Estimating Total Cost of Bridge Construction using Accelerated Bridge Construction (ABC) and Conventional Methods of Construction

PROGRESS REPORT

Period Ending June, 2016

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September 2016

A. DESCRIPTION OF RESEARCH PROJECT

According to the U.S. Department of Transportation status report of 2013, 25.9% of the total bridges in the United States are either considered structurally deficient or functionally obsolete. There is therefore a pressing need for significant bridge repair and replacement efforts (DOT 2013). These bridge projects create a challenge to State Transportation Agencies (STAs) across the country in order to minimize the associated traffic disruptions in a safe way, while preserving the quality of the work and fulfilling budget constraints. In an effort to combat this challenge, the Federal Highway Administration (FHWA) is adopting and promoting the implementation of accelerated bridge construction techniques (ABC) through the "Every Day Counts" initiative to expedite project delivery and minimize their impacts on the transportation network (FHWA 2012).

Accordingly, a number of STAs are implementing ABC techniques and experienced positive outcomes in a significant number of bridge replacement and/or rehabilitation projects. However, ABC techniques are often associated with high initial costs, which deters many STAs from a wider implementation of these techniques (TRB 2013). In addition, the impact of adopting these accelerated techniques to current bridge design and construction processes is not fully understood, which adds to the complexity of choosing ABC over conventional methods in bridge projects. Therefore, there is a pressing need to provide decision makers with a comprehensive tool for estimating the total cost of ABC projects including: construction, indirect, agency cost, and user costs. This tool will facilitate comparing the total cost of bridge repair and replacement work under both ABC and conventional methods.

A.1. Problem Statement

Accelerated Bridge Construction (ABC) methods have been successfully used by many STAs for both planned and emergency bridge projects. However, the total cost of ABC projects are not completely understood let alone being included in the decision making process for such projects. This total cost include: construction, indirect, agency, and user costs. These costs need to be analyzed and estimated to support better decisions in selecting ABC versus conventional bridge construction methods. However, this analysis and estimation process is a complex process as it involves the evaluation of different types of costs including but not limited to: construction costs, engineering and inspection costs, user costs (with consideration of impacts on mobility, reliability, motorist and construction worker safety, and emission), right of way, quality of work, and the impact on surrounding communities and businesses (Salem & Miller 2006). Unfortunately however, the lack of appropriate tools inclusive of the aforementioned factors does not allow the agencies to fully realize the true benefits and appreciate the true costs of ABC compared to conventional bridge construction. In order to address these gaps in both the body of knowledge and current ABC practices, the objectives of this project are to: (1) better understand and estimate the costs associated with ABC; and (2) Analyze different ABC case studies to determine the drivers and barriers for implementing ABC as well as performing a benefit-cost analysis.

A.1.a. Brief Description of Current Practices of ABC Decision Making

There are a number of existing tools that are currently in use by or available to STAs to support their decision-making related to ABC; these tools can be categorized under two main categories: qualitative and AHP-based quantitative tools, as shown in Figure 1.

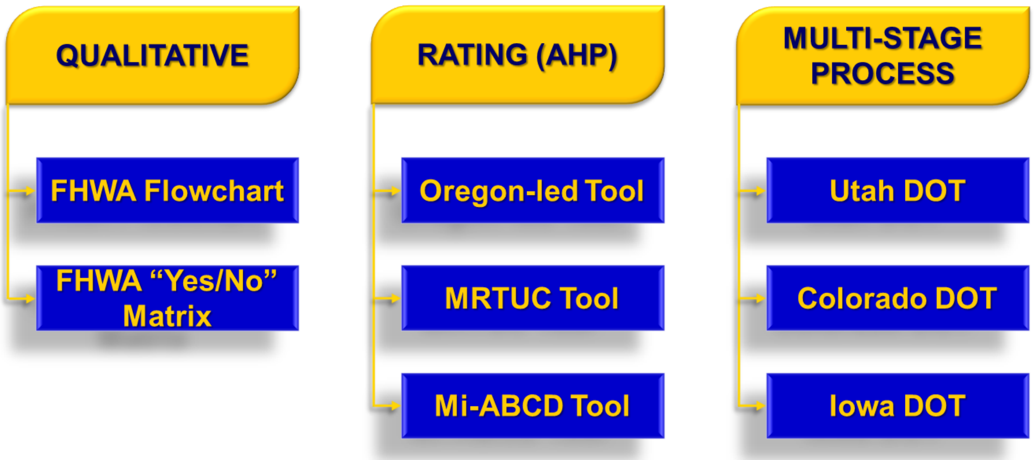


Figure 1: Current Decision Making Tools for Bridge Construction Projects

Qualitative tools currently in use by STAs include flowcharts, matrices, and questionnaires. One of the most widely used qualitative tools is the FHWA flowchart (FHWA 2005) that is designed to assist decision makers in determining whether the use of prefabricated bridges is suitable for their projects or not. The flowchart (Figure 2) includes questions related to major factors that might trigger the use of ABC, such as: average daily traffic; whether it is an emergency bridge replacement project; whether the bridge is on an evacuation route; detours and lane closures times; and whether the bridge construction is on the critical path of the project schedule. If the user answers "no" to all these questions, the use of ABC is only justified if it improves safety and/or if the construction cost is less than that of conventional bridge construction. Alternatively, if the answer to any one of five aforementioned questions is "yes", then the decision maker should consider ABC after examining the bridge's need for rapid construction, and the associated safety and costs impacts. Similar decision making practices are followed in other qualitative tools, such as the FHWA matrix and STA questionnaires. This kind of subjective practice that uses a yes/no and/or Likert scale approaches to evaluate ABC projects is insufficient in identifying and evaluating the true costs of ABC methods.

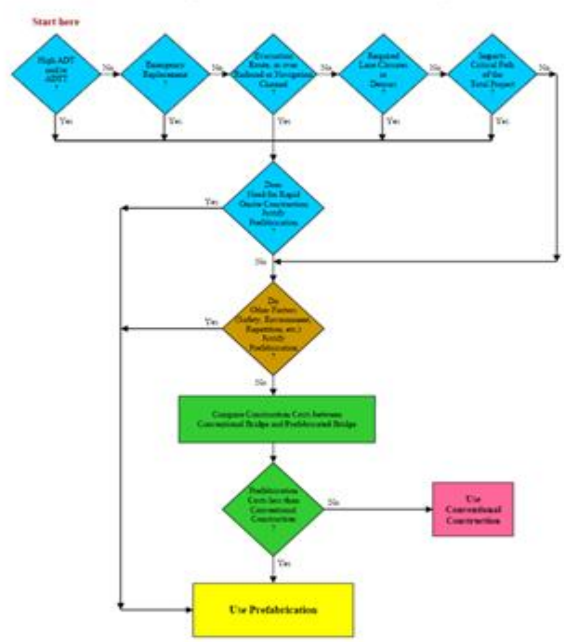


Figure 2: Flowchart for PBES Decision Making

AHP-based quantitative tools are also used for ABC decision making. One of these tools, and perhaps the most well-known ABC decision making tool, is developed by the Oregon Department of Transportation (ODOT) in collaboration with seven other DOTs (Doolen et al. 2011). In this tool, five main decision criteria are considered: direct cost, indirect cost, schedule constraints, site constraints, and customer service. Furthermore, a set of sub-criteria was developed for each of these five criteria as seen in Figure 3. The tool guides the decision makers through performing two-step pair-wise comparisons between the construction alternatives for each of the criteria selected by the users based on their goals and priorities. This method considers myriad factors and reduces the very high subjectivity inherent in the qualitative tools by attempting to assign scores to each construction method based on its performance in each of the criteria considered. However, these scores and their relative weights are still subjective since they are assigned based on the user's perceptions rather than objective evaluation and in-depth analysis. These tools are therefore susceptible to underestimation or overestimation of the utility of different alternatives. While such methods might be suitable for inherently subjective criteria, such as customer service, they are insufficient to objectively evaluate criteria such as construction, indirect, and user costs.

