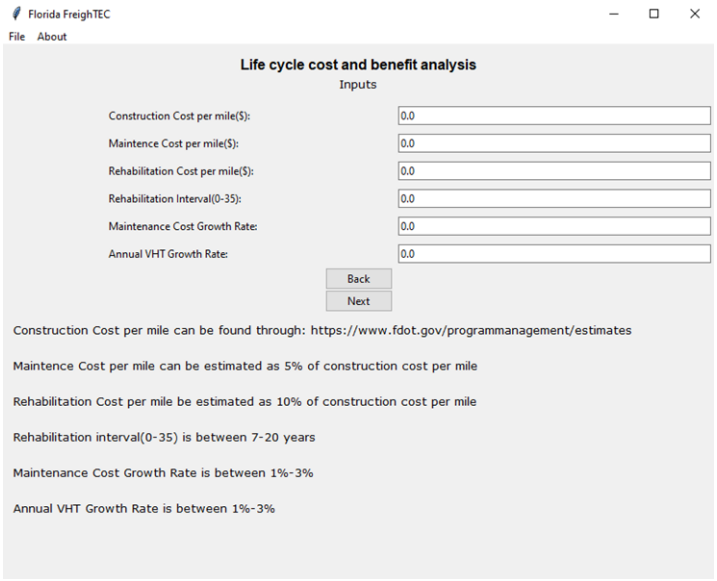

Figure 3-10 Life-cycle cost and benefit analysis input information

Construction cost: The construction cost is usually estimated based on historical pavement and bridge construction project costs. To estimate the construction cost for different types of transportation projects, we suggest to use the actual estimated project costs. Otherwise, the tool will use default values from the FDOT cost per mile model to estimate construction cost.

Maintenance cost: The maintenance cost of a transportation project is based on different type of roads and areas. FDOT does not provide methodology to estimate maintenance cost of transportation projects. According to Li & Madanu (2009), the maintenance cost is usually about 2%-5% of construction cost. The FreighTEC uses 3.5% as default value.

Rehabilitation cost: The total rehabilitation cost of a transportation project during its life-cycle ranges from 10%-19% of its total costs (Li & Madanu, 2009). Therefore, depending on the number of rehabilitations activities during the life cycle of a transportation project, the rehabilitation cost per mile could be determined. In the default model, we choose 14.5% of the construction cost as the rehabilitation cost.

Rehabilitation interval: Except for rehabilitation cost per mile, the rehabilitation interval is also required for the analysis. A transportation project usually has a predefined length for rehabilitation and maintenance. The year length for rehabilitation interval is between 7-20 years (Walls & Michael, 1998). In our analysis, we choose the default rehabilitation interval as 9 years.

Annual VHT growth rate: An annual traffic growth rate will be used to measure annual traffic growth on the transportation network. This value usually ranges between 1% to 3% (Todd, 2009). In our model, we choose 2% as the default value.

3.7 Project Life-Cycle Cost-benefit results

After entering inputs for the life-cycle cost analysis, a new page will show up. By clicking the calculation button, the tool will combine all inputs data from project information and life-cycle cost and benefit inputs to conduct the calculation. The cost of a project mainly includes initial construction cost, maintenance cost, and rehabilitation cost, and the benefit refers to the user benefit on the transportation system. Figure 3.11 and Figure 3.12 shows the LCCA results for countywide and statewide respectively. The construction cost, maintenance cost, and rehabilitation cost represent total costs for each category during the life-cycle. These costs are consistent for countywide analysis and statewide analysis. The salvage value represents the remaining value of the investment after the analysis period. It will also not change for county analysis or state analysis. Since changed VHTs are different for countywide analysis and statewide analysis, total user benefits are different for countywide analysis and statewide analysis.

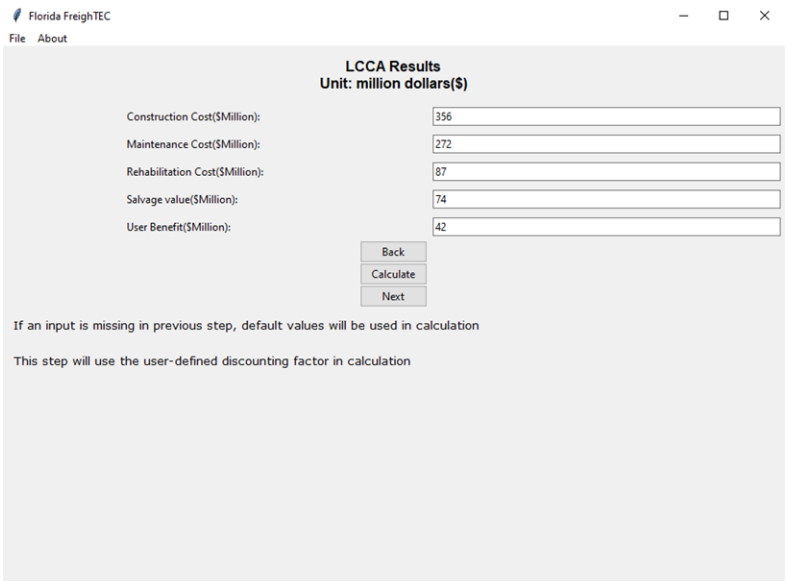

Figure 3-11 Countywide life-cycle cost and benefit results

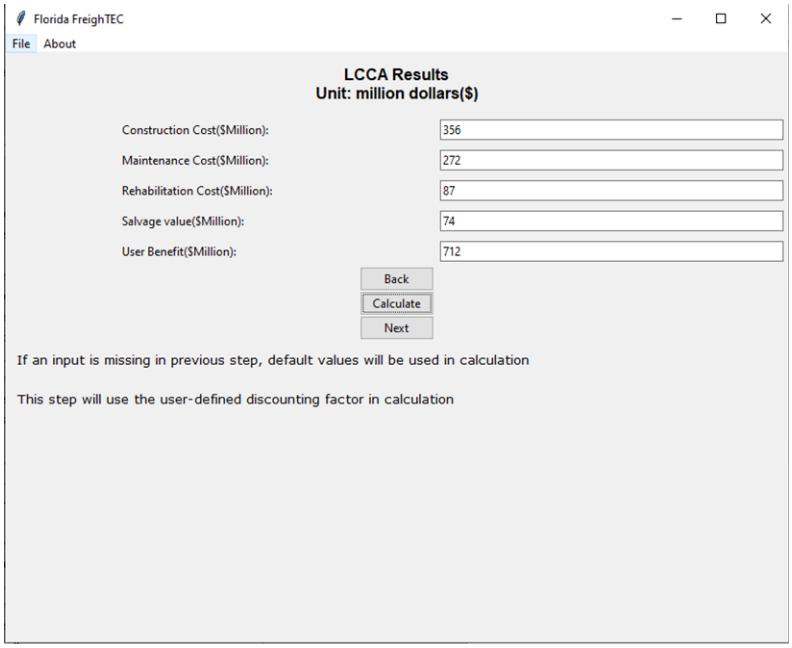

Figure 3-12 Statewide life-cycle cost and benefit results

3.8 Life-Cycle benefit and cost sensitivity analysis results

After finishing the LCCA calculation, a sensitivity analysis can be conducted. If users do not need this step, the model can continue to conduct the next step analysis. In this step, a sliding discounting factor

from 3% to 7% will be examined to evaluate model results for countywide and statewide analysis, as shown in Figure 3.13 and Figure 3.14.

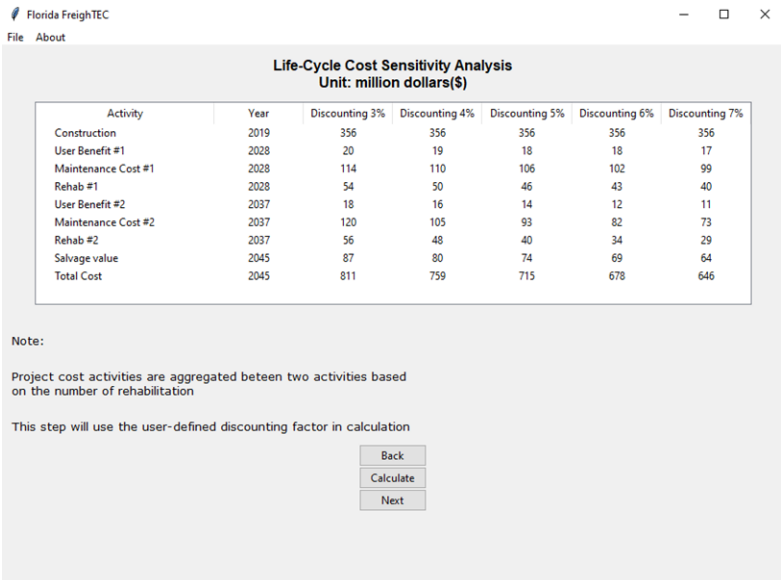

Figure 3-13 Countywide LCCA sensitivity analysis results.