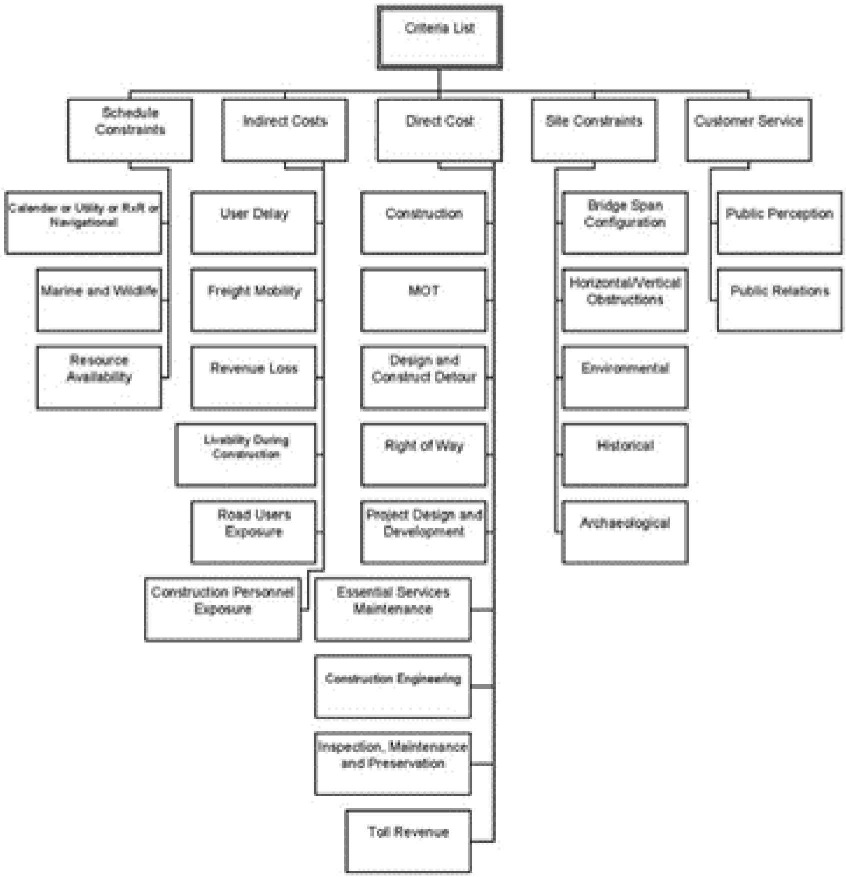


Figure 3: ODOT AHP Tool Decision Criteria and Sub-criteria

Another important component in decision-making process is to assess the user costs. The "Work Zone Road User Costs – Concepts and Applications" report produced for the Federal Highway Administration presents a framework for the use of user and construction costs in alternative analysis and associated decision making process. The report also discussed how the unit cost of delays, vehicle operating cost, crashes, and safety can be calculated based on outputs from tools and methods that can calculate these parameters. A number of tools have been developed to assess the impacts of work zones o mobility. The FHWA Traffic Analysis Toolbox Volumes VIII and IX classifies these tools to sketch planning tools, traffic demand models, signal optimization tools, macroscopic simulation, mesoscopic simulation, and microscopic simulation. These documents provide guidance to assist in selecting between these different types of tools based on various factors.

The sketch planning tools range from simple spreadsheets that allow the analysis of a single link (like the Q-DAT developed for Texas A&M) to slightly more complicated tools like the QuickZone developed by FHWA that allows the modeling of multiple links on the subject facility and alternative route. A good example of macroscopic simulation models are the tools that implement the freeway and urban street facility procedures of the Highway Capacity Manual (HCM) including the soon to be updated work zone procedures in the 2015 update of the HCM. An example of the use of demand forecasting-based and simulation-based dynamic traffic assignment modeling tools is the WISE approach developed as part of the SHRP 2 R11 project. Most of the above mentioned tools do not consider in details reliability, emission, and safety impacts. Recent information, tools, and findings from the TRB SHRP 2 Reliability program, EPA MOVES emission modeling, and Highway Safety Manual (HSM) procedures are not considered. Real-word data from advanced monitoring systems and other sources are also becoming available that will allow the provision of more detailed data to the developed tools and to confirm their performance. The use of the data needs to be further considered to support the decision making processes related to ABC construction.

A.2. Contribution to Expanding Use of ABC in Practice

Development of a comprehensive tool that has the capability of estimating the total cost of ABC projects and compare them with those of the conventional methods will help decision makers in understanding and evaluating the true benefits and costs of ABC methods at an early stage of the project development which, in return, will lead to the expansion in the use of ABC methods versus the conventional ones.

A.3. Research Approach and Methods

Due to the limitation of the existing ABC decision making tools, there is a need for an integrated tool that can assist decision makers in reliable estimation of a wide range of costs and impacts related to ABC. Such integrated decision support tool should facilitate decision-making at different planning stages based on the information available at each of these stages. Hence, this project aims at creating a vision for a multi-tier tool decision making tool, which has the capability of assisting the decision makers during these different stages; namely: the early planning, preliminary design, design & implementation, and construction stages. Thus far, the research team has developed a preliminary framework for a multi-tier tool composed of two tiers, as seen in Figure 4. Each tier includes a set of modules for estimating the costs and benefits of ABC based on the information available at that stage.

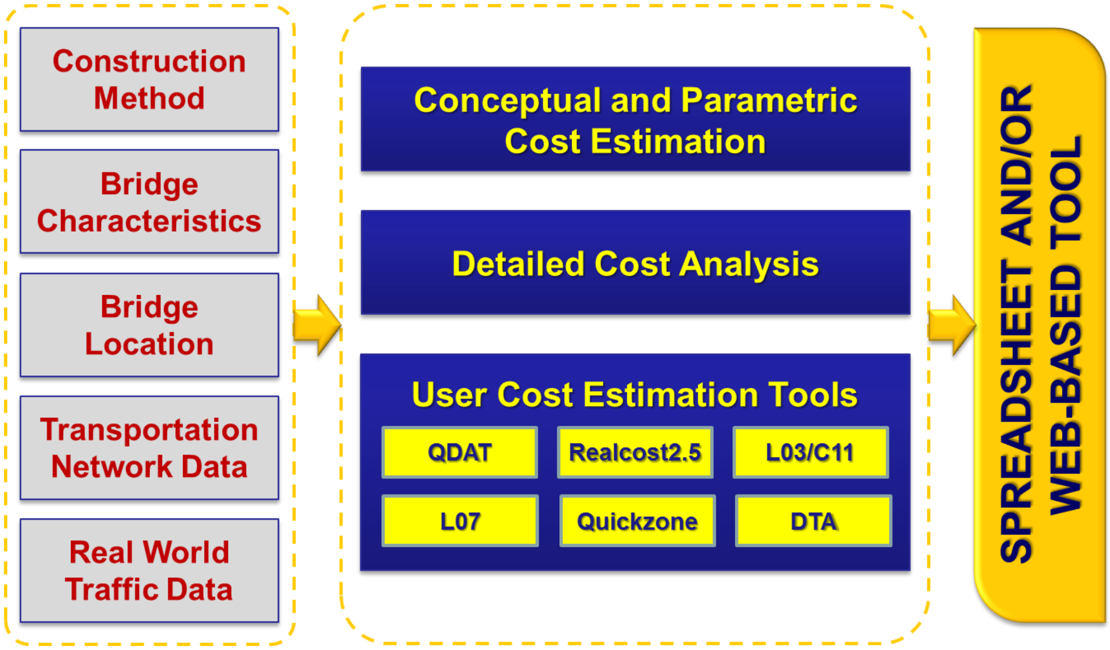


Figure 4: Overview of the Envisioned ABC Cost Estimating Tool

- ***Tier 1***: The modules included in this tier will be used during the early planning stage when little information is known about the project or during the preliminary engineering design stage at which more specific information is available. This tier will primarily help the decision makers to get a conceptual and parametric estimation of ABC costs and impacts.

- ***Tier 2:*** The modules included in this tier will be utilized during the project's design & implementation phase. By this stage the decision to adopt ABC is already taken, but with a more detailed analysis of the costs and impacts, decision makers can reach the decision of which ABC method is best suited for their project by utilizing multi-objective optimization methods based reliable estimates of a wide range of costs and benefits.

As seen from the above discussion, the envisioned ABC decision making framework consists of two different tiers, each takes into account and analyzes a different set of decision factors and considers the availability of information at that phase of decision making. While the scope of the current project is only limited to developing modules for estimating user and construction costs of ABC projects in various stages and combining these two cost components to assess the true cost of ABC, the vision for the integrated ABC decision support tool is to continue this research effort to create, validate, and deploy a multi-tier ABC decision support tool that includes the product of this project as a component.

A.4. Description of Tasks to be Completed in Research Project

The following tasks will be completed to achieve project tasks.

Task 1: Review of State-of-the-Practice and State-of-the-Art: This review will include review and assessment of existing methods and tools used in calculating public costs and in supporting agency decisions, as they relate to ABC. This task will also review current agency practices and policies in evaluation of public costs and in making decisions regarding ABC during the planning, design, construction, operations, and preservation of roadway infrastructure. The research team will conduct an extensive review of the existing literature on the subject.

Task 2: Create a Two-Tier Model for ABC Construction Cost Analysis: The research team will utilize various ABC data sources (e.g., FHWA database) and case studies to develop a two-tier cost analysis. The Tier-1 will include a conceptual cost estimation model that will provide a high level cost estimate for an ABC project based on different characteristics such as number of spans, ABC type, road type, and materials. The Tier-1 model will be developed mainly based on the FHWA data. The tool will be created in a spreadsheet platform and will be posted on the ABC-UTC website for use by transportation agencies. This model will be appropriate for early stages of the project, when limited information is available and a less detailed analysis is sufficient.

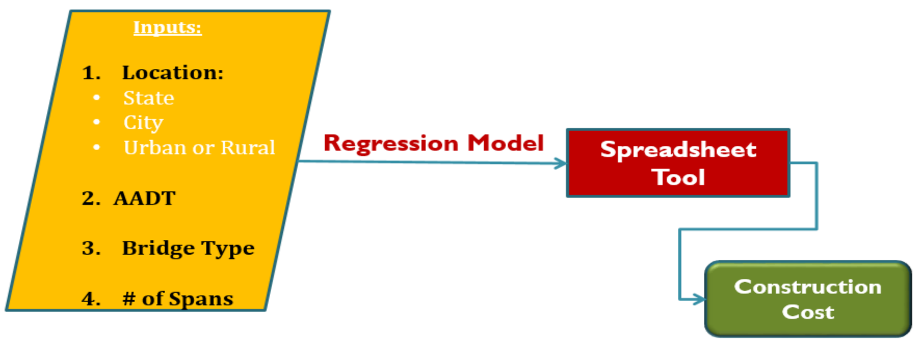


Figure 5: Tier-1 Cost Estimation Tool

The Tier-2 tool will include a mean for detailed cost estimation of ABC project. To this end, the research team will identify the key cost items for three main ABC methods (i.e., SPMT, Lateral Slide, and Modular method). For this purpose, data will be collected from various ABC case studies and cost reports and schedules will be analyzed to identify the cost items (Figure 6) and activities that cause cost difference between these methods as well as the conventional methods of bridge construction. Based on the collected data, a checklist of detailed cost items for the three main ABC methods will be developed. The checklist will be shared with selected transportation agencies for verification and collection of numerical values of cost items. The research team will emphasize collecting the indirect costs of ABC projects, in order to make comparison with the conventional methods, since very limited information is currently available related to this item. Based on the feedback and data collected from the transportation agencies, the research team will create a spreadsheet tool for comparative cost analysis of different ABC methods vs. conventional methods of bridge construction.

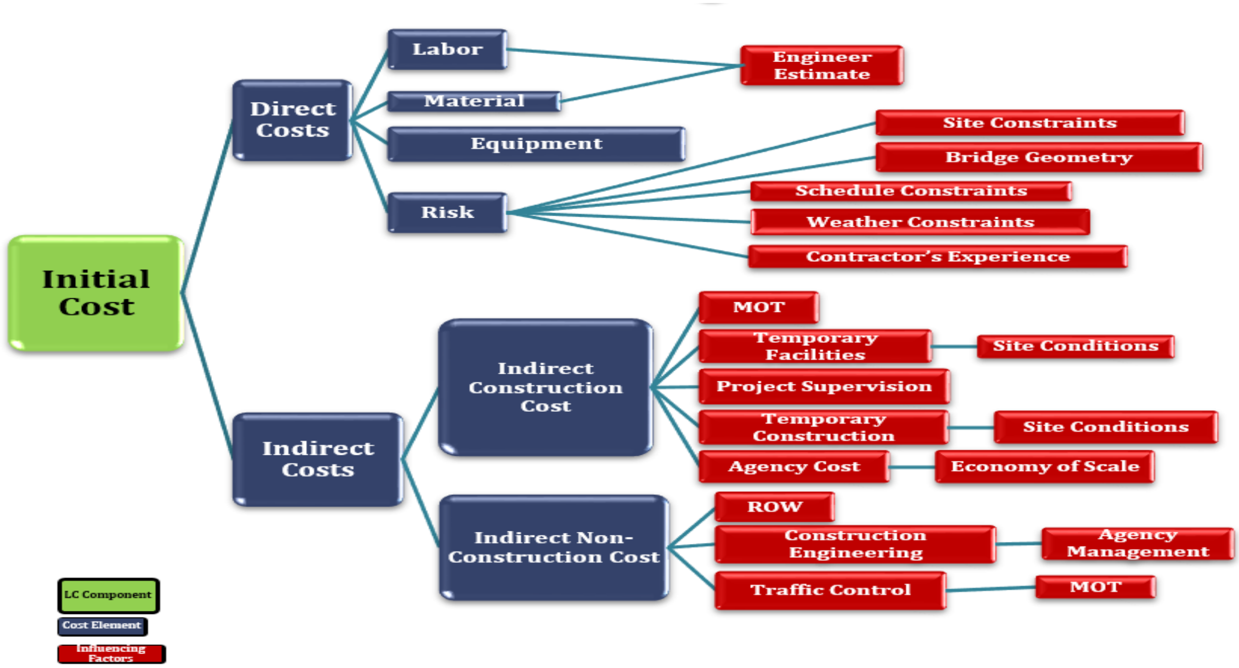


Figure 6: Components of the Tier-2 Estimation Tool

Task 3: User Cost Analysis: An integrated environment of methods and tools will be developed in this study to support scenario analysis and the estimation of associated user costs at early stages of bridge construction projects when less detailed analysis is needed and at later stages when more detailed analysis is needed. Within such an environment, the impacts of bridge construction on traffic mobility and reliability can be estimated utilizing different analysis methods and tools, depending on the level of details available at the current phase of bridge construction. In the first stage, the early planning stage, the analysis of bridge construction impacts may be conducted at the sketch-planning level. Available sketch-planning tools such as Q-DAT developed by TTI, SHRP 2 C11, and RealCost developed by FHWA, analysis is needed and more data is available QuickZone tool developed by FHWA, and SHRP 2 L07 tool can be used, in combination with other procedures. The selection between these tools depends on the data availability at the early stages of the implementation since some of them require more data than others. A route diversion model will be developed in this study and integrated with these sketch-planning level tools to capture the diversion of travelers resulted from bridge construction and provide a better estimation of mobility impacts..