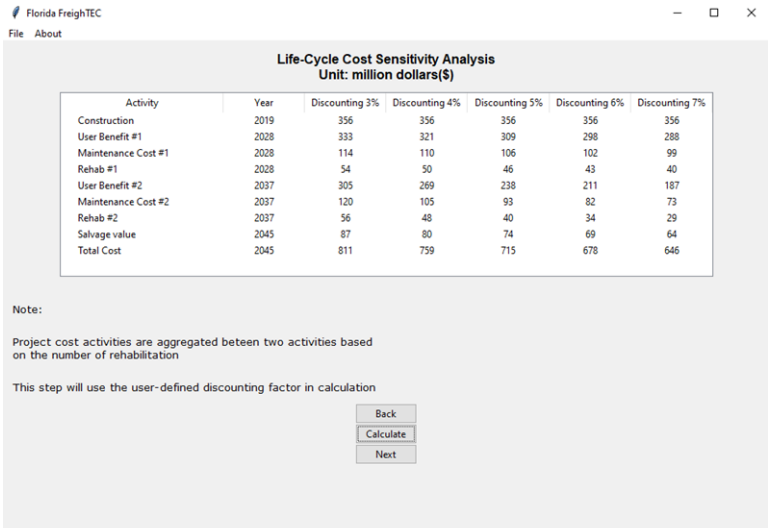

Figure 3-14 Statewide LCCA sensitivity analysis results.

3.9 Economic impact analysis results

This step is the same as the previous version tool, where the economic impacts are evaluated based on the VHT analysis for both built and no-built scenario. In this step, the tool will use user benefit and total project investments from previous steps to derive economic impacts in different industry sectors in the

regional IO model. The result window is shown in Figure 3.15 and Figure 3.16 for countywide and statewide analysis respectively. To get analysis results, users need to do the following operations:

1. Analyze Input: This command will analyze the input including the customized values and VHTs for two scenarios. The final result will not be shown in the window until the button Industry Results is clicked.

2. Industry results: This command will show the detailed industry results with total economic benefits. Note that there are many ways to show the economic benefits. The kit uses three types of economic impacts including industry output impact, industry employment impact, and economic income impact.

3. Clear results: This command will clear all the results.

4. Save output: This function allows the user to save the results in a .txt file with the tabulate format. Finally, the total costs and benefits of the freight project are shown in Figure 3.17 and Figure 3.18 for countywide and statewide analysis respectively. The total costs represent life-cycle costs of the transportation project. The total benefits include life-cycle user benefit, economic impacts, and total impacts within the life-cycle of the project. Figure 3.17 and Figure 3.18 show the total benefit of case study 1. The total benefit is negative for countywide analysis, while when considering the statewide benefits, the total benefit is positive. These results show that the total cost of the project is lower than the total benefit on the local scale, while when considering total benefits of the project on the whole transportation system in the Florida, the total benefits is still positive.

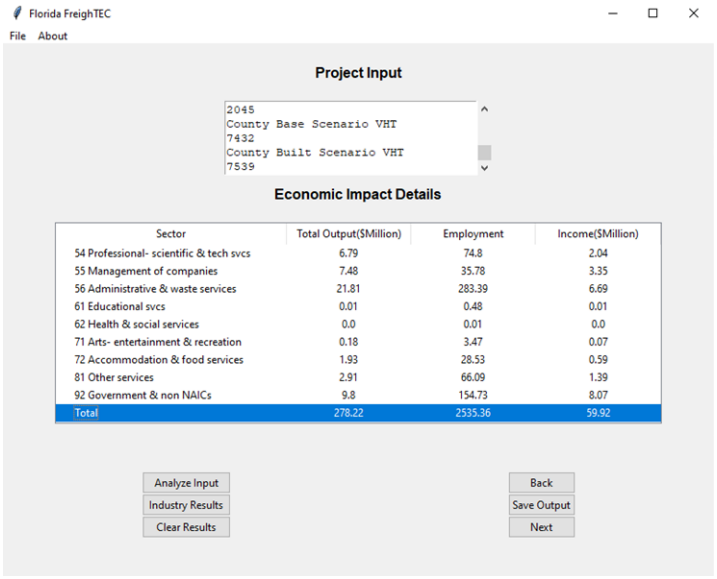

Figure 3-15 Countywide economic impact analysis results

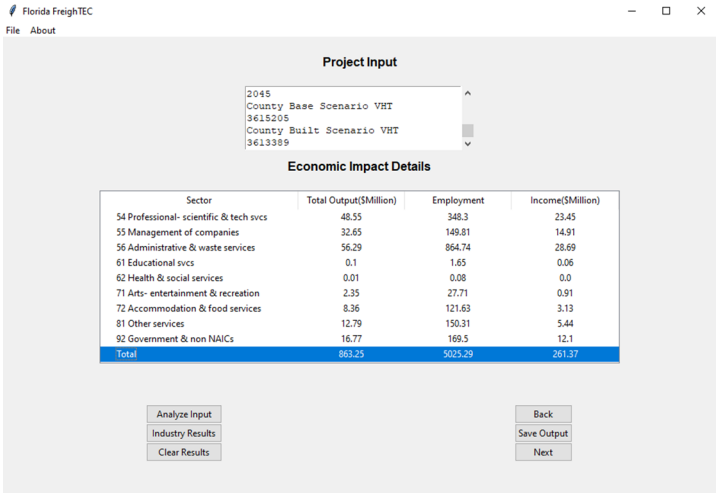

Figure 3-16 Statewide economic impact analysis results

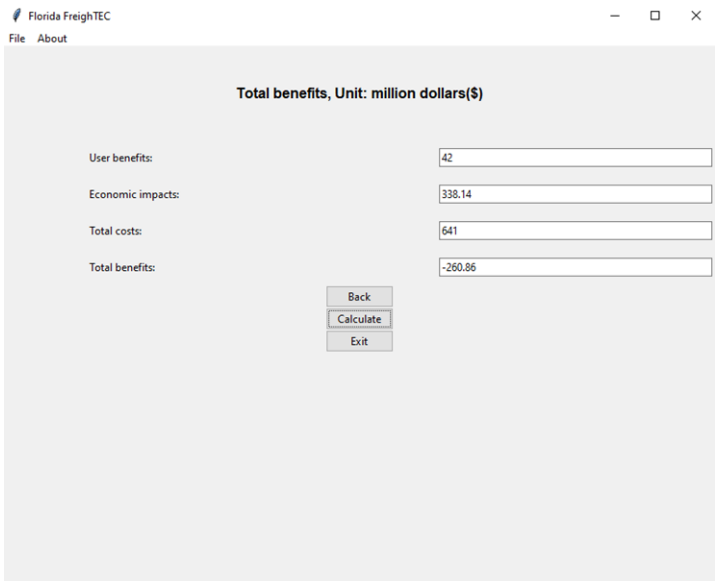

Figure 3-17 Countywide results summary

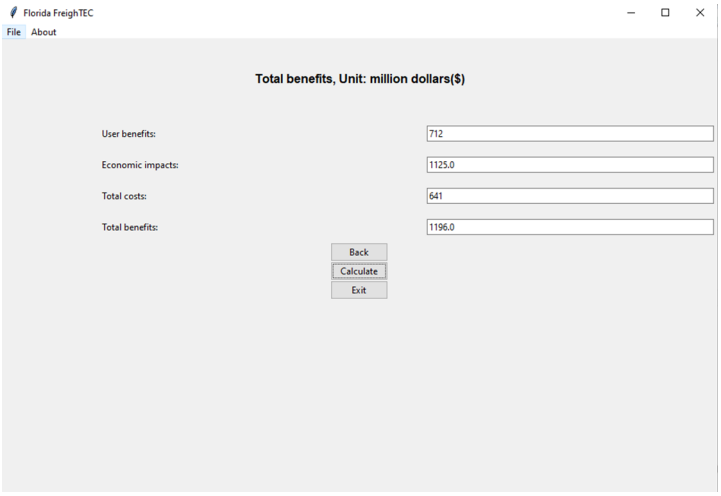

Figure 3-18 Statewide results summary

4. Case Study 1: Highway expansion project in Gadsden County

4.1 Introduction

The first case study derives from the Florida 2040 Strategic Intermodal System (SIS) unfunded needs plan from District 3. The project aims to improve interstate highway capacity with additional lanes planned to be built on the I-10. This section will present the use of FreighTEC and results at the county and state level.

The hypothetical project will be in the Gadsden county in the Tallahassee metropolitan area. The project will be adding additional lanes to build 6-lanes on the I-10 interstate highway, which starts from the Florida State Highway 12 and ends at the west of U.S. 90.

Since user benefits of the new project can be measured as the decreased travel time, to avoid impacts of travel demand changes on the results, the output files of FreightSIM need to be based on the same year of simulation, which is the year when the project is constructed.