At the design and implementation stages of the project, more detailed analyses may be required to assess the impacts of bridge construction. In this case, more detailed modeling tools such as static traffic assignment or simulation-based dynamic traffic assignment (DTA) are more appropriate. At this stage, the principals of the WISE tool proposed by SHRP 2 R 11 project, can be used to model the construction impacts with the consideration of traffic diversions. When lacking detailed data and the required resources to perform simulation-based DTA, the highway capacity manual (HCM)-based procedures and tools may be applied.

During the construction and post-construction stages, real-world data may be available and therefore a before and after study can be conducted based on collected data to evaluate the mobility and reliability impacts of construction. This study will also recommend procedure to monitor the actual user cost incurred by an agency during construction based on real-world data.

The outputs of traffic counts, speed, and delays from the different levels of analysis can be associated with the MOtor Vehicle Emission Simulator (MOVES) developed by the United States Environmental Protection Agency (EPA) to estimate the emissions and meanwhile applied to produce vehicle operating costs.

Work zone safety including both motorist safety and worker safety is also an important component when assessing user costs. The statistics of work zone crashes and crash modification factors resulting from mitigation strategies will be collected based on existing studies and used as part of the developed tools.

Another important component of the developed integrated environment is to estimate the business and social impacts of bridge construction. The application of ABC method is expected to reduce these impacts. Land use data, trip purpose, type, and socio-economic characteristics of the trip maker that pass the construction zone or divert to alternative routes because of construction will be extracted from either the conventional four-step travel demand model or more advanced activity-based demand model and used in the calculation of business and social impacts. Similarly, the different types of freight trips affected by bridge construction can also be obtained from travel demand model and combined with the data of commodity distribution and value of commodity to assess the loss due to impacts on freight mobility and reliability.

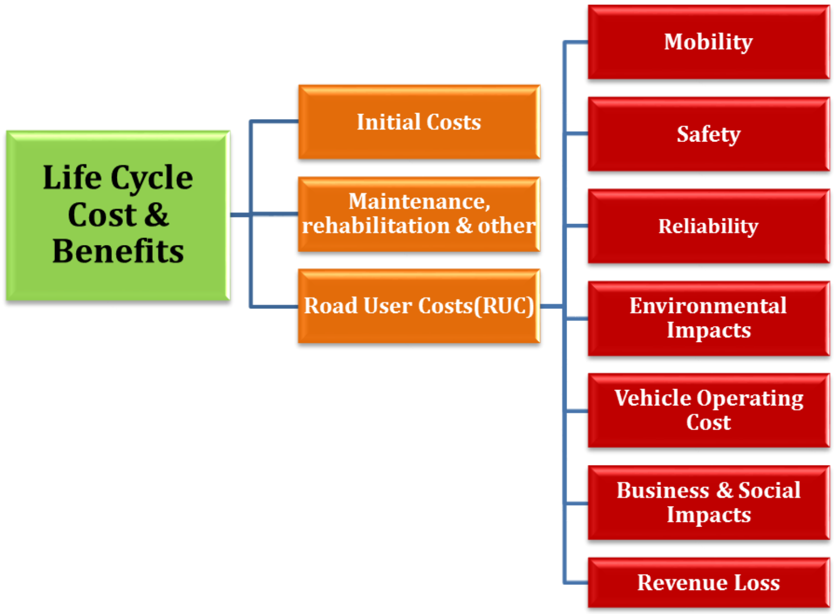
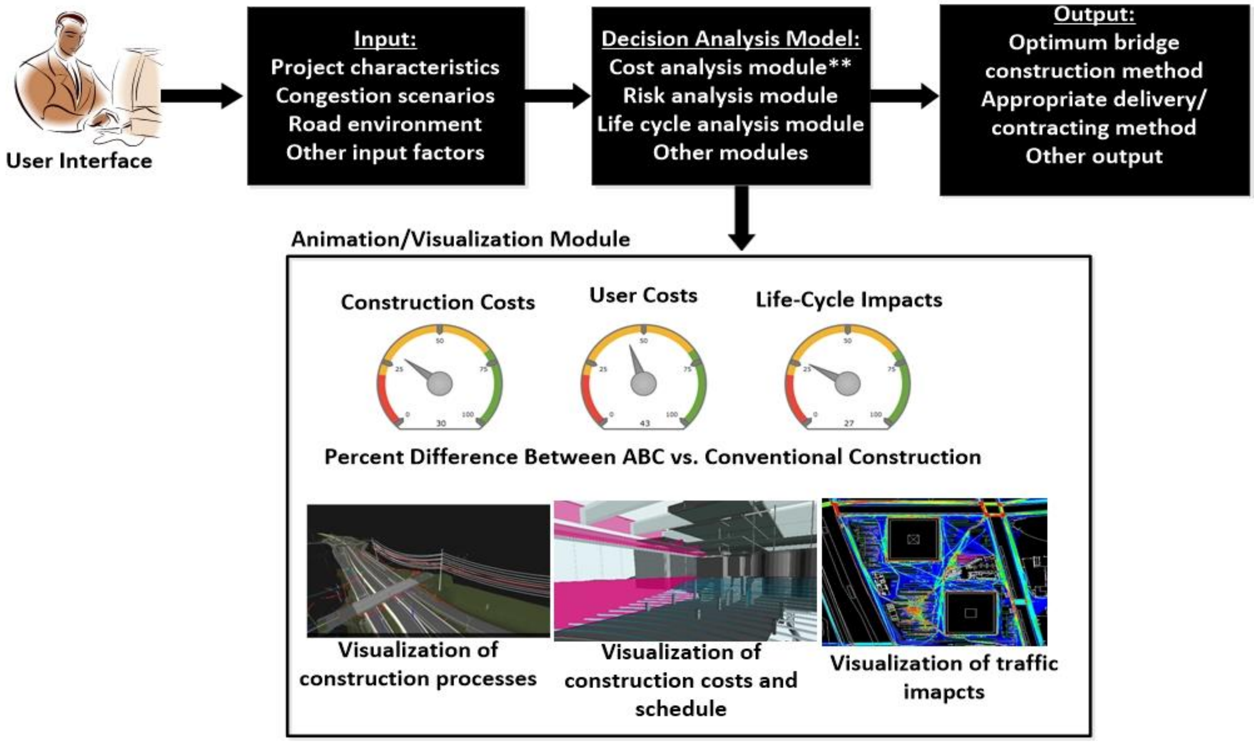


Figure 7: Components of the User Costs

Task 4: Recommendation of Estimation and Assessment Framework: The tools developed in Task 2 and Task 3 will be integrated into a spreadsheet tool for transportation agencies to determine the total costs of ABC projects. In addition, a framework will be proposed for a web-based decision support system that integrates the recommended methods and tools in a user-friendly system. Figure 8 demonstrates an example of components of the envisioned decision support framework. The cost estimates produced by different components of the framework will be combined through a fuzzy logic algorithm. The users will be able to assign different weights to different costs components based on local conditions. This will used as the basis of a quantitative multi-criteria decision making process to support agency decisions.



***This project will only focus on the cost analysis module and development of cost estimation tool of the envisioned framework rather than development of animation and visualization tools*

Figure 8: Components of the Envisioned Bridge Construction Decision Support Framework

Task 5: Method Applications to Identified Scenarios: This task will demonstrate the use of the recommended framework and the cost analysis module utilizing a number of scenarios. The results will be analyzed to determine the effectiveness of the proposed framework and if any adjustments are needed. This task will first identify few bridge construction scenarios that are representative of typical bridge project characteristics. These characteristics include, for example, bridge size (number of spans and lanes), traffic demands, operating environment (e.g., area type, facility type, etc.), and the availability of near-site space for bridge component prefabrication. The data needed for identifying such scenarios will be collected from the agency survey mentioned in Task 1, case studies, geographical information system (GIS) data, and traffic volume data.

Once the scenarios are selected, the recommended methods in Tasks 2 and 3 will be applied and the results will be examined to determine any issues with the estimated costs and associated decisions based on identifying the major differences between the conventional and accelerated construction methods. In addition, sensitivity analyses will be applied to study the impact of variables uncertainty on construction time, traffic operations, and user and construction costs. The sensitivity analysis will facilitate evaluating the impact of risk factors, such as weather conditions, traffic conditions, and other project characteristics on construction production rates and hence project time and costs for the different scenarios. The results of this task will be used to recommend refinements, if needed, to the framework developed in Tasks 2 and 3.

Task 6: Production of Guidebook and Final Report: The results of the research will be incorporated in a guidebook describing key cost factors and outlining the decision support framework. The deliverables will also include a tool for analyzing and estimating public costs of ABC. In addition, final report will document the efforts and results of Tasks 1 to 5 of the project in accordance with ABC-UTC guidelines.

B. CURRENT PROGRESS

B.1. Completed activities:

Thus far, several research tasks have been conducted to attain the research objectives:

1. *State-of-the-Art literature review:* During this task, a comprehensive literature review was conducted to identify the current ABC decision making tools, the decision factors taken into account, and the way these factors are accounted for. Furthermore, a literature review identifying the different components of indirect & agency cost was completed. From this information, the limitations of the current tools and the requirements of the new tools were identified. Finally, a comprehensive review of the current user cost estimation tools was conducted to assess the strengths and weaknesses of each tool and determine their suitability to be used in the context of this study.

2. Tier-1 Construction Data Collection: In this task, data related to the final construction cost and duration of several nationwide completed ABC projects as well as the characteristics of these projects were collected. In total, data from 65 projects related to 29 different states were collected as shown in the table below.

Table 1: Construction Cost Data

	State	Project Name
1	Alaska	O'Malley
2		Grayling Creek
3		Kouwegok Slough
4		Pelican Creek
5	Arizona	Mescal Road / J-Six Ranch Road
6		Oak Creek
7	California	Craig Creek
8		Hardscrabble Creek
9		North Fork of Mill Creek
10		Carquinez Strait
11		Ft. Goff Creek
12	Connecticut	Church Street
13	Georgia	Kia Blvd
14	Hawaii	South Punaluu Stream
15		North Kahana Stream
16		Keaiwa Stream
17	Idaho	Vista Interchange
18		Black Cat Road
19	Illinois	Illinois Rt. 29 over Sugar Creek
20	Iowa	US 6 over Keg Creek
21		Little Cedar Creek
22		640th Street over Branch Raccoon River
23		Jakway Park
24		24th Steet over I-29/80
25		Madison Co
26		Mackey (Marsh Rainbow Arch)
27	Louisiana	LA 3249 (Well Road) Bridge over I-20
28		I-10 over Lake Pontchartrain
29	Maine	Boothbay
30	Maryland	MD Route 24 over Deer Creek
31	Michigan	Parkview over US 131
32	Minnesota	TH 53 over Paleface River
33		TH 61 over Gilbert Creek
34		MN Bridge 27504 over SH 62
35	Mississippi	Kickapoo Road over Bogue Chitto Creek
36	Missouri	I-44 over Gasconade River
37	New Hampshire	I-93 over Loudon Road
38		Mill St. over Lamprey River
39	New Jersey	Route 202 over Passaic River
40		Gordon's Corner Road over Route 9
41		Route 70 over Manasquan River
42		Route 1 over Olden Ave & Mulberry Street
43	North Carolina	Biltmore Avenue
44		Tar River - Washington Bypass
45		NC 12 over Molasses Creek - Ocracoke Island
46	Ohio	Bowman Road
47	Oregon	OR 213 over Washington Street (Jughandle)
48		Kimberly
49	Pennsylvania	Montour Run #6
50	South Dakota	Buffalo Creek
51		41st Street
52	Texas	SH 290 at Live Oak Creek
53		Sam White over I-15
54		Layton Parkway over I-15
55	Utah	I-70 over Eagle Canyon
56		I-80 over 2300 East
57		Riverdale Road over I-84
58		I-215/4500 South Bridge
59	Vermont	Rte 4 Bridge 50 - Woodstock
60	Washington	US 12 over I-5 at Grand Mound
61		Northeast 8th Street
62		South 38th Street
63	Wisconsin	CTH B over Parsons Creek
64	Wyoming	Ham's For River
65		Inyan Kara Creek

3. Tier-1 Indirect Cost Data Collection: In this task, data about the magnitude and types of different components of the indirect & agency costs are being collected and at this stage data from 13 projects from ODOT and one project from MassDOT were compiled as shown in the table below.

Table 2: Indirect Cost Data

	State	Project Name
1	Massachusetts	Holyoke Bridge H-21-039
2	Oregon	Willamette River, Hwy 61 (Fremont)
3		I-5 Bridge Trunnion, Columbia River & N Hayden Island
4		Multnomah Channel, Sauvie Island Rd.
5		Mill Creek, Hwy 53
6		Jughandle, Hwy 160 over Washington St
7		Elk Creek, Hwy 45 at MP 39.64, Crossing No. 3
8		Imnaha River, Little Sheep Creek, Hwy 350
9		Rogue River (Depot Street)
10		Elk Creek, Hwy 45 at MP 39.97, Crossing No. 4
11		Volmer Creek, Hwy 47
12		Johnson Creek, Hwy 47 At MP 3.26
13		Hardscrabble Creek, Hwy 45
14		Hayes Creek, Hwy 33

4. Tier-1 Construction Cost and Indirect Cost Analysis: To analyze the data, the collected data were normalized for time and location using the RS Means indices and a statistical classification model was used to create a model for cost estimation at the early planning stage. Table 3 and Figure 8 present the comparison of construction costs using ABC method versus conventional method based on the costs data collected from different sources. The results show that the costs of ABC projects are less than conventional projects in 11 projects among all the data collected, that is, about 21%.