4.2 Scenario Run

FreightSIM simulates the transport of freight between supplier and buyer business in United States, focusing on movements that involve Florida. Its output files provide traffic volume information in the state of Florida. The following nodes are located to match the hypothetical project:

1. 36879-36717(36717-36879)

2. 36921-37214(37214-36921)

These two links were modified to increase both the capacity and lane numbers in the FreightSIM. We use the 2015 FreightSIM model without future travel demand projection in the analysis. Based on output files of FreightSIM, two scenarios in the year of 2015, Build and No-Build, are evaluated using the FreighTEC tool to calculate the cost and benefit of the project in 2045. FreightSIM includes multimodal networks for rail, waterways, airports, and ports, and highways, as well as distribution center locations, for

the US, with more detail in Florida. Figure 4.1 shows the location of the proposed project in FreightSIM. Different link colors in Figure 4.1 represent the number of lanes.

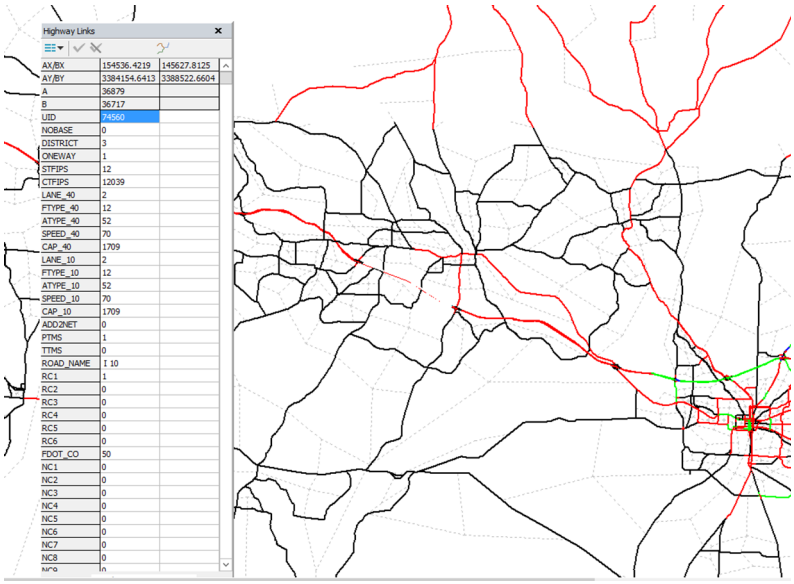

Figure 4-1 The location of the proposed project on the FLSWM network in Case study 1

4.3 Results

4.3.1 Vehicle Hours of Travel (VHT) calculation for the Built and No-Built scenarios

The VHT and VMT from FreightSIM outputs was used as a model input for FreighTEC to calculate the total VHT and VMT for both the Build and the No-Build scenario. A model run was then produced for Gadsden County and the results of the simulation are shown below in Table 4.1 and Table 4.2 for both countywide and statewide results.

Table 4-1 Countywide VHT and VMT with (Build) and without (No-Build) scenarios in Case study 1.

	No-Build Scenario	**Build Scenario**	**Differences**
VHT	2,804.72	2,736.02	-68.70
VMT	2,143,236.30	2,145,244.50	2,008.20

Table 4-2 Statewide VHT and VMT with (Build) and without (No-Build) scenarios in Case study 1.

	No-Build Scenario	Build Scenario	Differences
VHT	522,412.61	524,439.26	2,026.65
VMT	450,448,220.91	450,536,469.49	88,248.58

The model shows that total VHT in Gadsden County would decrease by approximately 68.7 total hours per day in the built scenario, while the total VHT in the state of Florida would increase 2,026.65 total hours per day in the build scenario. These changes in VHT could generate user benefits on transportation system. On the other hand, the countywide VMT increases 2,008.2 miles per day, and the statewide VMT increase 88,248.58 miles per day in the built scenario.

4.3.2 Life-cycle cost analysis inputs

The life-cycle cost analysis (LCCA) of a freight project includes the life-cycle agency cost and life-cycle user cost. The life-cycle agency cost includes: 1) the initial construction cost, 2) maintenance and operation costs, and 3) rehabilitation costs. Annual cost growth rates and VHT growth rates are applied to estimate the annual routine costs of maintenance and rehabilitation in the future. Since only the construction cost of the project is available at the time of this analysis, the LCCA inputs will use the construction cost and default parameters to estimate maintenance and operation costs and rehabilitation costs. The default parameters are derived from DOT reports and the existing literature (Li & Madanu, 2009; HERS-ST, 2020; FDOT, 2014, ODOT, 2013). It should be noted that the LCCA is sensitive to parameter values, so results could be different under higher cost growth rates and different cost estimation methods. The initial maintenance and operation cost are estimated as 3.5% of the construction cost, the initial rehabilitation cost is estimated as 14.5% of the construction cost, the annual cost growth rate is used as 3%, and the annual traffic growth is chosen as 2%.

4.3.3 Life-cycle cost analysis calculation

In Table 4.3, all results are displayed in million dollars. The total construction cost (including the initial costs of planning and construction) is estimated at $98 million using the default FDOT cost per mile values, and the total maintenance cost during the life-cycle of the project is about $75 million, the total life-cycle rehabilitation cost is about $24 million, and the salvage value after the analysis period is about $20 million. The total countywide user benefit is about $27 million.

Table 4-3 Summary of Life Cycle Cost Analysis Output in Case study 1

Cost Category	Dollar Amount ($ Millions)
Planning, design and construction Cost	$98
Maintenance Cost	$75
Rehabilitation Cost	$24
Salvage Value	$20
Countywide User Benefits	$27
Statewide User Benefit	$795

4.3.4 LCCA Sensitivity Analysis

The Net Present Value (NPV) used in the analysis represents the discounted monetary value of expected costs (Walls and Michael, 1998). Future costs are discounted using a discounting rate. Discounting rates can significantly influence analysis results. Therefore, sensitivity analysis would be needed to measure results based on different discounting rates. In this study, we estimated different costs and benefits based on discounting rates ranging from 3 to 7 percent as shown in Table 4.4. The results in Table 4.4 consider countywide total costs during the life cycle of a transportation project. Construction cost represents total initial cost of the project. Maintenance costs are aggregated based on the length of rehabilitation interval and user benefits only show countywide results. There are two rehabilitation activities during the analysis period, which will happen in 2028 and 2037, respectively. Therefore, in Table 4.3, Maintenance Cost #1 represents total maintenance costs from 2019 to 2028, and Maintenance Cost #2 represents total maintenance costs from 2028-2037. The salvage value represents the remaining value of the investment at

the end of the analysis period. These results show that as the discounting rate is increased, the total cost of the project decreases.

Table 4-4 Case study 1 LCCA sensitivity analysis outputs ($million based on 2019 Net Present Value (NPV))

Activity	Year	Discounting 3%	Discounting 4%	Discounting 5%	Discounting 6%	Discounting 7%
Construction	2019	98	98	98	98	98
Maintenance Cost #1	2028	32	30	29	28	27
Rehabilitation Cost #1	2028	15	14	13	12	11
Maintenance Cost #2	2037	33	29	26	23	20
Rehabilitation Cost #2	2037	15	13	11	9	8
Salvage Value	2045	24	22	20	19	18
Total Cost	**2045**	**223**	**209**	**197**	**187**	**178**

4.3.5 Results of economic impacts

In the economic impact analysis, we consider the generated economic impacts from the total project investments and the user benefits. The calculation is based on the input-output (IO) model parameters in the study area. The IO model parameters utilized in this tool are derived from IMPLAN. The industries in IMPLAN consist of 546 different industry codes and names. Our tool selects industry sectors that are related to freight transportation. The results of the calculation for employment sectors are shown in Table 4.5 and Table 4.6 for countywide and statewide analysis respectively.

Table 4.5 shows the countywide major economic impacts for all industry sectors in Gadsden County using the 2019 Net Present Value (NPV). The total economic impacts in all industry output is $83.1 million, the total income impact is $17.9 million, and the total increased employees would be 757. The economic growth from the proposed project is mainly concentrated in transportation, finance, real-estate, and wholesale trade sectors. Results for statewide economic impacts are shown in Table 4.6. The total

economic impacts in all industry output is $116.12 million, the total income impact is $35.16 million, and the total increased employment is 676.