Table 3: Construction Costs Comparison Based on Collected data

	ABC ($\$/FT^2$)	Conventional ($\$/FT^2$)	% Difference
Average	275	228	20%
Min	33	28	17%
Max	1061	1257	-16%

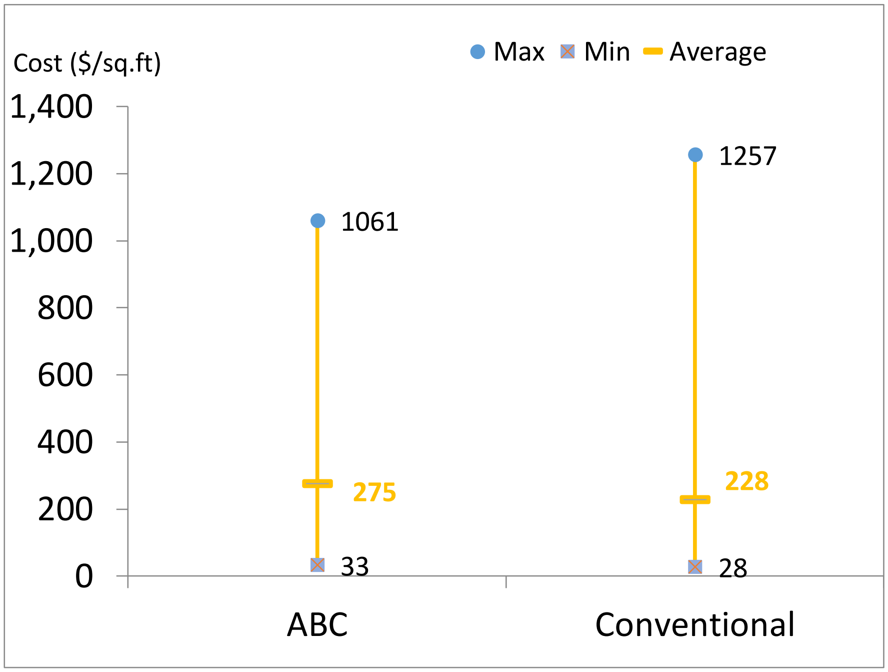


Figure 8: Comparison of ABC and Conventional Construction Costs

Four factors were identified as the main factors influencing the project construction cost; these factors are: the project location, AADT, type of bridge structure, and number of spans. A multinomial logistic regression model was developed based on these four bridge characteristics inputs. In this model, the inputs were categorized and the cost output was treated as a range based on the frequency of the cost in the collected data and each was assigned a categorical value, as shown in Table 4.

Table 4: Categories of Multinomial Logistic Regression Model Cost Output

Cost Interval ($/sq.ft)	Categorical Value
0 to 100	1
101 to 200	2
201 to 300	3
301 to 400	4
401 to 500	5
501 to 600	6
601 to 700	7
701 to 800	8
801 to 900	9
901 to 1000	10

In addition, a preliminary analysis of the indirect cost data collected up to this stage was conducted to understand the different characteristics of these data. In this analysis, the cost data of the ten ABC projects collected from Oregon DOT were further analyzed to study the following four types of agency and indirect costs: right-of-way (ROW), construction engineering (CE), project engineering (PE), and inspection. Figure 9 presents the average values of agency and indirect costs based on the Oregon DOT ABC projects and Figure 10 shows the corresponding percentages compared to the total costs. Tables 5 to 8 list the comparison of each type of indirect costs resulted from the ABC and conventional construction methods.

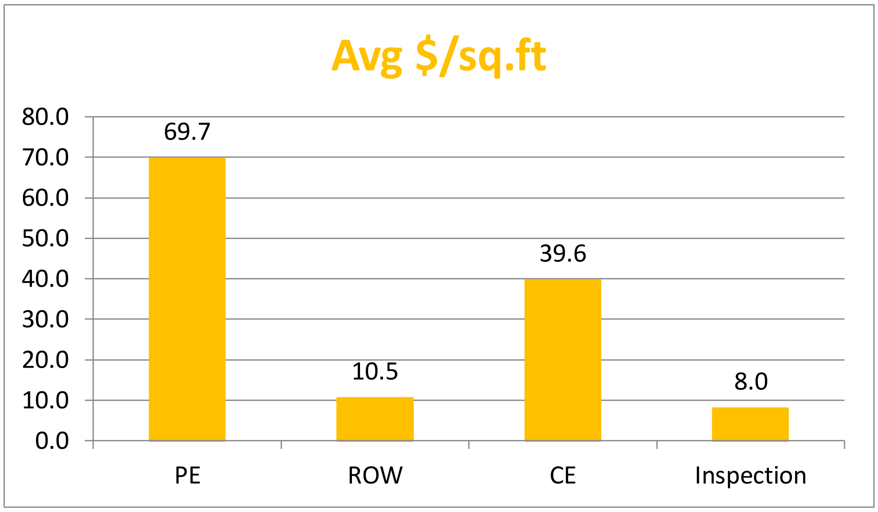


Figure 9: Average Values of Agency and Indirect Costs

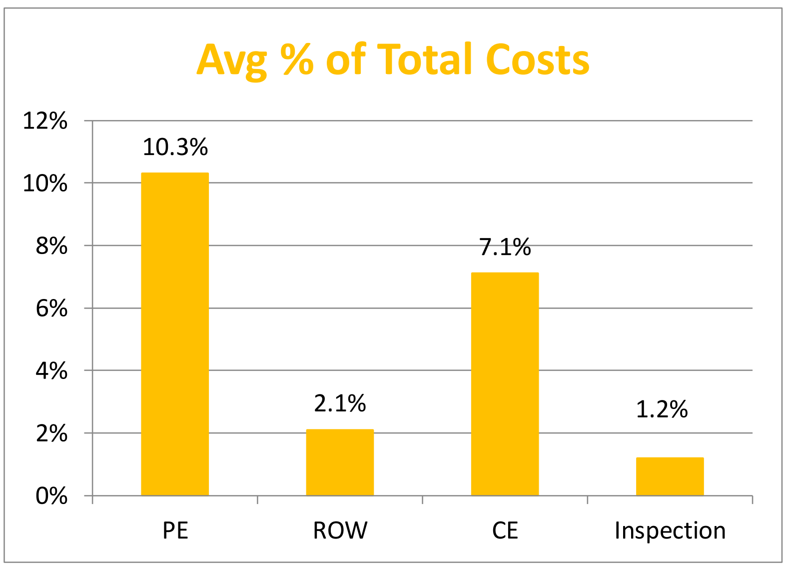


Figure 10: Percentages of Average Values of Agency and Indirect Costs Compared to Total Costs

Table 5: Project Engineering Costs Comparison Based on Collected data

	ABC	Conventional	Difference
Average	11.2%	10.8%	0.4%
Min	2.1%	1.8%	0.3%
Max	25.1%	23.7%	1.4%

Table 6:Right-of-Way Costs Comparison Based on Collected data

	ABC	Conventional	Difference
Average	11.2%	10.8%	0.4%
Min	2.1%	1.8%	0.3%
Max	25.1%	23.7%	1.4%

Table 7: Construction Engineering Costs Comparison Based on Collected data

	ABC	Conventional	Difference
Average	11.2%	10.8%	0.4%
Min	2.1%	1.8%	0.3%
Max	25.1%	23.7%	1.4%

Table 8: Inspection Costs Comparison Based on Collected data

	ABC	Conventional	Difference
Average	1.2%	2.8%	-1.6%
Min	0	0	n/a
Max	2.9%	6.5%	-3.6%

5. Tier-2 Data Collection & Categorization: in order to be able to perform a detailed cost estimating for an ABC project, data about the different activities involved in that project have to be first collected. To achieve this objective, detailed schedules for a total of 16 different ABC projects were collected from 11 different states using the FHWA database. In addition, data from a CMGC project in Tennessee was collected, this project consists of four different bridges. Furthermore, data from six hypothetical ABC projects (SPMT) and their comparable conventional projects were collected from an analysis of the ABC costs posted on the FDOT website. The collected data were categorized according to the ABC method used in order to facilitate a reliable analysis. These methods were: modular construction, SPMT, and lateral sliding, with 13, 6, and 1 project in each category, respectively

6. Tier-2 Data Processing: using the collected schedules, a generalized activity's list for each ABC method was generated. This list captures the major activities associated with each ABC construction method.