Table 4-5 Case study 1 countywide economic impacts in industry sectors based on 2019 NPV ($ Millions)

Sector	Sector Output Impact ($)	Sector Employment Impact	Sector Income Impact ($)
22 Utilities	1.1	1.28	0.08
23 Construction	1.67	11.03	0.4
31-33 Manufacturing	1.03	3.7	0.23
42 Wholesale Trade	13.21	59.58	3.64
44-45 Retail trade	2.54	38.97	0.88
48-49 Transportation & Warehousing	27.89	365.73	4.62
51 Information	0.48	2.48	0.12
52 Finance & insurance	7.95	50.01	0.99
53 Real estate & rental	11.93	30.4	0.28
54 Professional- scientific & tech svcs	2.03	22.34	0.61
55 Management of companies	2.23	10.69	1
56 Administrative & waste services	6.51	84.64	2
71 Arts- entertainment & recreation	0.05	1.04	0.02
72 Accommodation & food services	0.58	8.52	0.18
81 Other services	0.87	19.74	0.42
92 Government & non NAICs	2.93	46.22	2.41
Total	83.1	757.27	17.9

Table 4-6 Case study 1 statewide economic impacts in industry sectors based on 2019 NPV ($ Millions)

Sector	Sector Output Impact ($)	Sector Employment Impact	Sector Income Impact ($)
22 Utilities	1.64	1.38	0.17
23 Construction	1.71	10.79	0.46
31-33 Manufacturing	7.09	18	1.2
42 Wholesale Trade	9.54	38.06	3.12
44-45 Retail trade	2.94	36.6	1.21
48-49 Transportation & Warehousing	32.7	175.11	10.21
51 Information	3.83	8.76	0.77
52 Finance & insurance	16.91	83.84	4.95
53 Real estate & rental	15.49	53.65	1.07
54 Professional- scientific & tech svcs	6.53	46.85	3.15
55 Management of companies	4.39	20.15	2.01
56 Administrative & waste services	7.57	116.32	3.86
71 Arts- entertainment & recreation	0.32	3.73	0.12
72 Accommodation & food services	1.12	16.36	0.42
81 Other services	1.72	20.22	0.73
92 Government & non NAICs	2.26	22.8	1.63
Total	116.12	675.98	35.16

4.3.6 Project costs and benefits

The economic benefits include two parts: the user benefits and economic impacts to the local economy. The user benefits, economic impacts, the total benefits and costs of the project are shown in Table 4.7 and Figure 4.2 for countywide analysis and Table 4.8 and Figure 4.3 for statewide analysis. The user benefits refer to the benefits of the new interchange on the travelers on the transportation system. It does not consider multiplier impacts of the investment. The economic impacts include direct and induced benefits of the new interchange and the multiplier impacts of investments in construction, maintenance and rehabilitation, as well as travel time saving on the economy.

As the results show, the total benefit is negative for countywide analysis. Table 4.7 shows economic impacts of the proposed project ranges between $90 million-$115 million. The user benefits are only $22

million-$34 million, while the total costs of the project ranges between $160 million and $200 million. Therefore, the total countywide net benefits are negative. This indicates that the investment will not bring positive benefits on the local level. When considering statewide impacts, the total project costs remain same, while the total user benefit will be as high as $654 million-$990 million, and the economic impacts ranges between $676 million-$989 million. Therefore, the total net benefits could be significant. Therefore, when decision-makers consider systemwide benefits of the investment on the whole transportation system in Florida, the proposed project would be worthwhile.

Table 4-7 Case study 1 countywide total costs and benefits of the project ($million, based on 2019 NPV).

Discounting factor	User benefits	Economic impacts	Total costs	Total benefits	Net benefits
0.07	22	90	160	112	-47
0.05	27	101	177	128	-49
0.03	34	115	200	149	-50

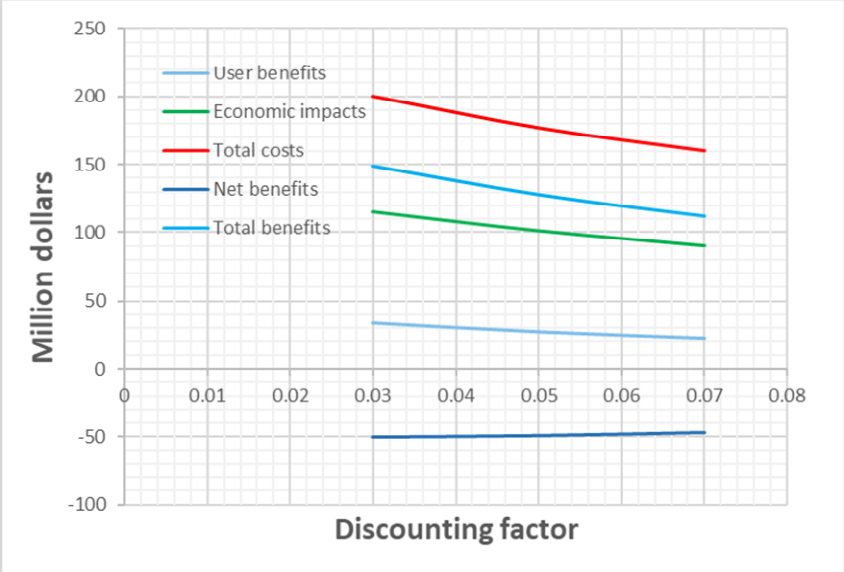

Figure 4-2 Countywide total benefits under different discounting rates in Case study 1

Table 4-8 Case study 1 statewide total costs and benefits of the project ($million, based on 2019 NPV).

Discounting factor	User benefits	Economic impacts	Total costs	Total benefits	Net benefits
0.07	654	676	160	1330	1170
0.05	795	807	177	1602	1425
0.03	990	989	200	1979	1779

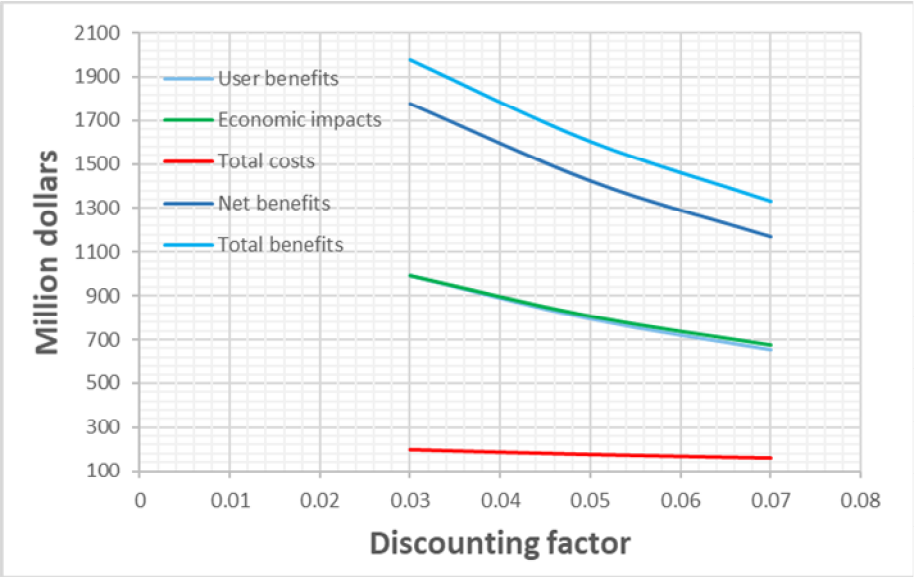

Figure 4-3 Statewide total benefits under different discounting rates in Case study 1

4.4 Conclusions

In general, the Highway expansion project in Gadsden County could generate negative countywide impacts and positive statewide impacts. The total project cost during the life cycle is between $160 million and $200 million. The countywide user benefits range from $22-$34 million, while the total countywide net benefits are between -$50 and -$47 million. When considering statewide economic impacts, the total net benefits would be as high as $1170 - $1779 million. The economic benefits are mainly concentrated in Wholesale Trade, Transportation Infrastructure, Finance & Insurance, and Real Estate & Rental. For example, the Transportation & Warehouse industry could get $32.7 million economic impact based on 2019

NPV (which was also used for the following economic impacts) and the Real Estate & Rental sector could produce $15.49 million in economic impacts.

5. Case Study 2: Florida State Interstate Highway Improvement in Miami-Dade County

5.1 Introduction

Case study 2 derives from the Florida 2040 Strategic Intermodal System (SIS) unfunded needs plan. The project aims to improve interstate highway capacity with additional lanes planned to be built on the Turnpike in the Miami-Dade County. The hypothetical project will be in the Miami-Dade County in the Miami metropolitan area. The project will be adding additional lanes to build 6-lanes on the Turnpike highway, which starts from the Florida State Highway 27 and ends at Florida 823 highway.

The focus of this case study is to illustrate the economic costs and benefits of the unfunded project proposal. This assessment utilizes the Florida Statewide Model's (FLSWM) Freight Component (FreightSIM) and the Florida Freight Transportation Economic Impact Kit (FreighTEC) post-processing tool to evaluate the potential project benefits.

5.2 Scenario Run

FreightSim output files provide traffic volume information in the state of Florida. Based on output files of FreightSIM, two scenarios in the year of 2015, Build and No-Build, are evaluated using the FreighTEC tool to calculate the cost and benefit of the project in 2040. Figure 5.1 shows the location of the proposed project in FreightSIM. In Figure 5.1, different link colors represent the number of lanes. The following nodes are located to match the hypothetical project:

3. 71575-72059 (72059-71575)

4. 72104-71572 (71572-72104)

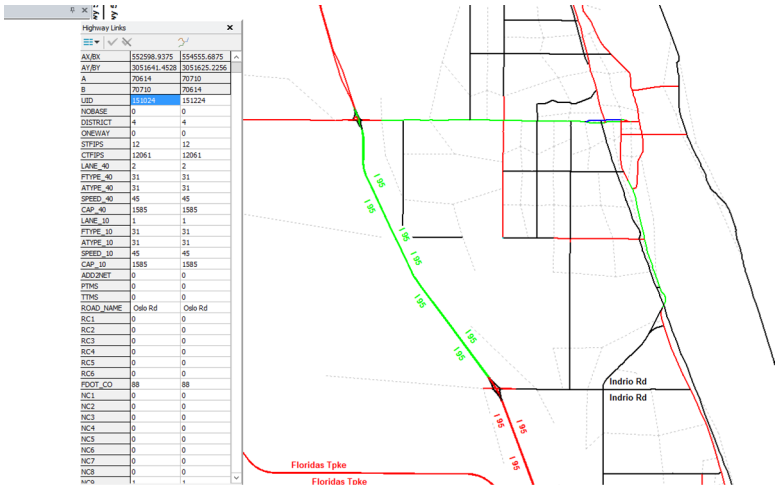

Figure 5-1 The location of the proposed project on the FLSWM network in Case study 2

5.3 Results

5.3.1 Vehicle Hours of Travel (VHT) calculation for the Built and No-Built scenarios

The VHT and VMT from FreightSIM outputs was used as a model input for FreighTEC to calculate the total VHT and VMT for both the Build and the No-Build scenarios. A model run was then produced for Miami-Dade County for countywide and statewide analysis and the results of the simulation are shown below in Table 5.1 and Table 5.2 respectively.

Table 5-1 Countywide VHT and VMT with (Build) and (No-Build) in Case study 2.

	No-Build Scenario	**Build Scenario**	**Differences**
VHT	49336.29	49297.79	-38.50
VMT	46,032,834.20	45,921,492.04	-111,342.16

Table 5-2 Statewide VHT and VMT with (Build) and (No-Build) in Case study 2.

	No-Build Scenario	**Build Scenario**	**Differences**
VHT	522,412.61	524,112.01	1,699.40
VMT	450,448,220.913	450,395,260.39	-52,960.52

The model shows that total countywide VHT in Miami-Dade County would decrease by approximately 38.5 total hours per day, and the statewide VHT could increase about 1,699.40 total hours per day in the scenario that the interchange is built. These reductions in VHT could generate benefits for those utilizing the facility. On the other side, countywide VMT decreases 111342.16 miles per day, and statewide VMT decreases 52,960.52 miles per day in the built scenario.

5.3.2 Life-cycle cost analysis inputs

The life-cycle cost analysis (LCCA) of a freight project includes the life-cycle agency cost and life-cycle user cost. The life-cycle agency cost includes: 1) the initial construction cost, 2) maintenance and operation costs, and 3) rehabilitation costs. Annual cost growth rates and VHT growth rates are applied to estimate the annual routine costs of maintenance and rehabilitation in the future. Since only the construction cost of the project is available at the time of this analysis, the LCCA inputs will use the construction cost and default parameters to estimate maintenance and operation costs and rehabilitation costs. The default parameters are derived from DOT reports and the existing literature (Li & Madanu, 2009; HERS-ST, 2020; FDOT, 2014, ODOT, 2013). It should be noted that the LCCA is sensitive to parameter values, so results could be different under higher cost growth rates and different cost estimation methods. The initial maintenance and operation cost are estimated at 3.5% of the construction cost, the initial rehabilitation cost is estimated at 14.5% of the construction cost, the annual cost growth rate is used at 3%, and the annual traffic growth is chosen at 2%.

5.3.3 Life-cycle cost analysis calculation

In Table 5.3, all results are displayed in million dollars. The total construction cost is about $36 million, and the total maintenance cost is about $28 million, the total rehabilitation cost is about $9 million, and the salvage value after the analysis period is about $8 million. The total countywide user benefit is about $15 million and the total statewide user benefit is about $548 million. These results show the project will generate positive benefits to countywide and statewide users.

Table 5-3 Case study 2 summary of Life Cycle Cost Analysis Output

Cost Category	Dollar Amount ($ Millions)
Planning, design and construction Cost	$36
Maintenance Cost	$28
Rehabilitation Cost	$9
Salvage Value	$8
Countywide User Benefits	$15
Statewide User Benefit	$548

5.3.4 LCCA Sensitivity Analysis

Sensitivity analysis are conducted using different discounting rates. In this study, we estimated different costs based on discounting rates ranging from 3 to 7 percent as shown in Table 5.4. The results in Table 5.4 consider total costs during the life cycle of the transportation project. Construction cost represents total initial cost of the project. Maintenance costs are aggregated based on the length of rehabilitation interval. There are two rehabilitation activities during the analysis period, which will happen in 2028 and 2037, respectively. Therefore, in Table 4.3, maintenance costs #1 represents total maintenance costs from 2019 to 2028, and maintenance costs #2 represents total maintenance costs from 2028-2037. The salvage value represents the remaining value of the investment at the end of the analysis period. These results show that as the discounting rate is increased, the total cost of the project decreases.

Table 5-4 Case study 2 LCCA sensitivity analysis outputs ($million based on 2019 Net Present Value (NPV))

Activity	Year	Discounting 3%	Discounting 4%	Discounting 5%	Discounting 6%	Discounting 7%
Construction	2019	36	36	36	36	36
Maintenance Cost #1	2028	12	11	11	10	10
Rehabilitation Cost #1	2028	5	5	5	4	4
Maintenance Cost #2	2037	12	11	10	8	7
Rehabilitation Cost #2	2037	6	5	4	4	3
Salvage Value	2045	9	8	8	7	7
Total Cost	**2045**	**83**	**78**	**73**	**69**	**66**

5.3.5 Results of economic impacts

In the economic impact analysis, we consider the generated economic impacts from the total project investments and the user benefits. The calculation is based on the input-output (IO) model parameters in the study area. The IO model parameters utilized in this tool are derived from IMPLAN. The results of the calculation for employment sectors are shown in Table 5.5 and Table 5.6 for countywide and statewide impacts, respectively.

Table 5.5 shows the countywide economic impacts for major industry sectors in Miami-Dade County using the 2019 Net Present Value (NPV). The total economic impacts in all industry output is $48.87 million, the total income impact is $14.43 million, and the total increased employees would be 266. Table 5.6 shows statewide economic impacts for major industries. The total statewide economic impacts in all industry output is $387.92 million, the total statewide income impact is $117.45 million, and the total statewide increased employees are 2,258. The countywide and statewide economic growth from the proposed project mainly concentrate in transportation, finance, and real-estate sectors.

Table 5-5 Case study 2 countywide economic impacts in industry sectors based on 2019 NPV ($ Millions)

Sector	Sector Output Impact ($)	Sector Employment Impact	Sector Income Impact ($)
22 Utilities	0.54	0.48	0.06
23 Construction	0.73	4.51	0.19
31-33 Manufacturing	1.05	2.96	0.16
42 Wholesale Trade	3.96	14.74	1.42
44-45 Retail trade	1.34	16.17	0.58
48-49 Transportation & Warehousing	15.33	58.18	3.73
51 Information	1.53	3.15	0.35
52 Finance & insurance	8.1	36.62	2.77
53 Real estate & rental	6.88	27.55	0.6
54 Professional- scientific & tech svcs	2.77	18.57	1.38
55 Management of companies	1.5	7.16	0.65
56 Administrative & waste services	2.78	48.81	1.29
71 Arts- entertainment & recreation	0.13	1.25	0.05
72 Accommodation & food services	0.49	6.48	0.2
81 Other services	0.79	10.37	0.32
92 Government & non NAICs	0.93	8.54	0.67
Total	48.87	265.86	14.43

Table 5-6 Case study 2 statewide economic impacts in industry sectors based on 2019 NPV ($ Millions)

Sector	Sector Output Impact ($)	Sector Employment Impact	Sector Income Impact ($)
22 Utilities	5.48	4.6	0.57
23 Construction	5.72	36.05	1.52
31-33 Manufacturing	23.68	60.13	4.01
42 Wholesale Trade	31.88	127.15	10.41
44-45 Retail trade	9.83	122.27	4.03
48-49 Transportation & Warehousing	109.24	584.99	34.12
51 Information	12.79	29.27	2.56
52 Finance & insurance	56.48	280.09	16.53
53 Real estate & rental	51.75	179.24	3.56
54 Professional- scientific & tech svcs	21.82	156.52	10.54
55 Management of companies	14.67	67.32	6.7
56 Administrative & waste services	25.29	388.59	12.89
71 Arts- entertainment & recreation	1.06	12.45	0.41
72 Accommodation & food services	3.76	54.66	1.4
81 Other services	5.75	67.55	2.44
92 Government & non NAICs	7.53	76.17	5.44
Total	387.92	2258.22	117.45

5.3.6 Project costs and benefits

The economic benefits include two parts: the user benefits and economic impacts to the local economy. The user benefits, economic impacts, total benefits and costs of the project are shown in Table 5.7 and Figure 5.2 for countywide results, and in Table 5.8 and Figure 5.3 for statewide results. The user benefits refer to the benefits of the new interchange on the travelers of the transportation system. It does not consider multiplier impacts of the investment. As the results show, in all cases, the total net benefits of the project range between $8 million and $17 million. The economic impacts include direct and induced benefits of the new interchange and the multiplier impacts of investments in construction, maintenance and rehabilitation, as well as travel time saving on the economy. Table 5.7 shows countywide economic impacts of the proposed project ranges between $56 million and $72 million. For the state level, Table 5.8 shows

the total net benefits ranging from $2,535 million to $3,847 million. The total statewide user benefits could be as high as $993 -$1,507 million. The statewide economic impacts could be ranging from $505 -$751 million.