7. Tier-2 Cost Estimating Spreadsheet Tools: three detailed cost estimation spreadsheets are currently under development, one each for the ABC methods of modular, SPMT, and lateral sliding. These spreadsheets are based on the results of the analysis of the previous task. The user will, based on the specific characteristics of the bridge being considered, be provided with the most significant cost components that need to be evaluated. Identifying the most significant cost components will be made possible by analyzing the collected cost and schedule data for ABC and conventional bridge project in order to identify cost the components that:

i. exist in both types of construction, and
ii. are unique to either of ABC or conventional construction.

8. Tier-2 Cost Mapping & Normalization: detailed cost data of the different activities of the above-mentioned projects were collected from the projects' bid tabs and mapped with the activities in the generalized activity' lists. Moreover, in order for the cost mapping data to be comparable, the costs of each project were normalized by the project size in order to negate the impact of the project size on the activities cost and be able to compare cost/sq.ft for all the projects.

9. Tier-2 Statistical Analysis: paired sample t-tests were applied to the bridge project cost data of the hypothetical ABC and conventional bridge project cost data collected from the FDOT website. This statistical analysis identified the cost items that showed significant difference between ABC and conventional construction methods. This analysis was performed on direct and indirect costs, different types of bridge structures: superstructure and substructure, and different type of work: concrete and steel. The results of all these analyses are shown in table 9. This analysis proved that indirect and contractor's general condition costs could be significantly different between the ABC and conventional construction and therefore careful planning of ABC projects can provide cost savings over conventional construction methods.

Table 9: ABC vs. Conventional Bridges Statistical Analysis

Item			Conclusion
Total Cost			**Significant Difference (ABC Lower)**
	Indirect Cost		**Significant Difference (ABC Lower)**
	Direct Cost		No Significant Difference
		Detour	No Significant Difference
		General Conditions	**Significant Difference (ABC Lower)**
		End Bents	No Significant Difference

		Piers	No Significant Difference
		Superstructure	No Significant Difference
		Concrete	No Significant Difference
		Steel	No Significant Difference
		Expansion Joints	No Significant Difference
		Pads	No Significant Difference
		Pre-stressed Beams	No Significant Difference

10. Analytical Methods-Based Road User Cost Analysis: Three existing sketch planning tools with different levels of details (Q-DAT, Real Cost and Quickzone) were integrated with the reliability estimation methods of the SHRP 2 L03, L07 and C11 projects. In addition, the procedures to estimate emissions, vehicle operating cost, and safety were also integrated into the same spreadsheet-based tool, as shown in Figure 11. The estimation from these tools is being validated based on real-world construction zone data.

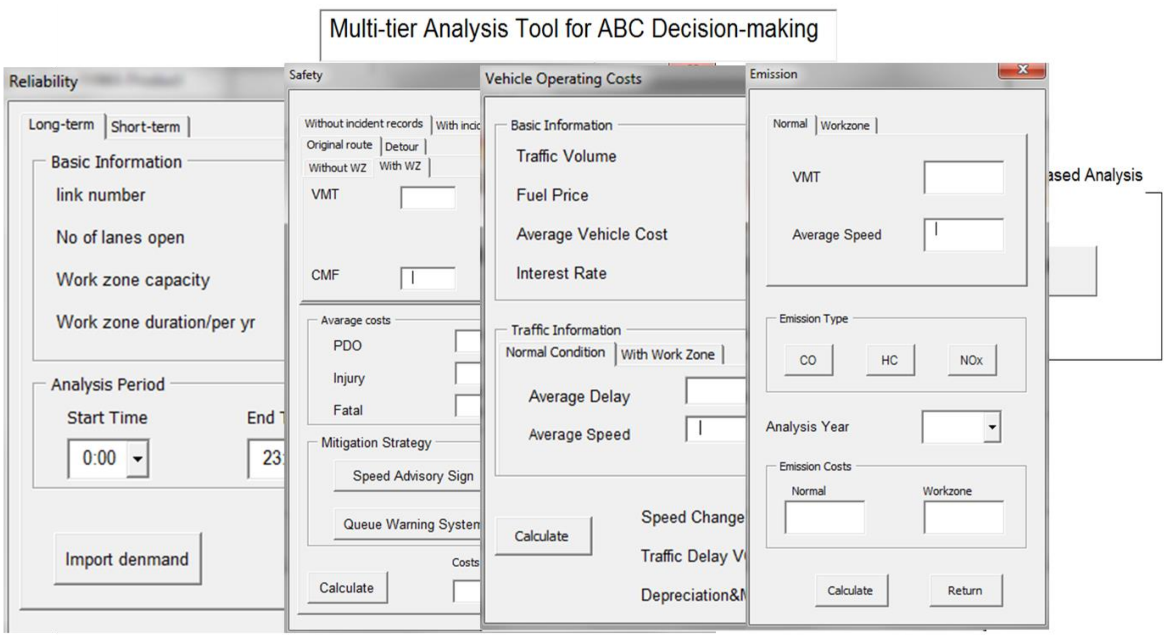


Figure 11: Screen Capture of the Developed Road User Cost Estimation Tool

11. Case Study: A case study was conducted for the bridge located at the interchange of I-4 and Graves Avenue in Orlando, FL. The construction costs and user costs of using ABC method were compared to those of convention methods and the results are shown in Table 9. This case study demonstrates the benefits of using the total costs that incorporates both the construction costs and user in the decision making process.

Table 10: Analysis Results for I-4 Case Study

Costs in dollar value ($)		Mobility Impact	Reliability Impact	Safety Impact	Emission Impact	Construction	Total Cost
C=1000 veh/hr/lane (Capacity with Const.)	ABC	120,347	32,807	40,864	1,615	430,000	625,633
	Convent.	224,591	258,414	77,313	2,274	342,125	904,717
C=1136 veh/hr/lane	ABC	120,347	32,489	40,864	1,615	430,000	625,315
	Convent.	191,339	202,851	77,207	2,425	342,125	815,947
C=1264 veh/hr/lane	ABC	120,347	32,311	40,864	1,615	430,000	625,137
	Convent.	183,026	73,715	77,207	2,499	342,125	678,572

12. Simulation-Based Road User Cost Analysis: Procedures to estimate additional road user costs including business impacts, and freight and commodity impacts using simulation-based tools have been identified. In addition, procedures to estimate diversion have been identified. A subarea network within Broward County, FL was imported into a mesoscopic dynamic traffic assignment (DTA) tool, DTALite. A DTA model has been calibrated and validated based on real-world data. A case study along the I-595 corridor using this model is being conducted. The impacts of traffic diversion due to bridge construction is also being examined in this case study.

13. Development of Desktop-Based Bridge Construction Decision Support Tool: An initial interface of a desktop-based bridge construction decision tool was designed. Figure 12 illustrates the main user interface of the developed bridge construction decision support tool while Figure 13 shows an example output of this tool.

14. Development of a Fuzzy Evaluation Framework for Decision Making: A multi-criteria evaluation framework has been developed to support alternative selection. This framework is based on the method of fuzzy Technique for Order Performance by Similarity to Ideal Solution (TOPSIS). A spreadsheet has been developed to implement this procedure.

15. Presentations: The outcomes of this project have been presented in the 2014 and 2015 National Accelerated Bridge Construction Conferences. One paper entitled "Estimation of the Total Cost of Bridge Construction for Use in Accelerated Bridge Construction Selection Decisions" was also presented at the 95th TRB Annual Meeting in January, 2016.

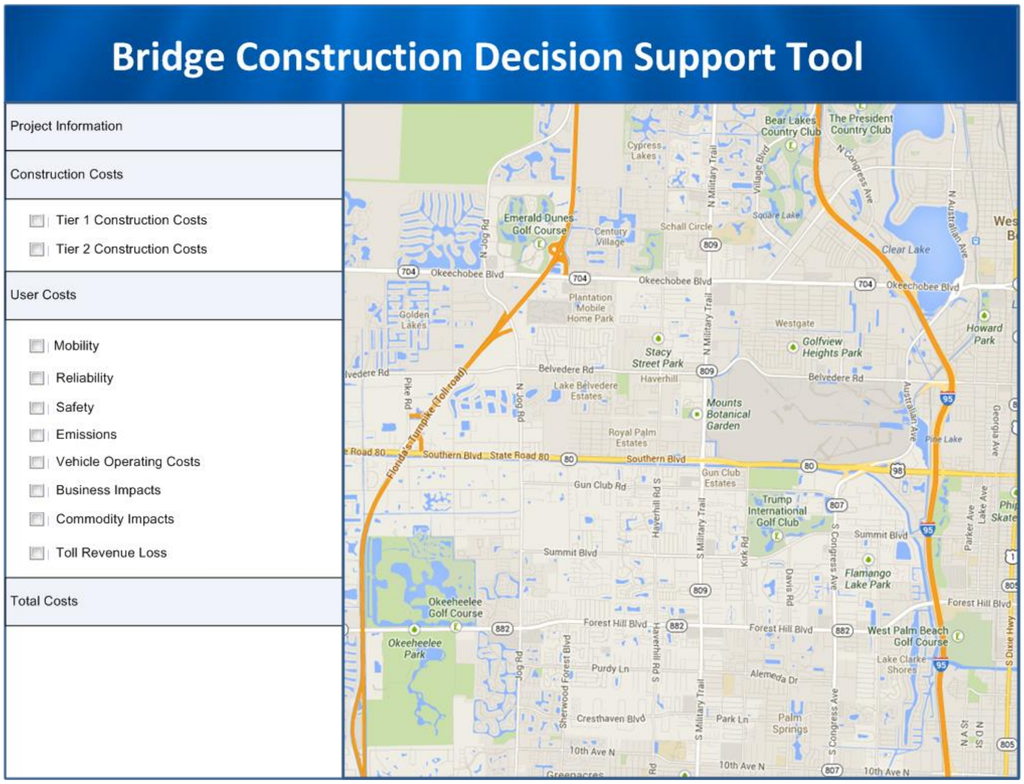


Figure 12: Main Interface of Bridge Construction Decision Support Tool

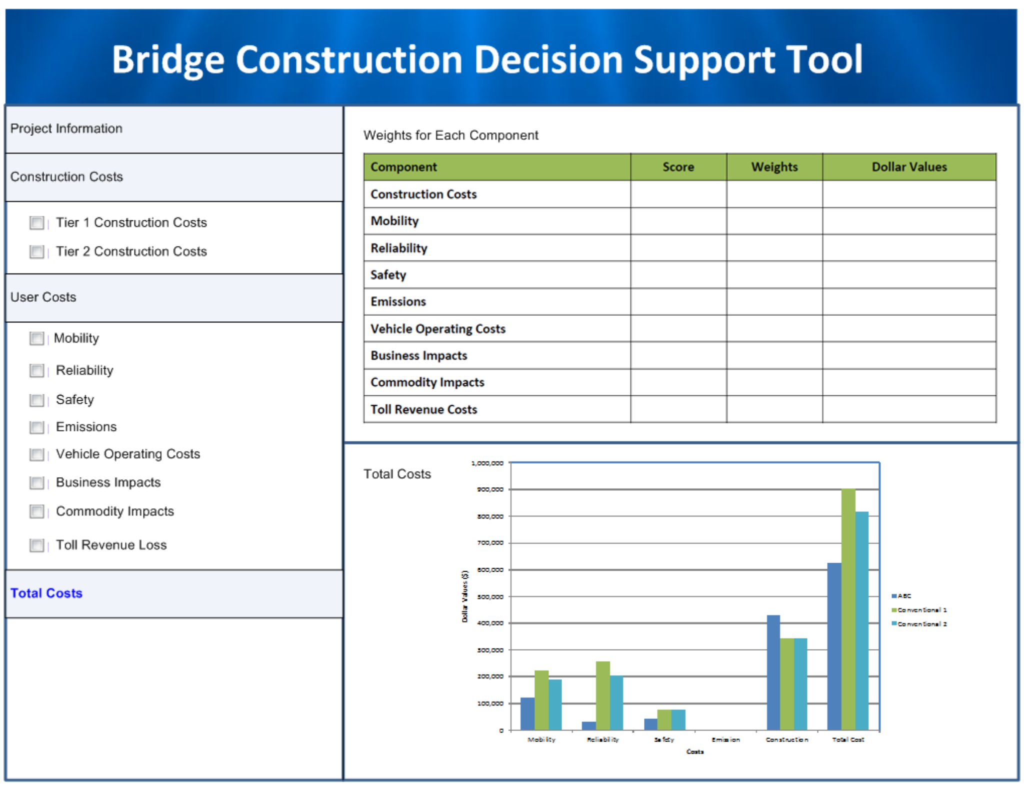


Figure 13: Example of Bridge Construction Decision Support Tool Output

B.2. In Progress and Future Activities:

The ongoing and future research tasks of this project are geared toward two main components:

(i) Refining the envisioned framework for multi-tier decision-making in ABC projects.

(ii) Creating and testing the cost estimation tools related to construction and user costs in ABC projects at different stages. For the first component, the collected cost information from previous projects will be analyzed to refine the requirements and functionalities in the envisioned multi-tier ABC decision-making tool. For the second component, more construction cost data are being collected to improve the reliability of the cost estimation tool. Once an acceptable level of accuracy is reached, an improved method will be devised to estimate the construction cost/sq.ft of ABC projects based on their characteristics. This will incorporate different factors as inputs and will provide the cost/sq ft adjusted to the project's particular location as an output.

(iii) Develop checklists of the different indirect cost activities associated with each ABC method.

(iv) Develop construction & indirect cost activities checklists associated with conventional construction and develop a comparison chart between the total cost of each of the ABC construction methods & the conventional bridge construction method and relate the differences to the different project characteristics.

(v) Collect data on: (i) comparable ABC and conventional project to confirm the cost items that contribute to the difference between ABC and conventional construction; and activities involved in both types of bridge construction to expand the list of activities in each category.

(vi) A case study along the I-595 corridor is being conducted based on a DTA model for the network of Port of Everglades. User costs due to the construction will be analyzed using this subarea network. The impacts of traffic diversion is also being investigated in this case study. In addition, the developed fuzzy TOPSIS-based multi-criteria evaluation framework will be applied to this case study.

(vii) The procedures and guidelines regarding estimating the user costs, selecting the analysis tool for the required analysis, and combining user and construction costs will be extended and integrated in the developed bridge decision support tool.

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