Table 5-7 Case study 2 countywide total costs and benefits of the project ($million, based on 2019 NPV).

Discounting factor	User benefits	Economic impacts	Total costs	Total benefits	Net benefits
0.07	12	56	60	68	8
0.05	15	63	66	78	12
0.03	19	72	74	91	17

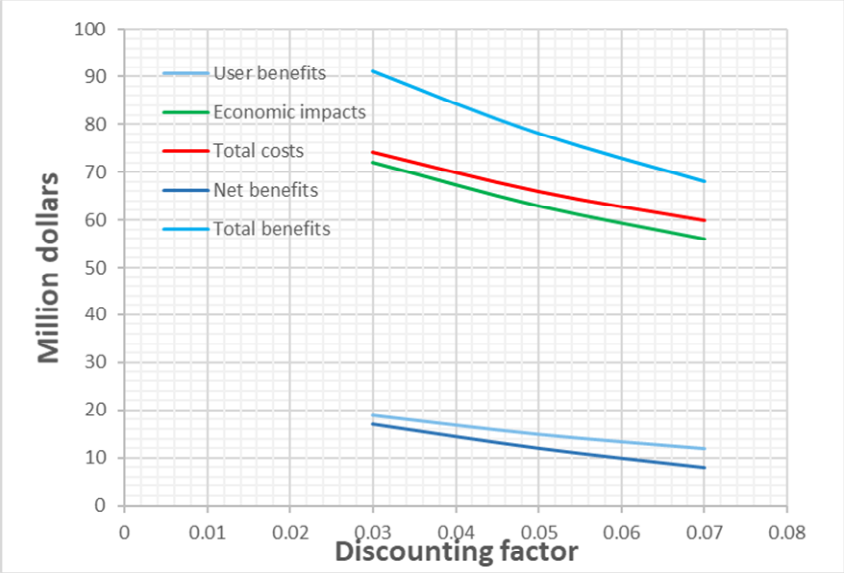

Figure 5-2 Total benefits under different discounting rates in Case study 2

Table 5-8 Case study 2 statewide total costs and benefits of the project ($million, based on 2019 NPV).

Discounting factor	User benefits	Economic impacts	Total costs	Total benefits	Net benefits
0.07	548	505	60	1053	993
0.05	667	609	66	1276	1210
0.03	830	751	74	1581	1507

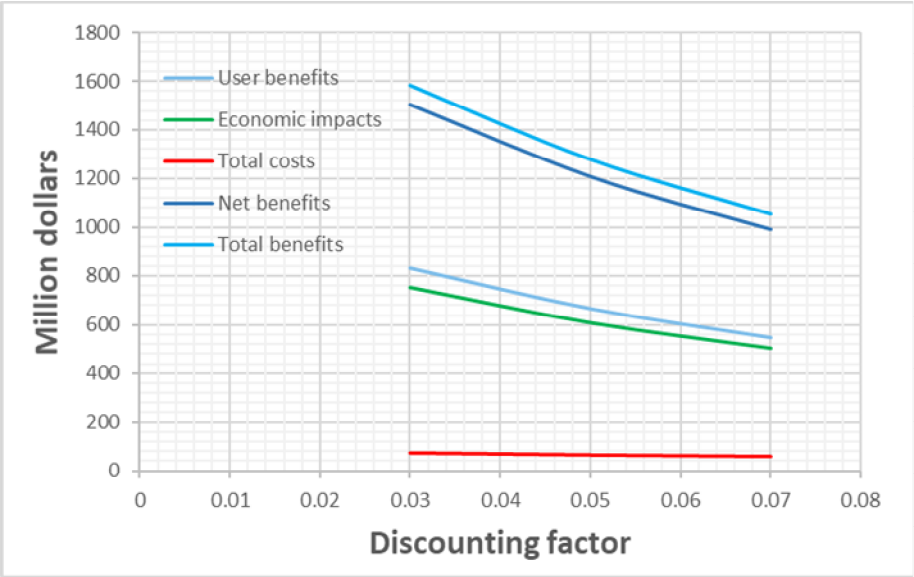

Figure 5-3 Total benefits under different discounting rates in Case study 2

5.4 Conclusions

In general, the proposed project could generate positive impacts on the freight transportation system to the user of the system and to the local economy as a whole. More specifically, the benefits are mainly concentrated in transportation infrastructure related industries. For example, the Transportation & Warehouse industry could produce $15.33 million countywide economic impacts and $109.24 million statewide economic impact based on 2019 NPV. The Real Estate & Rental sector could produce $6.88

million countywide economic impacts and $51.75 million statewide economic impacts. The countywide user benefits range from $12 - $19 million, while the statewide user benefits range from $548 to $830 million. The total countywide economic impacts range from $56 to $72 million and the statewide economic impacts are range from $505 to $751 million. When considering both the user benefits and the total economic impacts, the total net benefits would be as high as $8 to $17 million for countywide, and $993 to $1,507 million for statewide. Compared to the benefits, the total project cost during the life cycle is between $60 and $74 million. Based on the FreighTEC analysis, the life-cycle benefits of the unfunded project outweigh the life-cycle costs of the project.

6. Case Study 3: I-95 and Oslo Road Interchange Design Project

6.1 Introduction

The Florida Department of Transportation (FDOT) has proposed improvements for a new interchange at the junction of Oslo Road/ County Road 606 and I-95/SR-9. The purpose of these improvements is to provide additional capacity to accommodate future traffic needs. The proposed interchange will provide improved incident response time along I-95, improve regional connectivity and travel time for area travelers, provide an additional evacuation route for area residents, complement and facilitate the County's planned vision for this area, and provide roadway improvements that are compatible with adjacent planning and construction projects. Given the expectation of improvement in connectivity and travel time, the proposed project could also serve to benefit the state of Florida's freight connectivity, thus providing secondary economic benefits.

The proposed project, I-95 and Oslo Road Interchange Design Project, includes the construction of an interchange at I-95 and Oslo Road in southern Indian River County. Oslo road does not provide access to I-95 at its current location, the proposed interchange would be located approximately 5.5 miles north of the existing Indrio Road/SR 614 interchange and 3.8 miles south of the existing SR 60 interchange at milepost. The New Interchange project is designed as a rural diamond interchange with partial clover leaf loop ramps at I-95 and Oslo Road. Except for the proposed interchange, the project also includes the widening of Oslo Road from a two-lane facility to a four-lane divided facility and the replacement of the existing Oslo Road bridge over I-95. The project planning and design started as early as 2011 and it is expected to be constructed in 2020 and to be finished in 2023. The total expected cost of the project between 2011 and 2023 is about $59 million based on 2019 present values.

The focus of this case study is to illustrate the economic costs and benefits of the proposed I-95/Oslo Road Interchange. This assessment utilizes the Florida Statewide Model's (FLSWM) Freight Component (FreightSIM) and the Florida Freight Transportation Economic Impact Kit (FreighTEC) post-

processing tool. Florida's FreightSIM model is a travel demand model component integrated into the FLSWM that simulates the transport of freight and produces daily freight vehicle trip tables that can be assigned to the national and statewide networks within the FLSWM. Meanwhile, FreighTEC is an economic analysis kit based on a Florida-specific economic Input-Output (IO) model. Gains in freight mobility, such as the reduction of vehicle hours traveled (VHT), are converted into dollar values. These values are then used as inputs for the regional IO economic model to derive sectoral impacts. These two tools provide another method outside of regional transportation demand models and benefit cost analysis to evaluate the potential magnitude of project benefits. This additional method serves as a 'check and balance' in the transportation planning process, aids conservative evaluation of projects to support responsible fiscal planning.

6.2 Scenario Run

FreightSIM simulates the transport of freight between supplier and buyer business in United States, focusing on movements that involve Florida. Its output files provide traffic volume information in the state of Florida. Based on output files of FreightSIM, two scenarios in the year of 2015, Build and No-Build, are evaluated using the FreighTEC tool to calculate the cost and benefit of the project in 2045. FreightSIM includes multimodal networks for rail, waterways, airports, ports, and highways, as well as distribution center locations, for the US, with more detail in Florida. Figure 6.1 shows the location of the proposed project in FreightSIM. In Figure 6.1, different link colors represent the number of lanes.

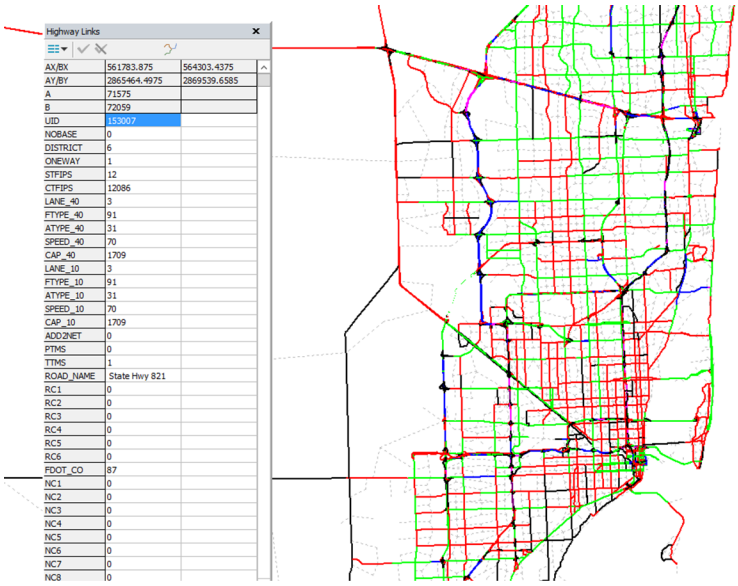

Figure 6-1 The location of the proposed project on the FLSWM network in Case study 3

6.3 Results

6.3.1 Vehicle Hours of Travel (VHT) calculation for the Built and No-Built scenarios

The VHT and VMT from FreightSIM output was used as a model input for FreighTEC to calculate the total VHT and total VMT for both the Build scenario (with the Oslo Road interchange) and the No-Build scenario (without the Oslo Road interchange) for both countywide and statewide impacts. A model run was then produced for Indian River County and the results of the countywide and statewide impacts are shown below in Table 6.1 and Table 6.2.

Table 6-1 Countywide VHT and VMT with (Build) and without (No-Build) the proposed Oslo Road interchange.

	No-Build Scenario	**Build Scenario**	**Differences**
VHT	4682.58	4634.9	-47.68
VMT	3186756.3038	3178334.93	-8421.37

Table 6-2 Statewide VHT and VMT with (Build) and without (No-Build) the proposed Oslo Road interchange.

	No-Build Scenario	**Build Scenario**	**Differences**
VHT	522412.61	525690.39	3277.78
VMT	450448220.913	450656604.8626	208383.95

The model results show that total countywide VHT would decrease by approximately 220 total hours per day and the statewide VHT would decrease by about 2091 total hours per day in the scenario that the interchange is built in Indian River County. These reductions in VHT could generate a significant reduction in travel time for statewide users. On the other side, the total countywide VMT deceases 752,916 miles per day and the total statewide VMT increases 37,222,961 miles per day in the build scenario. Therefore, the new project will attract more statewide trips when the new project is implemented.

6.3.2 Life-cycle cost analysis inputs

The life-cycle cost analysis (LCCA) of a freight project includes the life-cycle agency cost and life-cycle user cost. The life-cycle agency cost includes: 1) initial construction cost, 2) maintenance and operation costs, and 3) rehabilitation costs. Annual cost growth rates and VHT growth rates are applied to estimate the annual routine costs of maintenance and rehabilitation in the future. Since only the construction cost of the project is available at the time of this analysis, the LCCA inputs will use the construction cost and default parameters to estimate maintenance and operation cost and rehabilitation cost. The default parameters are derived from DOT reports and the existing literature (Li & Madanu, 2009; HERS-ST, 2020; FDOT, 2014, ODOT, 2013). It should be noted that the LCCA is sensitive to parameter values, so results could be different under higher cost growth rates and different cost estimation methods. The initial maintenance and operation cost are estimated at 3.5% of the construction cost, the initial rehabilitation cost

is estimated at 14.5% of the construction cost, the annual cost growth rate is used at 3%, and the annual traffic growth is chosen as 2%.

6.3.3 Life-cycle cost analysis calculation

In Table 6.3, all results are displayed in million dollars. The total construction cost (including the initial costs of planning and construction) is about $12 million, the total maintenance cost is about $12 million, the total rehabilitation cost is about $4 million, and the salvage value after the analysis period is about $3 million. The total countywide user benefit is about $23 million and statewide user benefit is about $1057 million, which means the project will generate positive benefits to both countywide and statewide users.

Table 6-3 Summary of Life Cycle Cost Analysis Output (($ Millions) in Case study 3

Cost Category	Dollar Amount ($ Millions)
Planning, design and construction Cost	$12
Maintenance Cost	$12
Rehabilitation Cost	$4
Salvage Value	$3
Countywide User Benefits	$23
Statewide User Benefit	$1057

6.3.4 LCCA Sensitivity Analysis

The Net Present Value (NPV) used in the analysis represents the discounted monetary value of expected costs (Walls and Michael, 1998). Future costs are discounted using a discounting rate. Discounting rates can significantly influence analysis results. Therefore, sensitivity analysis would be needed to measure results based on different discounting rates. In this study, we estimated different costs based on discounting rates ranging from 3 to 7 percent as shown in Table 6.4. The results in Table 6.4 consider total costs during the life cycle of a transportation project. Construction cost represents total initial cost of the project. There are two rehabilitation activities during the analysis period, which will happen in 2028 and 2037, respectively. Therefore, in Table 6.4, maintenance costs #1 represents total maintenance costs from 2019 to 2028, and maintenance costs #2 represents total maintenance costs from 2028-2037, same for maintenance costs. The

salvage value represents the remaining value of the investment at the end of the analysis period. These results show that as the discounting rate is increased, the total cost of the project decreases.

Table 6-4 Case study 3 LCCA sensitivity analysis outputs ($million based on 2019 Net Present Value (NPV))

Activity	Year	Discounting 3%	Discounting 4%	Discounting 5%	Discounting 6%	Discounting 7%
Construction	2019	12	12	12	12	12
Maintenance Cost #1	2028	4	4	4	3	3
Rehabilitation Cost #1	2028	2	2	2	1	1
Maintenance Cost #2	2037	8	7	6	6	5
Rehabilitation Cost #2	2037	4	4	3	3	2
Salvage Value	2045	3	3	3	2	2
Total Cost	**2045**	**27**	**26**	**24**	**23**	**22**

6.3.5 Results of economic impacts

In the economic impact analysis, we consider the generated economic impacts from the total project investments and the user benefits. The calculation is based on the input-output (IO) model parameters in the study area. The IO model parameters utilized in this tool are derived from IMPLAN. The industries in IMPLAN consist of 546 different industry codes and names. Our tool selects industry sectors that are related to freight transportation.

Table 6.5 shows the countywide economic impacts for major industry sectors in Indian River County using the 2019 Net Present Value (NPV). The total economic impacts in all industry output is $16.26 million, the total income impact is $5.47 million, and the total increased employees would be 119. The economic growth from the proposed project mainly concentrate in transportation, finance, real-estate, and wholesale trade sectors. Table 6.6 shows the statewide economic impacts is $834.54 million, the total income impact is $252.68 million, and the total increased employees would be 4,858.

Table 6-5 Case study 3 countywide economic impacts in industry sectors based on 2019 NPV ($million).

Sector	Sector Output Impact ($)	Sector Employment Impact	Sector Income Impact ($)
22 Utilities	0.01	0.02	0
23 Construction	0.32	2.1	0.08
31-33 Manufacturing	0.11	0.2	0.01
42 Wholesale Trade	1.59	4.3	0.69
44-45 Retail trade	0.68	8.64	0.28
48-49 Transportation & Warehousing	4.01	36.2	1.89
51 Information	0.39	1.11	0.08
52 Finance & insurance	2.78	16.81	0.75
53 Real estate & rental	3.35	11.95	0.18
54 Professional- scientific & tech svcs	0.96	7.88	0.44
55 Management of companies	0.3	1.49	0.13
56 Administrative & waste services	0.99	18.01	0.5
71 Arts- entertainment & recreation	0.03	0.37	0.01
72 Accommodation & food services	0.18	2.74	0.07
81 Other services	0.3	3.95	0.14
92 Government & non NAICs	0.27	3.41	0.22
Total	16.26	119.27	5.47

Table 6-6 Case study 3 statewide economic impacts in industry sectors based on 2019 NPV ($million).

Sector	Sector Output Impact ($)	Sector Employment Impact	Sector Income Impact ($)
22 Utilities	11.79	9.9	1.22
23 Construction	12.31	77.55	3.28
31-33 Manufacturing	50.94	129.36	8.62
42 Wholesale Trade	68.58	273.54	22.4
44-45 Retail trade	21.16	263.04	8.67
48-49 Transportation & Warehousing	235.02	1258.5	73.4
51 Information	27.51	62.96	5.5
52 Finance & insurance	121.52	602.57	35.57
53 Real estate & rental	111.34	385.59	7.67
54 Professional- scientific & tech svcs	46.94	336.72	22.67
55 Management of companies	31.56	144.83	14.41
56 Administrative & waste services	54.42	835.97	27.74
71 Arts- entertainment & recreation	2.27	26.79	0.88
72 Accommodation & food services	8.08	117.59	3.02
81 Other services	12.37	145.31	5.26
92 Government & non NAICs	16.21	163.86	11.69
Total	834.54	4858.15	252.68

6.3.6 Project costs and benefits

The economic benefits include two parts: the user benefits and economic impacts to the local economy. The user benefits, economic impacts, the total benefits and costs of the project are shown in Table 6.7 and Figure 6.2 for countywide impacts and in Table 6.8 and Figure 6.3 for statewide impacts. The user benefits refer to the benefits of the new interchange on the travelers on the transportation system. It does not consider multiplier impacts of the investment. As the results show, in all cases even without considering economic impacts, the user benefits of the project alone are positive. The economic impacts include direct and induced benefits of the new interchange and the multiplier impacts of investments in construction, maintenance and rehabilitation, as well as travel time saving on the economy. Table 6.7 shows countywide user benefits range between $15

million to $23 million. The countywide economic impacts of the proposed project ranges between $16 million and $21 million. The countywide total costs of the project are between $20 million to $24 million. When considering the economic impacts of the proposed project, the countywide total benefits range between $31 million to $44 million. When considering the total costs of the project, the countywide net benefits range between $11 million to $20 million. Similarly, Table 6.8 shows the statewide costs and benefits of the project. The statewide user benefits range between $1,057 million to $1,601 million, the total statewide economic impacts range between $895 million to $1,350 million. The total statewide benefits of the project are between $1,952 million to $2,951 million, and the total statewide net benefits could be as high as $2,927million.

Table 6-7 Case study 3 countywide total costs and benefits of the project ($million, based on 2019 NPV).

Discounting factor	User benefits	Economic impacts	Total costs	Total benefits	Net benefits
0.07	15	16	20	31	11
0.05	19	18	22	37	15
0.03	23	21	24	44	20

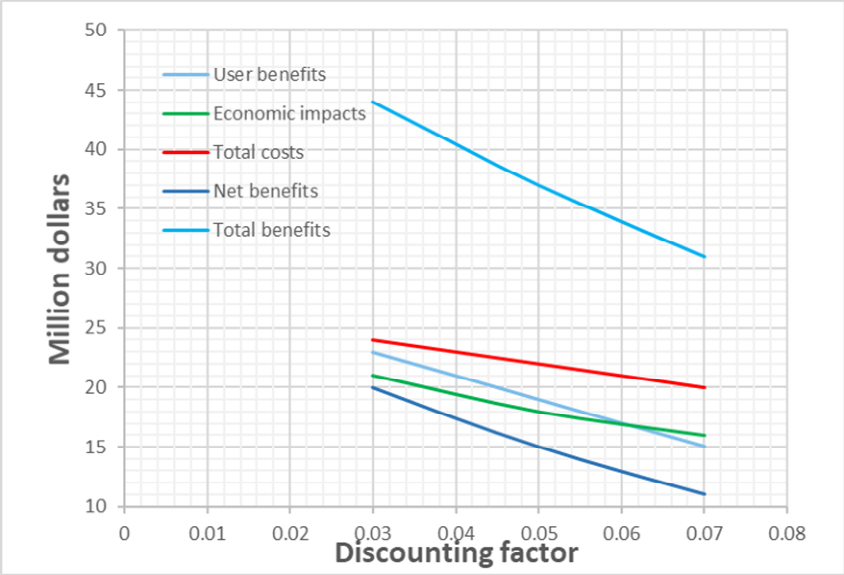

Figure 6-2 Countywide total benefits under different discounting rates in Case study 3.

Table 6-8 Case study 3 statewide total costs and benefits of the project ($million, based on 2019 NPV).

Discounting factor	User benefits	Economic impacts	Total costs	Total benefits	Net benefits
0.07	1057	895	20	1952	1932
0.05	1286	1087	22	2373	2351
0.03	1601	1350	24	2951	2927

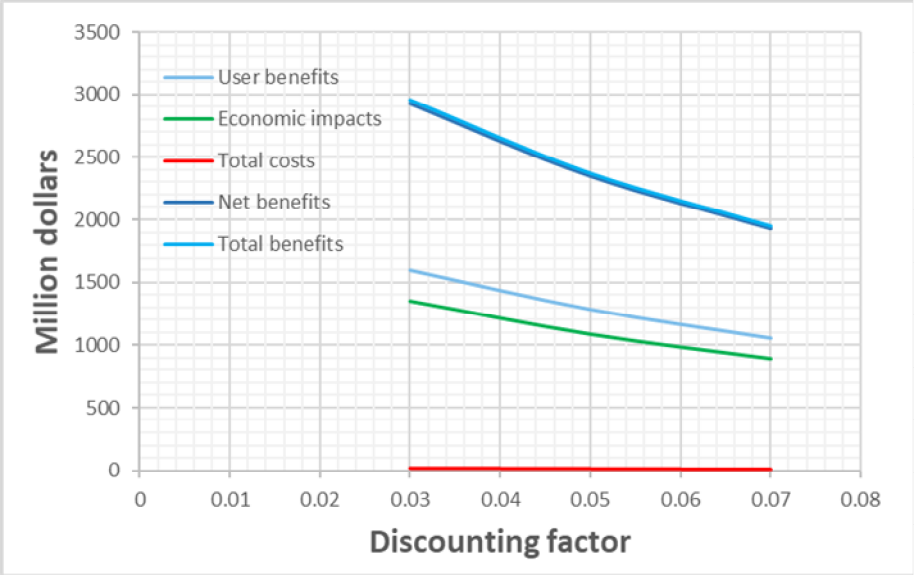

Figure 6-3 Statewide total benefits under different discounting rates in Case study 3.

6.4 Conclusions

In general, the I-95 and Oslo Road Interchange Design Project could generate positive impacts on the freight transportation system to the user of the system and to the local economy as a whole. More specifically, the benefits are mainly concentrated in transportation infrastructure related industries. For example, the Transportation & Warehouse industry could get $4.01 million countywide economic impact and $235.02 million statewide economic impact based on 2019 NPV (which was also used for the following economic impacts) and the Real Estate & Rental sector could produce $3.35 million countywide economic impacts and $111.34 million statewide economic impacts. The user benefits without considering economic

impacts range from $15 million to $23 million for countywide impacts and $1,507 million to $1,601 million for statewide impacts. The total countywide benefits are $31 million to $44 million, and the total statewide benefits are $1,952 million to $2,951 million. The total countywide net benefits are $11 million to $30 million, and the total statewide net benefits are $1,932 million to $2,927 million. Compared to the benefits, the total project cost during the life cycle is between $20 million and $24 million. Based on the FreighTEC analysis, the life-cycle benefits of the project will outweigh the life-cycle costs of the project.

7 Conclusion

This study developed the software tool, FreighTEC v2.0, to measure life-cycle costs and benefits of freight transportation project based on the existing freight economic analysis tool. We reviewed state of the art methods to measure economic benefits of alternative transportation projects and developed the methodology to combine life-cycle cost of transportation projects into the existing economic impact analysis tool to evaluate economic benefits of freight transportation projects. The developed framework is based on a Python 3.7. Compared with traditional cost-benefit analysis, the developed tool in this project incorporates direct, indirect and induced economic impacts of freight transportation projects in the evaluation of economic benefits.

The developed tool in this research includes more default parameters to evaluate the life-cycle costs of a transportation project. Results from case study 1 and 2 are measured based on the default model parameters, which indicate a reasonable estimation on the benefits of transportation investments. For example, results of the Highway expansion project in Gadsden County indicate a negative net benefit. This can be seen by the small improvement on local VHT. However, for the highway improvement project in Miami-Dade County, which could reduce higher total travel times in the area, will generate a positive impact on the transportation system. Nevertheless, given the high uncertainty of individual transportation project, it is highly encouraged to use more accurate project costs from the FDOT long-range forecasting office to evaluate the potential benefits from the transportation projects.

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